# MATERIALS AND WELDING GUIDELINES

# FOR

# BLACK LIQUOR RECOVERY BOILERS

THE BLACK LIQUOR RECOVERY BOILER ADVISORY COMMITTEE

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***CHANGES IN THIS ADDITION***

| Date | Description of Changes |
|---|---|
| March 2021 | • General Document Foreword – Incorporated Recommendations for New Recovery Boiler Construction (page 7).<br>• General Document Foreword – Added Recommendation of not using Backing Rings (page 7)<br>• General Welding Foreword – Added Paragraph on Manufacturer Data Report Forms (page 9)<br>• General Welding Foreword – Added Section Discussing Weld Quality (page 10) |
| October 2023 | • Added Bulletin 1.6 Copper Induced Cracking in Boiler Tubes (page 18)<br>• Welding Bulletins 1.3, added sentence 2.a (page 15)<br>• Updated ASME reference and added NBIC reference on page 33 |
| April 2024 | • Updated date on cover page to April 8, 2024.<br>• Moved information on April 2013 editions to Appendix A<br>• Changed all proposed text from March 2021 and October 2023 to red/purple text<br>• Change formatting 2.2.4.a and 2.2.4.b to 2.2.4.1 and 2.2.4.2 for consistency<br>• Minor formatting changes noted in blue text |
| April 2025 | • Added 3.7 Technical Bulletin Plugging Tubes in Drums and Headers based on Executive Committee email guidance (March 12, 2025)<br>• Added 4.5 Plugging Tube in Drums and Headers based on Executive Committee email guidance (March 12, 2025)<br>• Minor formatting, editorial and grammatical changes noted in green text. Entire document was updated to smart formatting to allow automatic renumbering<br>• Added hyperlinks to other Sections, Figures and Tables |

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# 1 GENERAL DOCUMENT FOREWORD

The BLRBAC Materials and Welding Subcommittee was formed to provide a center of expertise on recovery boiler materials and welding issues. The subcommittee's function is to promote safety and reliability of black liquor recovery boilers through development of materials and welding guidelines.

The following document provides information and guidance on matters relating to recovery boiler materials, welding and related issues. The term "materials" encompasses pressure and non-pressure part metals, paints and preservatives and refractories. The term "welding" encompasses precautions, preparation and procedures.

This document represents a compilation of materials applications and welding guidelines and practices drawn from experience during boiler manufacture, repair and maintenance. This document is not intended to be a "Standard" for repairs. Rather, it presents peer reviewed guidelines that can be considered for repairs and maintenance. The document sections will include the following elements:

- Problem Description
- Classification Indicator
- Details / Causes
- Areas Affected
- Recommended Inspection
- Recommended Actions
- Additional Information

The Subcommittee recognizes that these guidelines are only one small facet to the safe repair and maintenance of Black Liquor Recovery Boilers. No set of guidelines can cover all situations or specific problem areas encountered with individual boilers. This document may be helpful in the repair or upgrading of older boilers, but it still should be used as a guide only. The responsibility of the final decision(s) and or action(s) taken in any and all cases lies with those in charge of recovery boiler maintenance and is beyond the intent and purpose of this document. It is not the intent of this Subcommittee to force major designs or operational changes to existing black liquor recovery boilers.

New Recovery Boiler constructions should be manufactured in accordance with ASME Section I of the Boiler and Pressure Vessel Code and the American Forest& Paper Association's (AF&PA) Guidelines and Checklist for Specification and Construction of New Black Liquor Recovery Boilers.

Backing Rings should not be used in butt welds exposed to the fireside.

This document will be revised from time to time. Applicable codes and jurisdictional requirements shall take precedent over this document. This document is not intended to exclude alternative practices, procedures, codes and standards.

Additional information on recovery boiler welding maintenance and materials is available from TAPPI TIPs [1)], AF&PA Maintenance Manual [2)] and other sources. The reader is encouraged to refer to these additional references and use the section in this manual's binder to collect relevant articles.

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1) TAPPI TIP's are available for a nominal fee from www.tappi.org.
2) The AF&PA Recovery Boiler Reference Manual Volume II Maintenance and Repair Analysis: Repair Guidelines and Practices

# 2 GENERAL WELDING FOREWORD (FOR SECTIONS 3 AND 4)

Proper repairs to black liquor recovery boilers may be more critical than repairs to conventional power boilers. Improper or inadequate repairs may result in smelt/water explosion or extended loss of production.

An evaluation for permanent repairs should include a failure analysis using the failed component. However, it is understood that there are situations where it is not economical or feasible to obtain a sample to perform failure analysis.

Welded repairs should be based upon Jurisdictional requirements, National Board requirements, applicable standards, and mill requirements.

Several steps are required for successful weld repairs. The steps for a successful repair are to evaluate the need, determine the extent and type of repair, establish the repair plan, obtain proper inspector acceptance, review qualification requirements, implement repairs, and finalize repair acceptance criteria. Figure 2.1 provides the flow diagram for a successful weld repair.

## 2.1 Evaluating the Need for Repair

Considerations to be used when evaluating boiler repairs should include:

- Can the serviceable life of the defective component be extended without a weld repair?
- Should a sample be taken for failure analysis?
- Is the repair considered temporary or permanent?
- What are the consequences of the selected repair or alteration?
    - What is the impact of the repair on safety and operation of the boiler?
    - What is the impact of any modifications on future consideration?

## 2.2 Determining the Extent of the Repair

A permanent repair may significantly impact repair schedule when a temporary repair would safely span the interval to the next scheduled outage. However, a temporary repair may eliminate the ability to secure a sample for failure analysis. Availability of materials should be considered prior to making the repair. Evaluate the nearby components for collateral damage. Adjacent components may be damaged to gain access to the failed component.

## 2.3 Establishing the Repair Plan

Items to consider in the repair plan are securing the boiler, cleaning the boiler, accessing the area, material requirements, safety of personnel, identifying personnel, equipment, and documentation requirements, communicate the field identification method, and duration of the repair process. Establish the pressure test requirements, including test pressure.

Manufacturers Data Report Forms (P-3 or P-3A forms) document design and materials used in drums, tubes, headers, etc. This information is vital for selecting the correct material and Welding Procedure Specification (WPS) when repairs are required. Special attention is needed for all material and WPS selections but is especially necessary when high temperature conditions of the superheater or dissimilar metals are involved.

### 2.4 Obtaining Proper Inspector Acceptance

Identify the organization that will provide inspector acceptance. Identify the agency that will perform the inspection. Determine if this is a routine repair, a major repair or an alteration.

### 2.5 Reviewing Qualification Requirements

Qualifications of the repair organization should be verified. Qualifications to be verified include:

- An approved Welding Procedure Specification(s) is(are) available
- Welding Procedure Specification(s) and welder(s) shall be qualified to ASME Section IX
- Material Lists meet code requirements and may require Mill Test Reports
- Nondestructive Examination process and technician qualifications
- Heat treatment procedure is available if required

### 2.6 Implementing Repairs

Implement the traveler. Identify someone to ensure established repair plans and procedures are followed. Establish inspection hold points. Hold points may include material verification, fit-up, root pass and final pass.

### 2.7 Finalizing Repair Acceptance Criteria

Conduct the final closure inspection. Complete the final acceptance test procedure. Complete the final repair documentation. Documentation can include R-1, weld maps and drawings. Identify follow-up activities that are required at the next scheduled outage if temporary repairs were made.

Records of any pressure part repairs should include documentation of all NDE

that was performed.

A simple graphical representation or flow chart, Figure 2.1, of the repair process steps follows.

### 2.8 Weld Quality

One of the most important parameters which need to be controlled to prevent smelt-water reaction is weld quality. All pressure containing welds in the furnace should be performed in accordance with Section I and IX of the ASME Boiler and Pressure Vessel Code as well as the National Board Inspection Code.

