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Technical Paper

Replacement Pressure Parts Consideration for Replace In-Kind, Upgrade or Redesign

By

Sean Knowles
Stress Analysis Engineer
RILEY POWER INC.
a Babcock Power Company

Mark Lewis
Supervisor Proposal Engineering
RILEY POWER INC.
a Babcock Power Company

Presented at

ASME 2013 Power Conference
July 29-August 1, 2013
Boston, Massachusetts, USA

RPI-TP-0233

Proceedings of the ASME 2013 Power Conference
Power2013
July 29-August 1, 2013, Boston, Massachusetts, USA

POWER2013-98312

REPLACEMENT PRESSURE PARTS CONSIDERATION FOR REPLACE IN-KIND, UPGRADE OR REDESIGN.

Sean Knowles
Stress Analysis Engineer
Riley Power Inc.
Worcester, Massachusetts, USA

Mark Lewis
Supervisor Proposal Engineering
Riley Power Inc.
Worcester, Massachusetts, USA

ABSTRACT

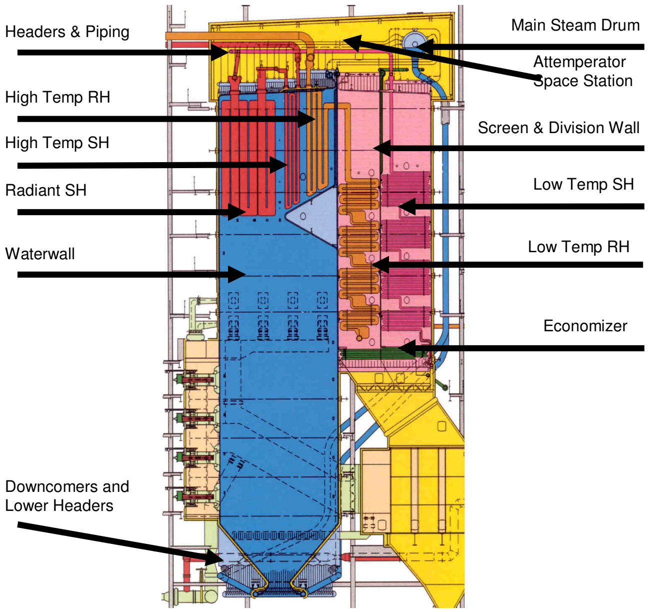
One of the largest costs after erection of a boiler is the maintenance cost. Typically these costs are manageable and modest except when replacement of pressure parts is required. When replacing pressure parts in a boiler the owner should take advantage of the opportunity to evaluate the boilers history, mechanical condition and thermal performance. This evaluation is critical as it can benefit the capital replacement cost and the maintenance cost after installation. Solutions can vary from replacement with an exact duplicate, upgrade to improve mechanical reliability, or modifications to improve the thermal performance. After an initial evaluation, further studies into future operating conditions such as cycling of the boiler, fuel changes and other plant modifications can greatly change the recommended replacement. Conducting an evaluation and developing a plan upfront will help support an optimized design and ensure the optimal replacement part is designed and installed. This paper discusses options and considerations to evaluate when developing a replacement plan for pressure parts utilizing current codes and standards.

INTRODUCTION

As a boiler pressure part nears the end of its useful life and replacement of the part becomes necessary, the opportunity arises to make improvements or upgrades. The term pressure part in this paper refers to superheaters, reheaters, economizers, and waterwalls. In order to take advantage of this opportunity it is critical that the owner/operator and the designer work together to come up with the appropriate design. Working together and evaluating past, current and future operating conditions will allow targeted solutions for the optimum replacement of the parts.

The decision making process requires some upfront work, including a review of the part's history and thinking ahead to what operational changes may be coming in the future. This paper reviews the various steps in the decision process for evaluating pressure part replacement opportunities.

This paper also reviews fabrication considerations, construction considerations and code definitions that play an important role in pressure part replacements.