All pressure containing butt welds in the furnace, or any weld that could admit water into the furnace, the entire weld should be examined by radiography(RT) and /or ultrasonic (UT) examination methods. All pressure containing welds, at a minimum should be examined visually.

Radiography or ultrasonic examination methods for pressure containing welds should be applied in accordance with Section V of the ASME Boiler and Pressure Vessel Code.

Acceptance Standards stated in ASME Section I should be used determine acceptability of welds.

Qualifications of personnel conducting examinations should be in accordance with SNT-TC-1A "Recommended Practice for Nondestructive Testing Personnel Qualification and Certification," published by the American Society for Nondestructive Testing (ASNT).

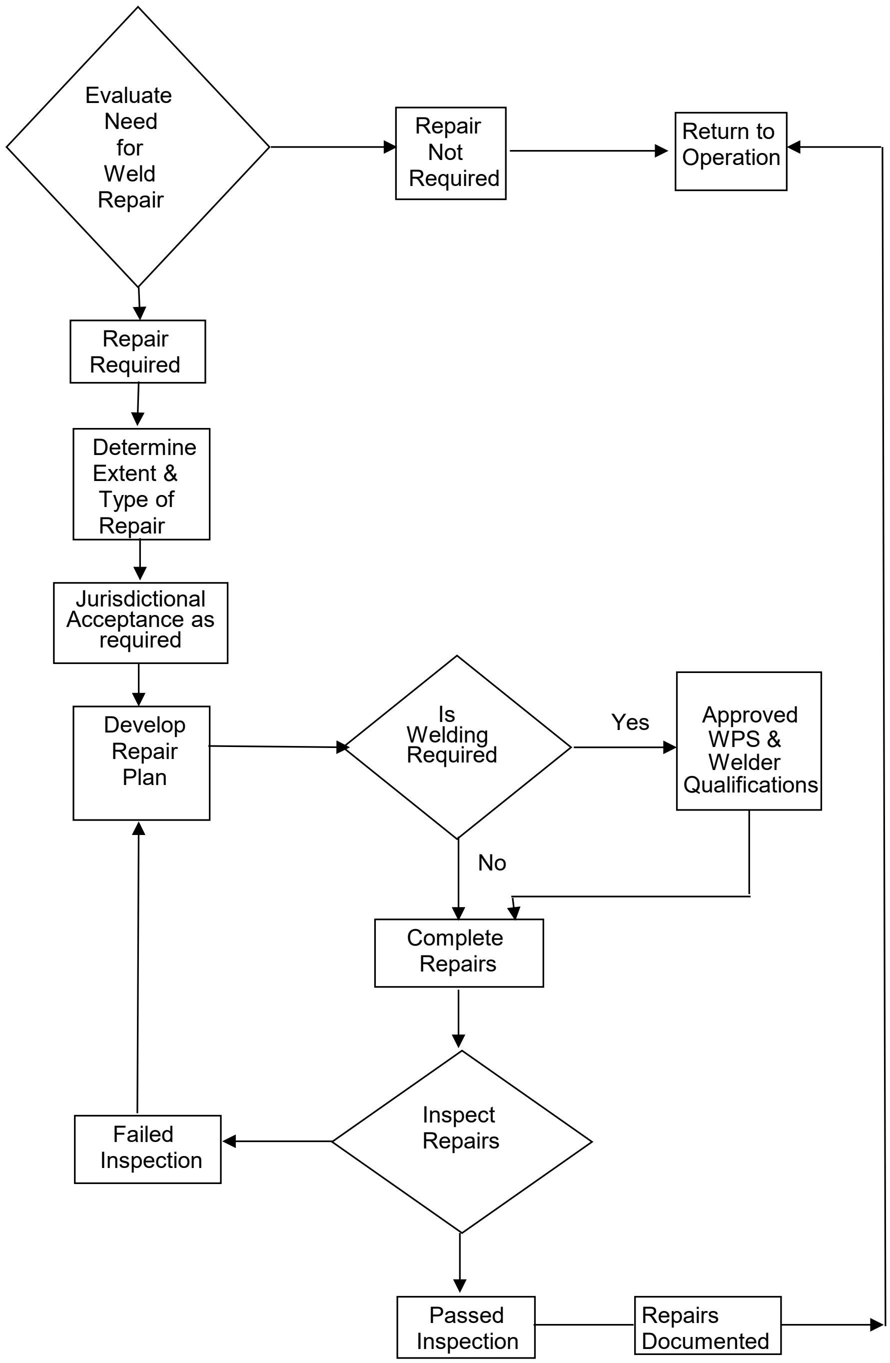



**Figure 2.1: Flow Diagram for a Successful Weld Repair**

# 3 (PREVIOUS SECTION 1) WELDING BULLETINS

## 3.1 Stress-Assisted Corrosion (SAC)

**Description:** Waterside Stress-Assisted Corrosion (SAC) is a common damage mechanism resulting in water leaks at weld attachments. SAC should be considered the likely damage mechanism whenever leaks occur in an area of weld attachments. The problem can occur in any of the water tubes of the boiler.

**Potential for Exposure:** Critical and Non-critical.

**Details / Causes:** The SAC mechanism is based on the premise that the highest stressed zone will selectively corrode in the boiler feedwater. Studies at the Electric Power Research Institute (EPRI) and elsewhere have shown that SAC occurs if the local strain on the internal surface of the tube exceeds a certain level such that the magnetite scale is fissured. This condition leads to corrosion of the steel at the bottom of the fissure and leaves the magnetite scale that eventually reforms at the fissure weaker, and therefore subject to repeated fracture. Repetitions of stress and/or changes in corrosivity of the feedwater cause crack-like crevices to grow.

**Boiler Areas Affected:** Areas of most concern are lower boiler regions where leaks are likely to introduce water into the furnace area: waterwalls at primary and secondary windbox scallop bar attachments, floor-to-sidewall seal bars and corner tubes. Other areas where SAC is common are nose arch seals, smelt box attachments, buckstay attachments and around port and manway openings.

**Recommended Inspection:** Several nondestructive test methods (including radiographic testing, ultrasonic shear wave testing, acoustic emission testing, and remote visual inspection) have been used to inspect for the presence of SAC. No best method has been identified to inspect for SAC. Radiography, which has been used more than other methods, is usually the preferred testing method once the boiler region has been found to have SAC present. It is important that the NDE service company be experienced and qualified to test for SAC indications, regardless of the inspection method used.

**Recommended Actions:**

**Inspection:** Inspection intervals for SAC are dependent on prior history. A baseline inspection for SAC should be performed if leaks have occurred at weld attachments, or if the boiler is older than about 15 years. If SAC is found, the inspection should be expanded to determine the extent of damage.

**Repairs:** Tube leaks caused by SAC damage should be confirmed by metallurgical examination. An alternative is to examine the leaking tube by RT to assist in identification of SAC. Repair of SAC damage by rewelding is not recommended because the extent of ID damage is usually unknown and not visible to the welder. Therefore, only tube replacement in the SAC affected area is recommended. Boiler OEMs have developed improved attachment designs to resist SAC; consideration should be given to use of an improved design for large and/or long-term repairs.

**Additional Information & References:**

1) BLRBAC ESP Document
2) OEM & Service References:

a) Babcock & Wilcox Plant Service Bulletin # 29
b) ANSI/NACE Standard RP0204-2004 Stress Corrosion Cracking (SCC) Direct Assessment Method
c) TAPPI: SP 05010
d) EPRI

## 3.2 Weld Repair of Cracks in Water Tubes

**Description:** This guideline addresses the repairs of stress propagated defects (cracks) that have gone some percentage into the tube wall, including through wall. This procedure is limited to repairs that compromise the pressure-retaining boundary of the tube.

**Potential for Exposure:** Critical/ Non-Critical, depending on the location of the crack and the potential of creating a smelt water reaction from the introduction of water into the furnace.

**Details / Causes:** Stress risers and/or corrosion generally assists cracking in boiler tubes. Cracks can propagate from the external or internal surface of a tube. The quality of fabrication, erection, and welds are also potential causes of cracking.

**Boiler Areas Affected:** Termination welds (fins, membrane), port openings (closure plates), port openings (composite tubes, weld overlay tubes), tube penetration location where movement of tubes are not adequately restrained (generating bank, economizer, screen tubes), structural attachment welds (buckstay, scallop plate), localized overlay weld repairs.

**Recommended Inspection:** For nondestructive testing (NDT) techniques used in initial crack detection. Some inspection techniques used to assess the severity of the detected indication are, Dye Penetrant Test, Ultrasonic Inspection, Radiographic Inspection, and magnetic particle inspection.

**Recommended Actions:** Completely remove the crack with a minimum amount of grinding, perform NDT examination to ensure complete removal. Weld repair the area using approved weld procedures and verify the quality of the repair. For through wall crack repairs, consider contamination from waterside deposits when selecting an appropriate weld repair procedure (reference xxx). Through wall cracks attributed to stress assisted corrosion (SAC) should not be repaired using the guidelines listed above. To address cracks caused by SAC refer to the BLRBAC Materials and Welding Subcommittee bulletin addressing SAC.

**Additional Information & References:**

1) OEM & Service References:
   a) The AF&PA Recovery Boiler Reference Manual Volume II Maintenance and Repair Analysis: Repair Guidelines and Practices 4.5.5
2) NBIC RB-4480, RD-2020, Appendix K-1032

### 3.3 Repair of Pressure Boundary Materials in Tubes

**Description:** Identification, Repairing and Inspection of pressure retaining materials in tubes.

**Potential for Exposure:** Critical

**Details / Causes:** Mechanical erosion, corrosion, impact damage, external pitting, grind marks and electrode arc-strike. The repair methodology described within this bulletin is for areas where sufficient material is present to eliminate the possibility of a blow-through with the available weld process method.

**Boiler Areas Affected:** Any tube within boiler

**Recommended Inspection:** Perform visual inspection to identify areas where wall thickness has been compromised followed by thorough UT of areas of concern.

- PT should be used when cracks are present in corrosion resistant coatings to determine potential exposure of pressure retaining materials.
- UT of these exposed base material to quantify wall thickness. Magnetic Lift Off (MLO) may be used to determine remaining coating thickness and whether base material is exposed.
- Copper Sulfate shall be used to determine the presence of corrosion resistant layer; corrosion resistant materials are contaminants to a base material weld.
- Routine UT mapping of boiler tubes per TAPPI guidelines.

**Recommended Actions:** Compare thickness data versus historical corrosion data to timeline for reaching minimal wall thickness. Several options exist for managing this challenge after historical data and next possible inspection date is considered:

1) If corrosion is not severe, it is possible to make no repair and revisit during next inspection date.
2) Make localized repairs using approved weld build-up procedures as described in Section 4.3, Repair of Pressure Boundary Materials in Tubes.
    a) If the repair is in a critical leak area, the repair should be re-evaluated for replacement on or before the next scheduled maintenance outage
3) Replace thinning tube with new tube
4) Perform post-repair visual inspection to identify general poor welding practices.

Further testing may be required to determine root-cause failure mechanism which may require sampling and destructive testing.

**Additional Information & References:**

1) TAPPI: TAPPI 0402-18 Ultrasonic Testing (UT) for Tube Thickness in Black Liquor Recovery Boilers
2) OEM & Service References: (none)
3) NBIC: (none)

### 3.4 Repair of Corrosion Resistant Weld Overlay Applications on Tubes

**Description:** Identification, Repairing and Inspection of existing corrosion resistant weld overlay materials

**Potential for Exposure:** Non-critical, but if not corrected could lead to critical potential for exposure. The repair methodology described within this bulletin is for localized thinning of overlay material that has not yet penetrated to pressure retaining material.

**Details / Causes:** Mechanical erosion, localized corrosion and electrode arc-strike

**Boiler Areas Affected:** Any tube within boiler where corrosion resistant weld overlay has been applied; in general, but not limited to, waterwall and superheat tubes.

**Recommended Inspection:** Visual inspection of applied weld overlay to identify areas where weld thickness has been compromised (weld bead ripples versus smoothing of weld overlay); followed by thorough UT of areas of concern.

- If tube material is removed for replacement, it is recommended to perform Destructive testing of samples to determine mechanism as chosen material may not be adequate for environment.

**Recommended Actions:** Compare thickness data versus historical corrosion data to timeline for reaching minimal wall thickness. Several options exist for managing this challenge after historical data and next possible inspection date is considered:

1) If corrosion is not severe, it is possible to make no repair and revisit during next inspection date.
2) Make localized repairs using approved weld repair procedures that minimize dilution of pressure retaining base material. Localized build-up of the corrosion resistant material is acceptable as long as the pressure retaining boundary is above the ASME minimum wall thickness.
   a) ***NOTE***: The pressure retaining base material Minimum Wall Thickness should be evaluated considering dilution after application of corrosion resistant material. When base material is at or below code minimum, a compatible material that meets or exceeds the ASME code allowable properties of the base material should be used to restore minimum wall thickness. Corrosion resistant material then can be applied.
3) Apply thermal spray corrosion resistant material. Note that surface preparation for thermal spray will remove base material and the concern for code thickness mentioned above must be considered.
4) Replace tubing with appropriate corrosion protection.
5) Perform post-repair visual inspection to identify general poor welding practices.

**Additional Information & References:**

1) NBIC: 3.3.4.3 Wasted Areas Section d) Tubes

### 3.5 Repair of Composite Materials on Tubes

**Description:** Identification, Repairing and Inspection of existing corrosion resistant composite materials

**Potential for Exposure:** Non-critical, but if not corrected could lead to critical potential for exposure. The repair methodology described within this bulletin is for localized thinning of composite material that has not yet penetrated to pressure retaining material.

**Details / Causes:** Mechanical erosion, localized corrosion and electrode arc-strike

**Boiler Areas Affected:** Any tube within boiler where composite tubes have been installed; in general, but not limited to waterwall and superheat tubes.

**Recommended Inspection:** Perform visual inspection of composite tube to identify areas where alloy thickness has been compromised followed by thorough UT of areas of concern.

- If tube material is removed for replacement, it is recommended to perform Destructive testing of samples to determine mechanism as chosen material may not be adequate for environment.

**Recommended Actions:** Compare thickness versus historical corrosion data to timeline for reaching minimal wall thickness. Several options exist for managing this challenge after historical data and next possible inspection date is considered:

1) If corrosion is not severe, it is possible to make no repair and revisit during next inspection date.
2) The pressure retaining base material Minimum Wall Thickness shall be evaluated considering dilution after application of the corrosion resistant material. If necessary, the base material must be built up prior to application of the corrosion resistant material. (Minimum Wall Thickness required for weld build-up of tubes using material of a different P group = ASME code minimum + dilution depth of weld process.
3) Make localized repairs using approved weld repair procedures that minimize dilution of pressure retaining base material. Localized build-up of the corrosion resistant material is acceptable as long as the weld build-up of the material does not dilute the tube material within the ASME pressure retaining boundary.
4) Apply thermal spray corrosion resistant material. Note that surface preparation for thermal spray will remove base material and the concern for code thickness mentioned above must be considered.
5) Replace tubing with appropriate corrosion protection.
6) Perform post-repair visual inspection to identify general poor welding practices.