Typical Pressure Parts that are Evaluated

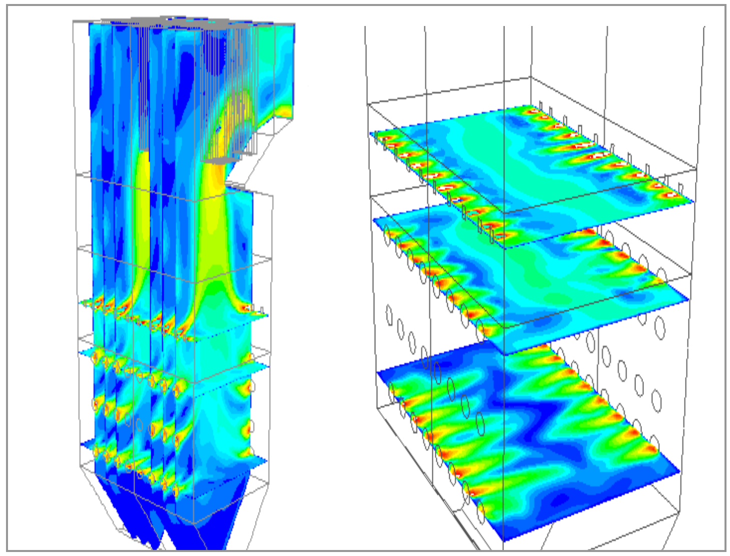
FEASIBILITY STUDY

By performing a Feasibility Study that addresses the identified options, and working as a team throughout the process, the results of performing a study can include several benefits such as:

- Instills confidence in approach selected
- Establishes a firm project scope and execution plan
- Identifies critical areas for evaluation and review
- Typically saves money over the total project

A Feasibility Study should be performed prior to any major pressure part modification. The objective of this study is to perform up-front engineering and evaluate potential options. Each of the potential options can then be evaluated based on several criteria to help determine the best replacement option including:

- Thermal performance
- Projected maintenance for mechanical upgrades
- Project capital costs
- Associated risks and identifying ways to reduce these risks
- Schedule
- Potential impacts to other equipment



CFD Modeling is one tool that may be used to evaluate a boiler

EVALUATING THE PRESSURE PART

When starting to evaluate the pressure part for replacement, three initial questions need to be asked to help select a replacement pressure part:

1. Has the pressure part met its performance expectations? (i.e. steam temperatures, pressure drop)
2. Has the pressure part been mechanically reliable over the life of the part?
3. Will the boiler and pressure part continue to operate in the same manner in the future?

If the answer to all three questions is yes, without a doubt the design of the part is most likely adequate and does not require any design changes. Generally a "no" or "uncertain" response to any one of the questions may initiate further detailed review. The three questions above represent the three major categories that are typically evaluated:

1. Performance
2. Mechanical reliability
3. Future outlook

With any new replacement part the owner may want to consider the value of a new feature or upgrade. In most cases there will be several different ways to accomplish the same goal, and each will have some advantages and disadvantages. These may include things like the ability to meet all of the objectives of a redesign, upfront cost, or maintenance cost in the long run. In any case each of these factors should be considered in the decision making process.

Performance

The performance of a pressure part refers to the thermal aspects, including heat absorption and fluid outlet temperatures. An evaluation of the pressure part's performance generally starts from a global perspective by asking several key questions:

1. Does the boiler's performance meet expectations?
2. Is there an issue with performance that is ongoing or something that started more recently?
3. Are there any areas that performance needs to improve?

Owner's and operator's answers to the above questions will highlight the current critical operating challenges of the plant. Once the critical issues have been identified, an Original Equipment Manufacturer (OEM) can be consulted for further investigation, including a Feasibility Study along with a thermal model of the current pressure part arrangement.

The evaluation of the thermal performance of a heating surface in a boiler requires a calibrated thermal heat transfer model of the boiler. The thermal model can range from a simple model of only the pressure part that is being modified to a complete model of the entire boiler. The extent of the boiler modeling generally depends on the owner's objectives and scope of the project. A calibrated boiler model allows the heating surface to be modified and more accurately predict the performance changes. Simple models of pressure parts (such as a model of only an economizer) result in an evaluation of only that heating surface and do not include upstream or downstream effects. A complete model of the entire boiler allows the heating surface to be changed and then evaluated in relation to the overall boiler and all of its heating surfaces. A complete boiler model also allows for the overall boiler performance to be evaluated for multiple scenarios. "What if?" questions can be asked and evaluated.

Some common areas that can significantly affect performance include:

- Steam temperatures
- Steam side pressure drop
- Flue gas temperatures
- Fly ash fouling

When making performance changes it is also important to recognize other areas that may be impacted by this change. For example, if the superheater surface is added upstream of a reheater, there is a chance that the reheater may not be able to achieve the steam temperatures it is designed to achieve, and thus the reheater may also require modifications.

High Steam Temperatures

Steam temperatures that exceed the current design should be investigated to determine the reason the temperature is higher. High steam temperatures can be difficult to notice due to spray attemperation. If a boiler is meeting steam temperature but the spray is excessive, it can be an indication of a high steam temperature conditions. High steam temperatures are potentially the result of high flue gas flows and temperatures and/or inadequate steam temperature controls. When the final steam temperatures on the boiler exceeds the design of the superheater or reheater the question arises if the tube metals selection is robust enough to handle the additional service requirements. Typically, this type of investigation involves evaluating the operating data as well as performing a thermal model of the boiler to get to the root cause(s).

There can be many options to reduce the steam temperatures back to the design values. A thermal model allows the cause and effect of proposed modifications to be evaluated. Generally, if the heating surface is reduced to lower the steam temperature, there will be an increase in temperature somewhere else. In some cases the solution may be to add heating surface in another portion of the boiler. As an example, if a superheater pendant above the nose arch has high steam outlet temperatures above the design due to high flue gas temperatures. To reduce the flue gas temperature, the owner may need to increase furnace cleaning, or add evaporative waterwall platens to the furnace.

In some cases the steam temperature meets the overall outlet design conditions, but there is a large imbalance in the temperature over the width of the boiler. Common causes of large temperature variations include fluctuations in the combustion system or unevenness in the steam flow. Tuning the combustion system can help with flue gas distribution. Steam-side imbalances are typically evaluated by investigating the header sizing and arrangement along with the pressure drop from header to header.

Low Steam Temperatures

If the steam temperature leaving the boiler is lower than the original design this can impact the turbine or balance of plant process and generally affects the overall plant heat rate. A low main steam temperature also has a negative impact on reheater steam temperatures. Generally the solution for low steam temperatures is to add heating surface to the affected superheater or reheater. In other cases, (such as a split backpass), it is possible to add surface to one side so more flue gas can be diverted to the other pass. For example, if surface is added to the reheater it may be possible to adjust the control dampers, sending more flue gas down the main steam pass thereby increasing the temperature.

Steam Side Pressure Drop

High or low steam side pressure drops can have an impact on the boiler's performance. A high pressure drop can result in high steam drum pressures and potentially leave little margin in the operating and safety valve lift pressures. Low steam side pressure drops could lead to poor steam distribution and high tube metal temperatures in sections with low flows. Pressure drop can be reduced by upgrading the material so that a thinner tube wall can be used. Increasing pressure drop is commonly achieved by adding orifices to the tubes.

Flue Gas Temperatures

The flue gas temperature is usually a concern at the following critical areas

- Leaving the furnace
- Leaving the boiler (economizer exit)
- At the stack

Flue gas temperatures leaving the furnace are usually controlled by the heat release rates in the furnace and the ability of the furnace to absorb the heat. Modifications may require changes in cleaning operations and addition or subtraction of radiant heating surface.

The economizer and air heater are commonly the first candidates for modifications to address flue gas temperatures leaving the boiler. Adding or removing heating surface from the economizer is an easy way to raise or lower the flue gas temperature. Other conditions such as environmental equipment may require bypass systems to maintain the flue gas temperature at lower loads.

For flue gas leaving the stack there are several conditions that commonly result in the flue gas temperature becoming a concern, including:

- Installation of environmental equipment on the back end
- Changes in fuels and air heater duty
- Improving the overall boiler efficiency
- Duct or breaching design limits

Fly Ash Fouling

The amount of fouling that occurs within the convective surfaces of a boiler is a function of the ash constituents, flue gas temperature, tube spacing and the equipment available to clean the surfaces. Heavy fouling of heating surfaces will reduce the heat transfer effectiveness of the pressure parts. As one surface fouls, other areas downstream may be impacted by the resulting higher flue gas temperatures. During boiler inspections, fouling conditions are one area that should be evaluated to verify effective cleaning. Areas with severe fouling and complete plugging should be noted in inspection reports. The pressure part arrangement can be evaluated to determine if the tubes can be re-spaced or the element redesigned to reduce fouling and/or improve the ability to clean the surface. In some cases the flue gas flow pattern has been evaluated and the fouling of an element reduced by changing the flow profile. An example of this is a redesigned nose arch which redistributes the flue gas temperature entering a pendant in order to bring the peak temperatures closer to the average temperature. This type of approach may involve CFD modeling to analyze the flow patterns. In other cases baffles may be used to re-direct the flue gas flow in order to prevent ash from building up in an area.

Superheater Platen Plugged with Ash

Mechanical Reliability

A review of the pressure parts' mechanical reliability generally starts with a review of the maintenance reports to determine where repairs have been made. Several questions may come up regarding mechanical reliability such as:

1. What repairs have been made? Are the repairs costly? Are these repairs considered routine?
2. Have there been any failures in the part?
3. Are all the tubes inline and supported as originally designed?
4. Have any modifications been made to the part?
5. Has a boiler tube evaluation been done on the part? If so, did the results indicate any potential trouble spots?