**Additional Information & References:**

1) The AF&PA Recovery Boiler Reference Manual Volume II Maintenance and Repair Analysis: Repair Guidelines and Practices 4.5.5.4
2) NBIC: 3.3.4.3 Wasted Areas Section d) Tubes

## 3.6 Copper Induced Cracking in Boiler Tubes

### 3.6.1 Introduction

Copper-induced cracking in boiler tubes is a type of liquid metal embrittlement failure that occurs when copper is melted during the welding process and penetrates the steel in the weld heat affected zone of the base metal. This may be from tube butt welds or from weld repairs made to inadvertent tube damage where copper has been deposited. The melted copper is concentrated along the austenite grain boundaries of the steel resulting in a reduction of the tube's mechanical properties (ductility, fracture toughness). The resulting mode of failure is intergranular cracking.

### 3.6.2 Sources of Contamination

Sources of copper contamination include the following:

- Contact with copper tips from wire feeders during the welding process
- Contact with copper nozzles for the delivery of shielding gas
- Copper tooling abrading the surface of the tube
- Copper deposit accumulation on the waterside surface of the tube.
- Energized copper wire arc strike
- Copper backing bars used as a heat sink source during welding of thick-walled steel material (this is not typically used in Recovery Boiler Welding)

Aqueous copper sulfate solution appears to be an unlikely source for copper contamination of welds, but proper cleaning (flap wheel ID and OD) should still be done to assure proper base metal cleanliness for welding.

### 3.6.3 Prevention

- The best method is to prevent molten copper from coming into contact with the susceptible base material during welding.
- Avoid using copper tools that could abrade and contaminate the surface of the base material
- Copper tips and nozzles can be replaced with tips or nozzles that are chromium plated, ceramic or which have Teflon sleeves, etc.
- Copper fixtures can be replaced with aluminum or nickel-plated fixtures
- Buff the ID and OD of the tubes at weld locations to ensure removal of possible copper deposits before welding. Flap wheels are preferred since wire wheel power brushing can smear the metal and contaminants.

### 3.6.4 Evaluation

Suspected contamination of copper is not readily detectable unless there is sufficient residual stress present to initiate cracking shortly after welding. If cracking is immediate, dye penetrant or Magnetic Particle testing can be used to detect cracking. The only definitive method of identification is destructive, metallographic examination.

If copper contamination is suspected, it is recommended that the affected portion of the tube should be replaced.

Hydrostatic testing alone has not proven sufficient to rule out the presence of cracking from copper contamination.

### 3.6.5 Welding

During the welding process, there should be a competent welding inspector onsite to witness the welding as it is being performed per the recommendations in the General Welding Forward.

Due to the increased use of sublet shops and the loss of experienced personnel, education as to the risks of copper contamination must be imparted to all shops, and adequate QA/QC included.

### 3.6.6 Weld Process

#### *3.6.6.1 Repair*

If copper contamination is suspected or detected, the only effective method of repair is complete removal of the affected area. Sufficient base material should be removed to ensure that the entire contamination has been completely removed. Depending on the severity, and the ability to ensure complete removal of the copper contamination, replacement may be the required option.

### 3.6.7 Final Inspection

Dye penetrant examination (PT) or Magnetic Particle Testing (MT) can be used to evaluate the repair area.

If the repair is on a coextruded or weld overlaid tube, the inspection of the carbon steel base metal should be made prior to restoring the corrosion protection layer.

For guidelines on the weld finish of a weld build-up, hydro testing, and documentation, see Section 4.3.5, 4.3.6, and 4.3.7, Repair of Pressure Boundary Materials in Tubes.

### 3.6.8 References

1) John C. Lippold, Welding Metallurgy and Weldability, Copper Contamination and Cracking p 201 – 207
2) W. F. Savage, E. P. Nippes and M. C. Mushal, Copper-Contamination Cracking in the Weld Heat-Affected Zone
3) James J. Dillon, Paul B. Desch, Tammy S. Lai, The Nalco Guide to Boiler Failure Analysis p 41 – 42
4) A.G. Glover, D. Hauser, and E.A. Metzbower, Failures of Weldments, Failure Analysis and Prevention, Vol 11, ASM Handbook, ASM International, 1986, p 411–449
5) LeBel, M. (2018, October). Recent Experience with Tube Failures Caused by Copper Contamination, Presentation at BLRBAC Fall 2018 Conference. Atlanta, GA.
6) Cone, F. Liquid Metal Embrittlement: Copper Contamination Cracking in Black Liquor Recovery Boilers, Presentation at BLRBAC Fall 2018 Conference. Atlanta, GA.

### 3.7 Plugging Tubes in Drums and Headers

**Description:** Identification, Repairing and Plugging Tubes in Drums and Headers

**Potential for Exposure:** Critical/Non-critical, depending on the location of the tube being plugged and the quality of the repair. The repair methodology described within this bulletin is for tubes that have been evaluated and determined that the most effective method of repair is to plug the affected tube/tubes.

**Details / Causes:** Corrosion, erosion, fatigue, leaks in seat, mechanical damage, and design changes.

**Boiler Areas Affected:** Generating bank, furnace screen, superheater, economizer and associated drums and header.

**Recommended Inspection:** Perform visual inspection of fireside surface of tubes looking for visible signs of thinning, dents, cracking, etc. Advanced nondestructive testing can be performed to detect signs of thinning or other tube irregularities. Nondestructive testing may include but is not limited to any of the following:

- Full tube length testing (drum to drum) using ultrasonic test method
- Near Drum Testing using an ultrasonic test method
- Electromagnetic Acoustic test method
- Manual ultrasonic test method
- Penetrant test method
- Radiographic inspection

**Recommended Actions:** After the tubes have been inspected, evaluated and the need to plug the tube has been determined, the loss of total surface area (total tubes plugged) and the concentration of tube plugs (plug density) should be considered. The proximity to the tube plug density threshold should be determined and consider when tube replacements should be planned. Because of potential issues with water side circulation, flue gas channeling, and drum shell overheating, both tube plug clusters and total number of tubes plugged should be considered in reaching the threshold. Accepted best practice is that the number of plugged tubes should not exceed 10%. Discussions with the OEM should be initiated to establish plugged tube cluster and threshold limits.

The type of plug and method of plugging shall be based on the component being plugged. Several options exist for plugging tubes and are based on the type of damage, the type of bore in the header or drum and the location.

A tube plug map should be developed and updated to reflect chronological plugging activity by location and cause.

The plugs shall have the required Material Test Reports (MTR) or Certificates of Compliance for material traceability necessary for use in pressure part repair.

Plug materials and electrode choices must be compatible with the drum material per governing ASME & NBIC guidelines.

### 3.7.1 Plugging at the Drums (Generating Bank)

1) Assess the condition of the tube bell mouth and the type of bore (straight, counter bore) before choosing the method of plugging.
2) Sound the tube to ensure the top and bottom of the tube ends are on the same tube being considered for plugging.
3) If the bell mouth is excessive, the bell mouth must be trimmed before installing the plug.
4) If the tube shows evidence of cracking in the bell mouth or seat area it may be necessary to remove the bell mouth of the tube in the drum and weld a plug directly to the drum. Or, remove the tube, install a short stub and install a plug in the stub.
    a) Refer to Section 4.5 Plugging Tube in Drums and Headers for additional information.
5) Tube Plugs
    a) If the plug is machined from bar stock (not forged material), a button weld should be made on the center of one end to prevent through wall leak potential.
    b) If the bore is countersunk or the tube end does not extend into the drum, a cylindrical plug with a head should be used and the plug seal welded to the drum. The plug should be installed from the ID of the drum to allow a seal weld.
    c) If the bell mouth extends into a drum, a tapered plug may be used. The preferred method is to remove the bell mouth and weld the tapered plug to the drum. However, a tapered plug may be welded to the tube and consider seal welding the tube to the drum.
    d) A cap may be used to cover the bell mouth and weld it to the drum.
6) For tubes being plugged in the generating section it is recommended that the majority of the tube be removed before the plug is installed. If the location of the tube being plugged does not facilitate removing the tube from the bank, a hole shall be made in the tube just outside the drum at both the steam drum and mud drum elevation.
7) Properly clean the surface of the tube/drum and plug.
8) Inspect visually and with NDE for any cracking before inserting the plug.
9) Necessity of preheating of the drum is dependent upon the following:
    a) thickness of the drum at the tube sheet
    b) drum metallurgy
    c) the ambient metal temperature
    d) whether the metals are wet
        i) leaving water between the tube seat and tube remnant could cause weld porosity leaks.
10) Nondestructive testing (PT or MT as a minimum) shall be performed after the repair has been made to verify the repair.