Typical Fish Mouth Failure

Reliability information should be clearly identified such as inspection and metallurgical reports so that appropriate evaluations can be made. In cases where a pressure part has lasted adequately it may be appropriate to install an in-kind replacement. However, there may be new alternatives available providing savings in either upfront pressure part replacement costs, or long term maintenance costs. These alternate design features can include changes to supports, alignment methods, tube swages, or even using weld overlay or cladding in place of tube shields.

Modifications or add-ons to a part may have been done for any number of reasons, such as to add or remove heating surface to improve performance or additional supports or lugs are added to keep an element hanging in the boiler. Commonly when modifications are made there is some thought that goes into how this can be done with the least amount of impact to the existing part. When going back in with a replacement part it is worth asking how this can be done better with the entire part being replaced.

Pendant Superheater with Tubes out of Alignment

Future Outlook

As market conditions and fuel costs continue to fluctuate it may be difficult to identify how a boiler will be operated in five (5) or ten (10) years. In general, major changes to the plant's daily operations do not happen overnight and may be a direct result of other equipment being installed. Future changes commonly fall into two main categories; fuel changes, and operating changes. These potential changes to the boiler can have an influence on how a part is designed and therefore should be included in the evaluation of the part.

Fuel changes may be made for any of several reasons including reducing emissions, lower cost fuel, or availability of a fuel. Some fuel changes, such as going from a high sulfur bituminous coal to a low sulfur bituminous coal to reduce emissions may have little impact on the steam and flue gas temperatures. However, changing from coal to natural gas is more likely to impact the design of a part, both in the thermal performance and in mechanical design.

Operating changes to the boiler is a fairly broad category and includes changes such as turbine modifications to load ramping. A modification to the turbine to get more generation output generally involves changes to the plant heat balance, more specifically, the reheat steam flow and temperature. In the current power market, plants that were designed to operate as base loaded units may now be cycling from minimum load to full load on a daily basis. Daily cycling can have significant effects on the design and reliability of pressure parts that were not evaluated in the original design.

Fuel Changes – Coal
The impacts of changing fuels in a boiler can be dramatic for the operation of the boiler, particularly when going from a low fouling high BTU bituminous coal to a high fouling low BTU sub-bituminous coal such as PRB. The decision to change fuels is driven by different reasons, such as lower cost fuel or fuels that are low in sulfur. Whatever the reason for the change the design of the heating surface can be impacted and, therefore, this should be considered when changing the part. A typical evaluation for a fuel change will include evaluating the flue gas temperature profile and the steam temperature profile along with the ability to handle changes in fouling conditions in the furnace and convection pass. Recommended changes in the design of heating surfaces may be the result of the study.

Fuel Changes – Coal to Natural Gas
Changing from firing coal to natural gas (NG) may seem like a drastic change to the boiler; however with the current emissions regulations and NG prices, this is a common evaluation being performed. With a coal to NG retrofit there can be a large change to the flue gas flow rates and temperature profiles throughout the boiler. In some cases flue gas recirculation (FGR) is also considered for further NOx reduction or for steam temperature control. Adding FGR will also have an impact on the flue gas and steam temperatures around a heating surface. In some cases, the result of this analysis shows that tube materials may need to be upgraded or there is a risk of overheating the tubes.

Turbine Upgrades
One way to get more megawatts out of a steam generator is to make upgrades to the turbine, which typically leads to changes in steam conditions particular to the cold reheat steam temperature. This change may result in the boiler not being able to achieve the design outlet temperatures. In this case, a thermal model of the boiler is created to evaluate the change and devise a plan to recover those temperatures. This may lead to heating surface modifications as described in previous sections.

Boiler Cycling (Load Ramping)
Many boilers were originally designed to be base loaded, meaning the intention was to run at full capacity for as long as possible between outages. In today's market, many boilers now cycle from full load during high demand periods of the day to the minimum loads at night. This increases the amount of thermal cycles on a pressure part. With the increase in cycling it is also important to evaluate the transient condition along with the ramp rate of the boiler to determine if there are any conditions that may cause a spike in temperatures that could lead to premature failure. In some cases where high temperature spikes were found, the boiler operations were modified to minimize the impact while changing loads. An example of this is when increasing the boiler load the main steam temperature increased and the spray attemperation is not able to keep up, by reducing the ramp rates, the steam temperatures can be kept under control. While the use of higher grade materials may be able to accommodate some of these off-design conditions, good operating practices and judgment should always be followed.