### 3.7.2 Plugging Tubes in Superheater, Furnace Screen, Single Drum Platen Generating Banks, and Economizer Headers

1) Determine whether the header can be accessed externally and if the tube to be plugged is exposed to the flue gas or not.
    a) Where external access is available, and the plug will not be exposed to hot flue gasses, the majority of the tube shall be removed leaving a stub end close to the header that can

accommodate the plug. If the tube is to be replaced at the next scheduled outage, leave sufficient stub length to allow welding a new tube without stress relief of the header. The preference is to leave the old weld line near the header. The plug shall be installed by inserting a disk-shaped plug into the tube to an appropriate depth to allow welding to the inside diameter of the tube or to butt weld a hemispherical cap on the end of the tube.

b) When headers are in the gas stream, it is preferred to remove the old tube stub without damaging the tube seat. Either a new, short tube stub (that will be properly cooled) with a cap butt welded on should be welded into the header, or a cylindrical tube plug with a head should be welded directly to the header (consider preheat requirements, refer to 9 above).
   i) For platen style assemblies, in some situations (because of access or if the problem causing leaks is widespread), it may be more expedient to plug / cap the supply inlet / outlet relief links (supply and riser tubes) instead of directly into the header.
      (1) As a precaution, the structural support should be assessed as should the potential for overheat of un-cooled assemblies. For these situations, full platen isolation is not recommended.
   ii) For platen style assemblies, when the best solution is to plug a tube instead of the platen, accessibility may be a problem.
      (1) For lower bottom mini-headers, a tube section may be removed and a tapered tube plug welded into the top of the mini-header.
      (2) For top mini-headers and upper bottom mini-headers, a "window" must be prepared in the mini-header. A shortened, cylindrical plug with a head fitted to the inside diameter must be welded inside the mini-header. Then the "window" weld must be completed on the mini-header.

2) The amount of heat input to the tube seat shall be controlled according to approved weld procedures.

### 3.7.3 Plugging Tubes

### 3.7.4 Plug Material

Plugs can be fabricated from any ASME compatible material for carbon and alloy pressure parts suitable for the intended service. Consult the OEM for the proper plug material

### 3.7.5 Additional Information and References

1) AFPA Reference Manual Volume 2 - Tube Repair Guidelines
2) NBIC Appendix B – Recommended Preheat Temperatures
3) OEM & Service References
4) TAPPI TIP 0416-22 Guidelines for Operating and Maintenance Practices Impacting an Economizer on a Recovery Boiler
5) ASME Boiler & Pressure Vessel Code

# 4 (PREVIOUS SECTION 2) WELDING GUIDELINGES & PROCEDURES SECTION

## 4.1 Replacing Hand Hole Caps (Weld in Style)

### 4.1.1 General

Some older recovery boilers utilize new and old-style hand hole caps of varying size and metallurgy. It is common that new style hand hole caps are installed during rebuilds. There are instances when OEM's suggested an alloy upgrade of all caps to avoid complication. Care must be taken when removing alloy caps and returning to carbon steel. Best practice is to consult the OEM or other competent technical advisor.

### 4.1.2 Hand Hole Cap Metallurgy

Hand hole caps are available in carbon steel (SA-181-70) or 2 ¼ Cr-1 Mo (SA-182 F22 CL3). The material identification for a typical B&W hand hole cap is stamped on the bottom (rounded) surface. Newer style B&W hand hole caps fabricated with carbon steel are stamped as 80MM, SM17, SM16, or SM70SI; and caps fabricated with 2 ¼ Cr-1 Mo are stamped as 78MM, AM17, AM16, or AM70SI. The old-style B&W hand hole caps sizes are 3-1/4" and 4-1/2". There are also "Master" caps, and "Standard" which the Owner should have new spares in stock.

Typical Hand Hole Material – Filler Metals selection

| **Table 4.1: Electrode Selection Based on Material** | | | |
|---|---|---|---|
| **Hand Hole Cap Material** | **Header Material** | | |
| | Carbon Steel (P1 Material) | 1 ¼ Cr-1/2 Mo (P4 Material) | 2 ¼ Cr-1 Mo (P5A Material) |
| Carbon Steel | E7015-A1<br>E7016-A1<br>E7018-A1 | Unacceptable combination between header and hand hole cap | Unacceptable combination between header and hand hole cap |
| 2 ¼ Cr-1 Mo | E7015-A1<br>E7016-A1<br>E7018-A1 | E8016-B2<br>E8018-B2 | E9015-B3<br>E9016-B3<br>E9018-B3 |

| **Table 4.2: Preheat and Inter-Pass Temperatures** |
|---|
| Preheat – Refer to WPS and code of construction<br>Inter-pass – Refer to WPS and code of construction |

### 4.1.3 Reusing Hand Hole Caps

It is recommended to replace all weld-in hand hole caps removed with a new cap. However, in the event a new cap is unavailable, re-using an old hand hole cap is acceptable if the cap can be adequately cleaned up; any removed cap material be replaced with weld metal and liquid dye penetrant testing performed.

### 4.1.4 General Good Practice Items:

1) The Contractor and Owner should agree on hand hole cap removal and installation requirements. It is advisable to have the Owner's representative and the Contractor both mark the specific hand hole caps that are to be removed and verify there are the correct replacement caps in hand, before removing any caps.
2) Owner's representative should monitor the hand hole cap removal and installation. (See suggested welder guidelines and welding traveler).
3) NDE work should be performed by technicians qualified according to SNT TC-1A for the test work performed. A minimum of Level II technician is required to interpret results.
4) Weld acceptance criteria, including VT, is to be in accordance with ASME Section I.
5) All welders who will be performing the cap removal and installation process should receive training on the procedure and QC requirements.
6) When a large number of caps are to be replaced such as for a boiler cleaning, it is best practice to set up a mock assembly for testing welder proficiency.
7) If there are alloy caps in the superheater headers, and carbon steel in the balance of headers, it is good practice to paint code both the header and the caps.
8) Account for all the removed caps (caps have been left in the headers, just out of sight).
9) Each header should be inspected internally by the owner's representative prior to closure.

### 4.1.5 Hand Hole Cap Removal Procedure

1) Only the seal weld is to be removed. The seal weld may be removed by arc gouging or grinding. Care needs to be taken so that excessive metal is not removed from the header and the header seat is not damaged.
2) Remove cap from the header. Account for all removed caps.
3) After cap removal, lightly prepare the header opening area to clean it up for inspection. Grind the header surfaces for at least ½" on each side of the welding area to remove any pitting, rusting or other surface oxides. Thoroughly clean the header seat and bore as well as all welding surfaces of weld spatter, oil or grease, debris, oxides, paint or other substances. Use a cleaning solvent to remove grease and oil if present.
4) Liquid dye penetrant examination should be performed on the header opening.
5) Determine whether header repairs are required. (Shoulder must be square, hole diameter within tolerances, header thickness in seat area within tolerance, no linear indications in parent header metal, no visual defects).
6) Remove any defects and perform a dye penetrant examination to assure no defects remain.

### 4.1.6 Header Repair Procedure

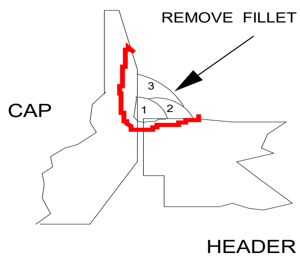
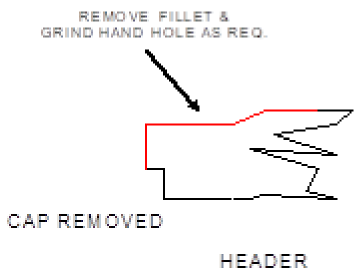
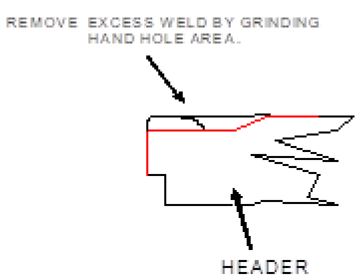
1) Header build up procedure is to be established by the contractor and approved by Owner. Weld inspection QC should verify proper weld metal, procedures, preheat and weld interpass temperatures. No repair to the header should be performed while welding in the hand hole cap, it should be done before installing the cap.
2) Clean the surface of all grease, oil and dirt.
3) Ensure preheat has normalized through the header per WPS and code of construction.
4) Build up the header opening and grind, or machine the surface to the original hole configuration. Verify that the header edge is square and is of proper thickness.
5) Final prepared surface to be VT, PT or MT examined, prior to welding to verify sound repairs and no porosity, cracks, etc.
6) Perform internal inspection of header before closure.

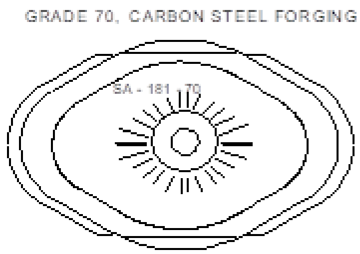
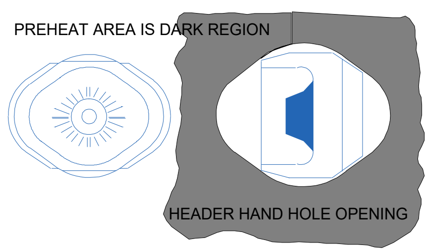
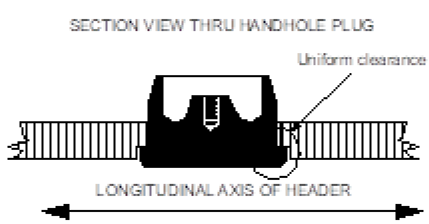
### 4.1.7 Hand Hole Cap Installation

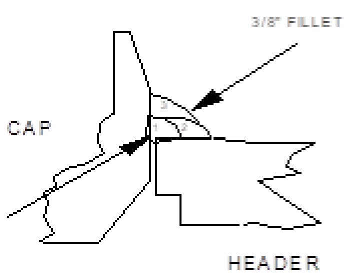
1) Do not “prick punch” the cap seating surface on a B&W style cap. The CE Style caps need this for shrinkage allowance of the weld metal.
2) Position the cap in the hole oriented per the drawings. The cap should be centered in the hand hole. Verify dimensions 90 degrees apart. There should be no excessive gap between the header and cap. Verify that cap dimension is correct, and check fit up gap.
3) Pull a non-CE Style cap up into the socket using a strongback, this helps to hold the hot hand hole cap and can eliminate the need for tack welds. Tack welds are best avoided, if possible, but if a cap pulling fixture is not available, place minimum 1” tacks, and feather the start and stop of each and VT examine, do not reduce the preheat if using tacks.
4) For CE Style caps, “prick punch” the cap seating surface using a center punch or chisel to apply several punch marks to the end of the mating face of the cap. This is to upset the mating faces and allow for shrinkage of the weld.
5) For other cap styles, refer to manufacturers guidelines for installation procedures.
6) Apply a preheat (refer to code to determine correct temperature for different metallurgies of cap and header) to the header and cap. Use temperature indicating crayons to confirm temperature is within parameter. The greater of 15 minutes or 15 minutes per inch of thickness should be allowed for temperatures to normalize. Check the header temperature approximately 1/2” and 3” away from the weld area. Confirm the cap for temperature at the same time.
7) Once temperature has been verified, hold and maintain the temperature, with periodic temperature verification throughout completion of the welding and NDE QC inspecting.
8) Root pass requires a VT inspection. Welder is to clean up the weld root pass of all slag for inspection. Maintaining the interpass and preheat temperature are vital.
9) Make a 3/8” throat fillet weld (1/2” or less leg) per specifications (refer to drawings in this guideline). Weld in excess of 3/8” throat will require PWHT as per ASME I-PW-39, or Alternate Rules to PWHT per NBIC.
10) The weld starts and stops are to provide continuous overlap of the previous weld pass (a staggered bead).
11) The root pass should provide uniform weld penetration into both the cap and header.

12) The completed weld is to be cleaned for inspection.
13) NDE final examination should include VT (including weld dimension) and MT if temperature is over 200□F, or PT or WFMT if cooled off.
14) Insulate the cap and surrounding area for slow cooling after final welding.

### 4.1.8 Handhole Caps Welding Guidelines

| Table 4.3: Removal Sequence & Header Repairs | | |
|---|---|---|
| **Step 1**<br><br>Cap Removal |  | Remove the header hand - hole cap seal weld by arc gouging or grinding.<br><br>Take care to remove only the old weld. Watch closely while gouging for any cracks.<br><br>If there is any indication of cracks forming during the gouging process, then preheat the header to 200°F minimum before further gouging. |
| **Step 2**<br><br>Clean/ Grind/ Dye Penetrant |  | Clean the header hand hole prep area by grinding; if cracks are present; use a rotary burr, to avoid "pushing, or chasing the crack".<br>Check fit up with the replacement cap.<br><br>Visually inspect for cracking or porosity. Porosity indicates old weld remains.<br><br>Perform MT or PT on weld prep surface area. |
| **Step 3**<br><br>Header Weld Repair |  | PREHEAT. (may vary with alloy, follow WPS).<br><br>Make any necessary weld repairs around the hand hole opening. Depth of repair may involve PWHT or NBIC Alternate Rules to PWHT.<br><br>The weld repairs should make a smooth base for the final hand hole cap fillet weld. |
| **Step 4**<br><br>Final PT / MT before Cap Install | Old cap removed,<br>Weld repairs made,<br>&<br>Call for inspection. | NDE examination should include VT and MT if temperature is over 200°F, or PT or WFMT if cooled off. |

<table>
<tr><th colspan="3">Table 4.4: Installation Sequence</th></tr>
<tr><td>Step 5<br><br>Check cap for proper marking.</td><td>
</td><td>Examine the handhole cap to assure that it is stamped with the material designation (e.g., SA 181–70 or SA 181–60). Manufacturer markings must be verified to identify code material. Check for appropriate welding procedure.<br><br>Clean the area to be welded using a clean wire brush and/or light abrasive wheel.</td></tr>
<tr><td>Step 6<br><br>Cap Prep</td><td></td><td>For B&W Style Caps go to Step 7.<br><br>For C.E. Style Caps: Using a center punch or chisel – apply several punch marks to the end of the mating face of the cap – this is to upset the mating faces and allow for shrinkage of the weld, which will pull the cap into the header.</td></tr>
<tr><td>Step 7<br><br>Insert cap and preheat</td><td>
</td><td>Insert the cap through the counter bored header handhole. The cap must be passed through the handhole and then rotated 90° so you can see the center boss thread.<br><br>Use the threaded boss to center the cap during welding.<br><br>Preheat cap and header (may vary with material; follow WPS and code of construction).</td></tr>
<tr><td>Step 8<br><br>Tack weld, feather tacks (CE style cap)</td><td>
</td><td>Welding may be performed with SMAW (STICK) OR GTAW (TIG).<br><br>DO NOT EXCEED MAXIMUM INTERPASS TEMPERATURE; follow WPS and code of construction.</td></tr>
</table>