BOILER CODES

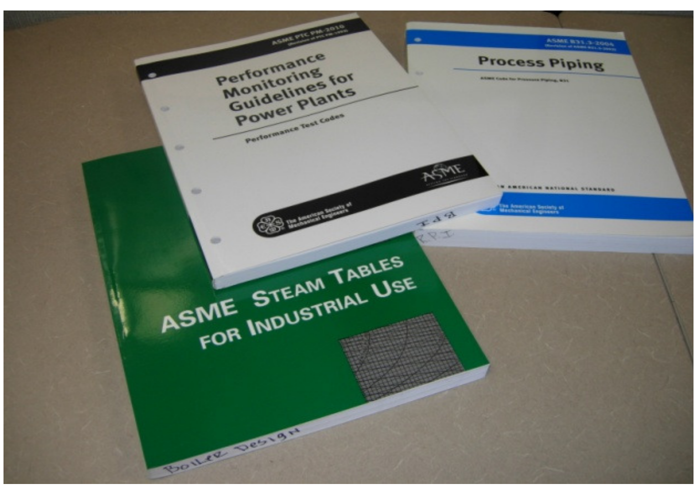
The subject of codes are fairly extensive since there are numerous codes to consider when replacing boiler pressure parts. It is important that all codes associated with pressure part replacements are fully comprehended and adhered to. The following lists the "national" codes typically associated with pressure part replacement.

1) ASME Boiler and Pressure Vessel Code
    a. Section I – Rules for Construction of Power Boilers
    b. Section II - Materials
    c. Section IX – Welding Qualification
2) National Board Inspection Code
3) Local Codes – State/Local Jurisdictional Requirements

Most frequently the two codes that impact the design of a replacement pressure part are the ASME B&PV and National Board Codes. In most cases the local jurisdictions adopt these codes in whole or in part. For example, some jurisdictions do not accept that ASME code cases are a formal part of the code. It should also be noted that the ASME B&PV Section I Code is considered a new construction code, however when a part is being replaced, this is usually the code referenced to since there is no replacement code. The benefit of using this code is that the replacement part will be fabricated to the latest code practices for welding and examination. The National Board does address replacement parts to an extent and goes as far as defining a repair and an alteration (discussed later).

ASME BPVC (Boiler Pressure Vessel Code), Section I

Boiler and pressure components in the United States today are designed and manufactured in accordance with the ASME Codes. ASME BPVC Section I, Rules for Construction of Power Boilers, is termed a new construction code. It is applicable to the materials, design, fabrication, examination, inspection, testing, certification and pressure relief of a power boiler in accordance with a specific code edition and addenda. The ASME process requires that the manufacturer of a boiler or the pressure components complete and sign the applicable ASME data reports to verify that the construction meets all the requirements of the code. Upon the completion of the design and fabrication of the boiler – including hydrostatic testing and the stamping and installation of the nameplate – the applicable data reports are filed with the National Board. Permanent files are maintained at the National Board to ensure that records of the details of the original construction of the boiler are available.



ASME Code books

Code Revisions

The requirements of the ASME BPVC's are not retroactive; however, there have been revisions to the code, which have improved the reliability in the fabrication of pressure components. When making repairs or replacement parts the consideration of the current code requirements should be carefully examined. Starting in 2013, new revisions of the B&PV code are issued every two years; previously an addendum was issued every year.

An example of a code revision that has benefited the boiler industry is in Section PG-19 of the Section I Power Boiler Code. Prior to the 1999 Addenda of the 1998 Edition of Section I, the heat treatment of highly strained austenitic materials, such as those that have been cold formed, had not been a code requirement. The code has been revised and the heat treatment for the cold forming of highly strained austenitic materials is now a requirement. Since implemented in the code this must be considered for austenitic stainless steel pressure part replacements regardless of the boiler vintage. In reality, most of the original equipment manufacturers (OEM's) recognized the need to perform the heat treatment of austenitic fabrications with high strains and heat treating was part of the OEM's standard manufacturing practice before it was required by code.

National Board

Registration of the manufacturer's data report forms with the National Board is now mandatory in all the United States, and all the Provinces of Canada. A basic advantage of National Board registration is that the process provides a design record of the boiler pressure parts. When repairs or alterations are made to the boiler, these records are important in determining original design data of the pressure component.

It is also a role of the National Board Inspection Code (NBIC) to establish the rules of safety governing the repair, alteration and inspection of pressure-retaining items for existing boilers. Within the NBIC there is an important distinction made between the words "repair" and "alteration". There appears to be a great deal of latitude taken by the industry interpreting the definition of these two words. To this purpose, the NBIC also provides examples in order to guide the user in the replacement of boiler components in an effort to distinguish between repairs, replacement parts, upgrades and alterations.

Repair

Repair is defined as the process of restoring a boiler component(s) to a safe and satisfactory condition such that the existing design requirements are met. Often times, an existing pressure component cannot be repaired by the methods outlined in the NBIC and it is more economical to replace the component.