| **Table 4.4: Installation Sequence** | | |
|---|---|---|
| | | If a welding fixture is used to pull the cap into the seat, omit the tacks; if not, apply 2 tack welds about 1" long (not a button weld) on each side of the cap.<br><br>Clean & "feather grind" each tack such that no slag remains from the tack welding. A rotary burr works well for feathering.<br><br>The weld root shall be made so as to tie-in the header and cap with no greater than 1/32" undercut, and no coldlap, or visible porosity. Weld out the root pass on one half of the cap. Complete the root pass and remove any slag. |
| **Step 9**<br><br>Weld & limit interpass temp |  | TEMPERATURE; follow WPS and code of construction.<br><br>The weld must have an effective throat of less than 3/8" which can be performed with a 3 pass or multi pass joint with a leg of less than 1/2".<br><br>A 3-pass fillet is shown.<br><br>Run bead number 2 with its start point staggered inside of and against the header side of the root pass. Use a staggered start / stop weld bead sequence, grinding the starts and the stops completely off to sound metal, to allow consistent weld height, and removal of any start porosity.<br><br>Complete the weld with bead number 3, placed so as to tie the passes 1 & 2 to the cap itself. This bead may be a stringer cover or a slightly weaved cover pass. |

| Table 4.4: Installation Sequence | | |
|---|---|---|
| | | For multipass welds greater than 3 passes, (refer to Section 4.1.9 Detail of ½" Leg Fillet Weld to see additional detail 6 pass weld showing ½" leg fillet profile). |
| **Step 10**<br><br>Final Inspection |  | Perform final VT (visual inspection) and assure a maximum 3/8" EFFECTIVE THROAT fillet weld.<br><br>A fillet weld with a ½" leg will typically have a 3/8" throat.<br><br>Final MT if temperature is over 200°F, or PT or WFMT if cooled off.<br><br>Fillet welds with a throat over 3/8" require PWHT. |

### 4.1.9 Detail of ½" Leg Fillet Weld

When necessary or requested, a multi pass weld with 6 passes is common, and it still has a throat of 3/8". This is shown as an option to the standard 3-pass fillet weld, as illustrated on the Handhole Caps Removal & Welding Guidelines installation sequence ~ handhole - cap.

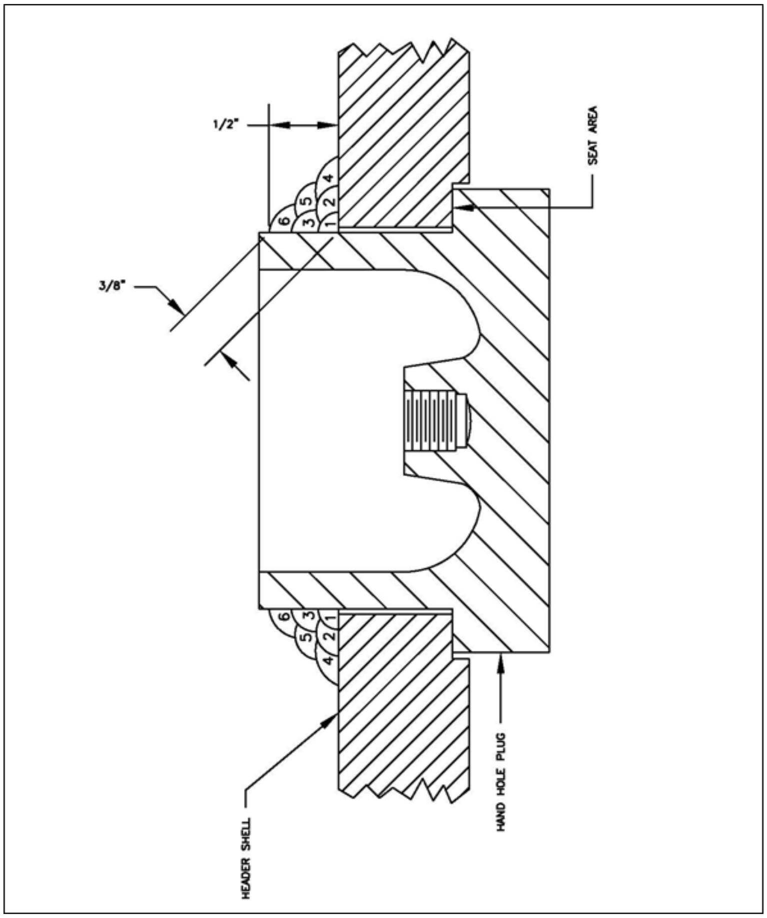



**Figure 4.1: Detail of 6 Pass Weld**

#### 4.1.10 Weld Traveler

| | |
|---|---|
| **Unit I.D. & Pressure Part:** | |
| **Welding Procedure:** | |
| **Header & Cap(s):** | |
| **H = Hold Point** | No work to proceed beyond the task item until the hold item is checked and signed off. |
| **V = Verification** | Work may proceed beyond the task, but it shall be noted as being checked, by leadsman, foreman, or supervisor on shift, so as not to hold up the work. There will be a final sign off of this "V" by owners' representative. |

| **Step** | **Item & Description**<br>Hand Hole Cap Installation | **Hold** | **Contractor**<br>Sign – Date | **Hold** | **Customer**<br>Sign – Date | **Hold** | **A.I**<br>Sign – Date |
|---|---|---|---|---|---|---|---|
| 1 | Removal of existing handhole cap | | | | | | |
| 2 | Clean-up header and seat | | | | | | |
| 3 | NDE-examination of cleaned header – PT/MT | | | | | | |
| 4 | Weld build-up of header (if required)<br><br>Preheat Monitored@_________°F | | | | | | |
| 5 | NDE-examination of header build up – PT/MT<br>*(may be waived for final PT)* | | | | | | |
| 6 | Internal header inspection<br>*(prior to closure)* | | | | | | |
| 7 | Fit-up of new cap – orientation & tacking<br>Review weld bead sequence | | | | | | |
| 8 | Preheat Monitored@_________°F | | | | | | |
| 9 | Root Pass | | | | | | |
| 10 | Welding Out | | | | | | |
| 11 | Inspection – Completed weld – Final Visual / PT, WFMT or MT Dry | | | | | | |

#### 4.1.11 References

1) Master Hand Hole (MHH) Plug Welding Recommendations, Babcock & Wilcox Plant Service Bulletin # 53, Babcock.com
2) ALSTOM's APComPower's Quarterly Newsletter "Tidbits", Issue #107, October - December 2002

## 4.2 Weld Repair of Small Holes / Cracks in Superheater Tubes

### 4.2.1 Introduction

1) This procedure applies once the need for a repair has been determined. Refer to Forward and Associated Technical Bulletin for guidelines to determine need for repair. Jurisdictional requirements should be considered and followed.
2) Small holes/cracks in superheater tubes may be weld repaired. The tubes being steam-filled, the internal surfaces should be free of deposits; therefore, there is little risk of weld contamination.
3) Types of holes/cracks in tubes that may be repaired if the criteria in 2.0 are met
4) Crack originating on the external surface at an attachment weld
5) Torch cut occurring during repairs
6) Excessive grinding during repairs
7) Deliberate grinding for known purposes, such as draining of superheater tubes
8) Mechanical damage from sharp tools driven into tubes
9) Attachment weld pulled from tube, which pulls out tube metal
10) Arc strikes that are severe enough to blow a hole in a tube
11) If the cause is internal corrosion pitting or fatigue, the tube section must be replaced.