Replacement In-kind
The term “replacement in-kind” and “replacement in-kind to the latest code” often appear in customer specifications. Replacement in-kind indicates that the fabrication and installation of the pressure component shall have the same design conditions and appurtenances as the original pressure component, part, subassembly or system. Certain substitutions and changes to the original design are permissible and these variations are defined within the NBIC. “Replacement in-kind to the latest code” allows the ASME pressure part manufacturer to fabricate to today’s code. This allows the use of current allowable stress values; however, there shall be no physical alternations or design condition changes from the original design of the pressure component, part, subassembly or system.

Alteration
An “alteration” as related to pressure components is any change in the item described on the original equipment manufacturer’s data report which affects the pressure containing capability of the pressure-retaining item. In addition, there are a number of non-physical changes, which denote an alteration. Such changes include increases to the design pressure (MAWP) of a pressure component and increases/decreases in design temperature.

Repair vs. Alteration
The question then becomes “how do you differentiate between a repair / replacement and an alteration”? A basic “rule of thumb” leads to the following questions being asked when assessing the replacement of existing pressure components, parts, subassemblies or systems.

1. Are the design conditions of the pressure part changing? This includes changes in MAWP, heating capacity, significant heating surface changes, steam flow, steam temperature?
2. Did you change any listed entry on the original ASME Manufacturer’s Data Report for any existing pressure component, part, or subassembly?

If the answer to any of the above questions is “yes”, then there is high probability that the request is an “alteration” per the NBIC rules.

Documentation
As required by the NBIC, there are specified forms such as R-1 and R-2 forms, which should be processed as the result of any repair, replacement or alteration of an existing pressure part. These forms should also be filed with the National Board in order to ensure that the changes and history associated with existing pressure components parts subassemblies or systems of an existing unit are known and maintained. It is the responsibility of the “R” Certificate holder performing the repair / replacement / alteration to prepare and file these forms with the National Board.

NBIC Form R-1 is for the repair / replacement of an existing pressure component, part, subassembly or system.

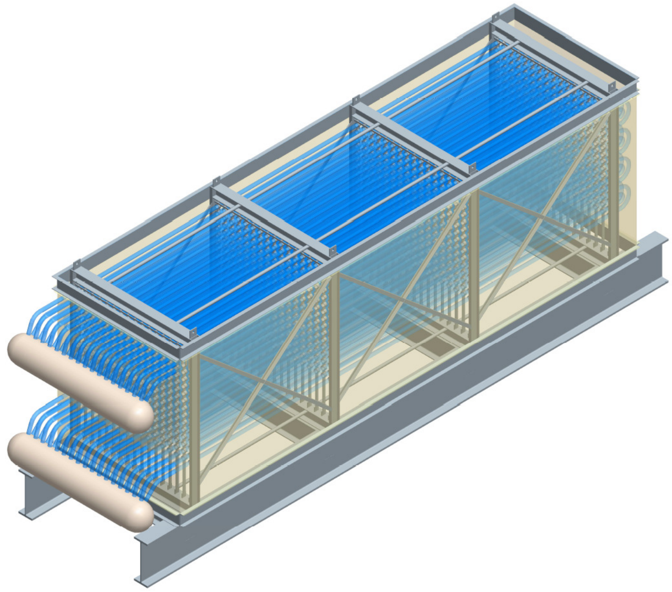
NBIC Form R-2 is used for the alteration of an existing pressure component, part, subassembly or system. It should be noted that Form R-2 also requires a design certification by a company holding a “R” stamp ASME certification which attests to the alteration of the pressure component, part, subassembly or system being in accordance with the NBIC and ASME Codes. Therefore a coordination effort must be considered by the “R” Stamp holder fabricating and installing the alteration to obtain sign-off in the design certification portion of the R-2 form.

Local Codes
One item that comes up on many customer RFQ’s is when the specification document lists the applicable national codes and also has the statement that all local codes apply. The problem is that many of the pressure part manufacturers are not local to the subject boiler and may not be knowledgable of local codes and special jurisdictional requirements. If there are local codes that deviate or are in addition to the national codes, it is recommended that these differences be listed in the contractual documention.

CONSTRUCTION

Construction input into the design is often forgotten during the initial design process but is critical for a successful project. The term “constructability” is commonly used in the industry today when referring to the “ease of construction”. It is highly recommended that the erector have a direct input into the design of the replacement pressure part.

Pressure part replacement on existing boilers is more difficult than installing pressure parts on a new boiler.



3-D Drawing of a Modularized Economizer

This is due to demolition, access around existing equipment, support of existing equipment, ambient conditions (cleanliness) and condition of remaining pressure parts.

It is also important to note that the existing equipment may not be in the same alignment as when new (due to bowing, differential thermal expansions, etc.) and the replacement part design may need to be flexible to account for possible field adjustments.

The most common constructability inputs to the final pressure part design include element size, modularization, field weld locations, types of field welds and design features to allow flexibility for field adjustments.

Element Size
Element size is normally dictated by access space for installation. The objective is to design the pressure part as large as possible to reduce the number of field welds. A typical field weld can range in price from $500 to $1000, which means by decreasing the field welds by 1,000 it can save the a project up to $1,000,000.

Modularization
Modularization is also controlled by access space. The objective is to shop assemble as much as possible to reduce field costs. When shop assembling, typically quality improves due to the controlled shop conditions. Of course, if the modules get too large, shipping size and weight limitations may take precedence.

Modular Economizer Ready to be Installed

Field Weld Locations
Field weld locations go hand-in-hand with module sizes and access. The objective is to minimize the number of field welds and locate the field welds for easy accessibility.

Types of Field Welds
For quality reasons, ferritic to austenitic dissimilar welds are preferred to be done in the manufacturing facility opposed to in the field. Quality of ferritic to austenitic dissimilar welds improves in the shop due to the controlled environment. If this type of dissimilar weld is required at a field weld location, a shop installed “safe-end” is recommended so that the field is welding similar materials. A “safe-end” is a short tube section that has the dissimilar weld done in the shop.

Orbital welding is a cost-effective alternative to manual field welds. This welding process requires design input at the beginning of the project to allow enough room between tubes for the welding heads. If tight spacing is required, manual welding may be the only option.

Design Flexibility
Design flexibility is the allowance that has been included for field adjustments during installation. The design may require special features for construction flexibility in the field. Common special features can include:

- If the cut-points are not consistent or fully known, add extra tubing material so that the field can “cut to fit”.
- Slit the membrane allowing for field flexibility when aligning tubes for welding.

Construction Sequence

Construction sequence is important for the structural integrity of the boiler during erection. A plan needs to be established to either temporarily support existing equipment or sequence the construction to maintain the structural integrity.

CONCLUSION

This paper covers a broad area of design challenges that are commonly evaluated in pressure part replacements. Commonly, solutions that work for one boiler may not apply to another. For this reason, it is important to review options early in the process and find the solution that best fits your specific situation. It is also important to remember that a good plan for replacement requires good input and planning.

Involving an OEM with experience in modeling, design, fabrication and erection can significantly benefit pressure part replacements projects. By evaluating the pressure part or performing a Feasibility Studies prior to a pressure part replacement project can help to identify key areas of improvement to maximize the benefits.

Hole Cut in Boiler Wall to Remove Elements

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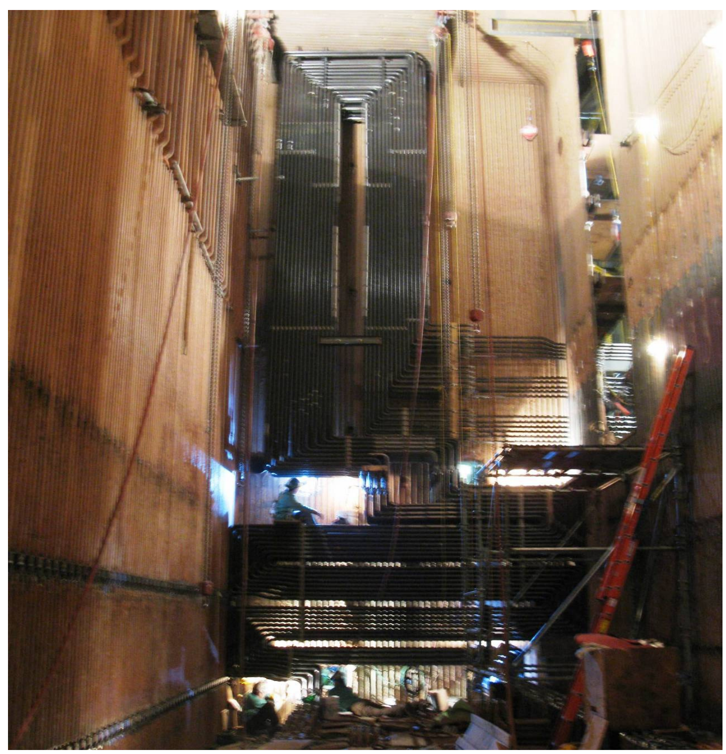

Elements Being Installed in Backpass

Table 1 – Typical Areas Evaluated and Potential Solutions

Condition	Impacts	Potential Remedy
Tube overheating Long term Short term Creep	• Tube failures • Reduces remaining life of tube	• Upgrade material • Evaluate steam and FG side to determine any improvements such as distribution or reduced temperatures
Tube Erosion Sootblower, Fly ash Falling slag	• Increased maintenance	• Shielding of erosion area • Flow modeling & baffling do redistribute FG • Sootblower adjustments • Increase erosion allowance on tube wall thickness
Corrosion Ash Corrosion Acid dew point	• Reduced tube life and ultimately failures	• Modify combustion system or • Evaluate and improve operating temperatures. • Increase material grade • Increase tube wall thickness by including and allowance
Tube alignment & support failures	• Bowing or sagging tubes • Fouling or increased erosion	• Evaluate location of solid ties and support locations (over or under constrained) • Evaluate thermal expansion between tubes & make sure there is enough clearance in design • Consider alternate alignment methods
Header tube connections	• Failures in the tube socket at the header	• Use latest design practice per EPRI
Thermal expansion	• Tubes bowing out of alignment	• Tube must be allowed to expand • Evaluate layout • Increase clearances if possible • Use guide lugs that offer flexibility
Fatigue	• Tube failures	• Modify supports or attachments
High Steam temperature {or high spray attemperation}	• High tube metal temperatures • Excessive steam attemperation (spray)	• Model boiler to add or remove heating surface • Reduce FG temperatures by adding evaporative surface • Improve furnace cleaning
Low Steam temperature	• Plant heat rate	• Model boiler to add heating surface
Low pressure drop	• Poor steam distribution	• Increase pressure drop with orifice
High pressure drop	• Increase drum pressure operating near safety valve lift pressure	• Upgrade material to thin wall thickness and reduce pressure drop
Tube temperature alarms	• Overheating of tubes = reduced life	• If local high temperatures, evaluate the steam and FG distribution, consider tube orificing • Evaluate materials, consider upgrading
High flue gas temperatures	• Environmental Equipment performance • Increased fouling	• Add heating surface (such as evaporative (waterwall platens) or economizer) • Improved furnace cleaning

Table 1 – Typical Areas Evaluated and Potential Solutions - Continued

Condition	Impacts	Potential Remedy
Fouling & plugging	• Reduces heating surface effectiveness – low steam temperatures & high FG temperatures • High FG velocities • Blocks FG path increasing velocities & Increased draft loss	• Improved ability to clean by tube spacing or sootblower coverage • Evaluate tube spacing – re-space if possible Enhanced designs for shedding slag • Evaluate sootblower coverage • Evaluate other furnace modifications (nose arch)
High FG Draft Loss	• FD / ID fan limitations	• Tube spacing, fouling & plugging
High FG velocities	• Reduces tube life due to erosion	• Increase tube spacing if possible • Baffling of the flue gas to redirect localized high flow areas • Operationally see what can be done to reduce flows. • Shielding of the tubes • Increase tube wall for erosion allowance
Coal Fuel Change (Bituminous to PRB)	• Low heating value - Increased firing rate, more FG through convection pass • Increased moisture content - Reduced boiler efficiency • Slagging / Fouling increases (Reduces furnace heat absorption, increases furnace exit FG temperatures, increased steam temperatures)	• Evaluate tube metals for new conditions 1. Higher velocities 2. Higher heat transfer 3. Higher FG temperatures 4. Higher steam temperatures • Possible tube material upgrades • Possible re-space tubes to improve cleanability
Fuel Change Coal to Natural Gas	1. SH & RH temperatures decrease 2. Low load operation – cold end corrosion 3. FG Temperature changes	1. Modify surface <u>or</u> add FGR 2. Review Economizer & Air Heater Surface 3. Review impact to tube metals upgrade material if necessary
Load Ramping / Shedding	• Quick ramping up or down of the boiler can cause high metal temperatures as the boiler is adjusting.	• Evaluate heating surfaces as needed • Review operations to identify potential ways to mitigate issues
Constant Pressure to Sliding Pressure Operation	• High superheat or reheat steam temperatures	• Evaluate heating surfaces for potential modifications as needed
Increased steam generating capacity	• Potential for overall changes to system including high or low steam temperatures	• Model boiler to identify potential areas that may be deficient
Turbine upgrades (changes to RH steam flow or inlet temperature)	• Modifications to the turbine to get more generation out of it	• Heating surface evaluation & potentially changes to compensate for the new operating conditions
Feedwater temperature changes	• Changing the feedwater temperature causes the boiler to firing rate to change.	• Evaluate system for potential changes and impacts. Results and recommendations may vary
Environmental equipment addition	• Specific flue gas temperature range for operation	• Maintain FG temperature over the load range using economizer surface modification (add remove, split), FG or water bypass of economizer, etc.