### 4.2.2 Evaluation

1) Criteria for weld repair of small holes/cracks in superheater tubes
2) After preparation for welding the excavation does not exceed:
3) 1/8" in width at the root
4) 25% of the tube circumference for circumferential length and 2" for longitudinal length (the limit on circumferential length is due to stresses in welds that do not run the entire circumference. These stresses are not a problem in longitudinal welds. The longitudinal length limit is intended to restrict the length of longitudinal repairs in lieu of sectioning).
5) Root cause is known, i.e., torch cut mechanical damage, etc.
6) Assuming there are no other thin areas, tube thickness adjacent to the area to be repaired is not less than Code minimum.
7) There are no branched cracks running from a crack intended to be repaired, as determined by MT or PT examination
8) The tube area adjacent to the repair area is free of distortion inward or outward from the normal plane of the tube surface

### 4.2.3 Materials

1) Welding materials shall be qualified for use by the Welding Procedure Specification (WPS).

### 4.2.4 Procedure

#### *4.2.4.1 Weld repair procedure for a torch cut, grinder cut, sharp tool damage or severe arc strike*

1) Measure the hole
2) Take thickness measurements immediately adjacent to the hole and compare the measurements to minimum allowable wall thickness
3) Remove all contaminants at the edge of the hole and bevel the edges to an approximate 37 ½ degree angle as for a butt weld
4) Make the repair per approved welding procedure.
5) Ensure interpass temperature for the chrome-moly material is not exceeded.
6) The root pass, and preferably the hot pass, should be made by the GTAW process to assure a full penetration weld if the repair is through-wall.

#### *4.2.4.2 Weld repair procedure for cracks*

1) Determine the length of the crack by MT or PT examination. Ensure that there are no branched cracks.
2) Take UT thickness measurements adjacent to the crack to ensure Code minimum thickness
3) If a crack adjacent to a tie weld or a spacer type tie (dovetail, “D” link or hinge pin sleeve) is to be repaired, remove the tie weld or spacer tie. When a spacer tie is removed, check the area adjacent to the weld repair with a copper sulfate solution to identify any remaining stainless or alloy material. All stainless or alloy material must be removed prior to making the weld repair.
4) Grind out the crack. Check for complete removal by MT or PT examination. The crack must be completely removed.
5) Make the repair per approved welding procedure.
6) Ensure interpass temperature for the chrome-moly is not exceeded.
7) The root pass, and preferably the hot pass, should be made by the GTAW process to assure a full penetration weld if the repair is through-wall.
8) Reinstall the tie 2”, ± 0.5”, above or below the weld repair.

### 4.2.5 Acceptance

1) Traveler documented at the discretion of the owner and repair contractor.
2) Final inspection, testing, and documentation of repairs
3) Examine the finished weld, visually and by MT or PT.
4) Documentation of hole/crack repairs in superheater tubes is at the discretion of the plant, however, a Report of Welded Repair may be required by jurisdictional requirements. If the repair is required because of an unscheduled outage, the repair should be documented in a failure report.
5) Information concerning the repair should be recorded as outlined below.
   a) Date of repair
   b) Platen number, tube number, row number and elevation should be recorded.

c) Cause of the hole
d) Size of the hole
e) Person authorizing the repair
f) Welding inspector accepting the repair

#### 4.2.6 References

1) The AF&PA Recovery Boiler Reference Manual Volume II Maintenance and Repair Analysis: Repair Guidelines and Practices 3.7.1.112

## 4.3 Repair of Pressure Boundary Materials in Tubes

### 4.3.1 Introduction

This procedure applies once the need for a repair has been determined. Refer to the General Welding Forward and Associated Technical Bulletin for guidelines to determine need for repair. Jurisdictional requirements should be considered and followed.

Erosion or corrosion of boiler tubes may occur over large areas or may be confined to relatively small spots. The repair options vary according to the severity of the metal loss, the area of coverage, the type boiler, the location in the boiler, etc. Weld buildup may be used for repair of eroded, corroded, or mechanically damaged tubes when the defects do not exceed those listed under Section 4.3.4 Special Restrictions of this document.

### 4.3.2 Evaluation

Ultrasonic thickness measurement or other nondestructive techniques shall be used to map the extent of thinning and assess the size of the area to repair. Visual examination shall also be conducted to look for any evidence of cracking or bulging of tubes. It is recommended that the last water wall tube sample data be reviewed to determine if water side deposits is a contributing factor to the thinning observed. Also, if there are high amounts of copper present in the waterside deposits, a problem with tube metallurgy (embrittlement) could be caused during welding.

### 4.3.3 Materials Selection

The area can be repaired using material conforming to the original code of construction including the material specification requirements.

### 4.3.4 Special Restrictions

This procedure should only be used on recovery boilers only when the following criteria are met:

1) The remaining thickness of the pressure boundary base material is:
   a) Sufficient to prevent burn through dependent upon welding process
   b) If below minimum wall thickness additional considerations should be applied
      i) Size of thinned area
      ii) Location in unit
      iii) Local jurisdictional requirements
      iv) Remaining wall thickness
      v) Other applicable codes and regulations
2) When the tube surface is free of defects such as bulges or cracks
3) The surface must be free of material that could be detrimental to welding. This normally requires grit blasting to a white metal finish, or localized grinding.

### 4.3.5 Welding

During the welding process, there should be a welding inspector onsite to witness the entire repair as it is being performed.

#### *4.3.5.1 Welding Technique*

Welding current that will produce complete-fusion without burn through. Fill the repair area with a series of stringer beads, except that weaving is permitted in the vertical position to a maximum width of about 2-1/2 times the electrode diameter. Deposit thin beads to minimize melt through.

More than one layer is permitted if the first layer does not completely fill the wasted area.

#### *4.3.5.2 Cleaning and Removing Defects*

All unfused weld metal, voids, slag, weld splatter, and irregularities should be removed from each weld bead before depositing a succeeding weld bead. If burn through or melt through is suspected, the tube section should be replaced or examined radiographically or ultrasonically (see final inspection).

#### *4.3.5.3 Weld Finish*

The surface of the completed weld shall be ground free of weld surface irregularities. The edge of the weld shall merge smoothly into the surface of the tube, but the tube should not be ground under-gauge. A slight crown or reinforcement up to 1/16" may remain and shall not exceed the width of the wasted area by more than 3/16 of an inch.

### 4.3.6 Final Inspection

Close visual examination by a welding inspector is required for all welded repairs.

The integrity of the repair shall be verified by one of the following methods for pressure boundary repairs where a failure is not likely to allow water to enter the furnace:

- Magnetic particle testing (MT)
- dye penetrant examination (PT)
- hydrostatic test

For repairs where failure is likely to allow water to enter the furnace MT or PT shall be performed prior to a hydrostatic test.

#### *4.3.6.1 Hydrostatic Testing*

The hydrostatic test pressure shall be adequate to verify the integrity of the repair.

### 4.3.7 Documentation

The location, extent, filler materials and base material shall be documented and maintained for future reference.

### 4.3.8 References

1) ASME PCC-2 – 2022 Article 304
2) NBIC Part 3

## 4.4 Corrosion Resistant Weld Overlay on Boiler Tubes

### 4.4.1 Introduction

Erosion or corrosion of boiler tubes may occur over large areas or may be confined to relatively small spots. The repair options vary according to the severity of the metal loss, the area of coverage, the type boiler, the location in the boiler, etc. The following procedure is provided assuming that weld overlay is the chosen method of protection. Weld metal overlay may be used to provide a corrosion resistant barrier on boiler tubes that have suffered erosion and/or corrosion during service and meet the criteria listed under Section 4.4.4 Special Restrictions of this document.

### 4.4.2 Evaluation

Visual examination shall be conducted to look for any evidence of localized erosion or corrosion. If there is any visual evidence of cracking or bulging on tubes, alternative means of repairs shall be considered to address those tubes before applying weld overlay for corrosion protection. Ultrasonic thickness measurement shall be used to map the extent of thinning and assess the size of the area to repair.

### 4.4.3 Materials Selection

If the thinning is the result of general corrosion or erosion occurring on the tubes, it may be necessary to apply a corrosion resistant weld overlay to the base material to prevent further metal loss. Depending upon the nature and severity of the metal loss, selection of the material to be used may be the original base material or a more corrosion resistant material. A list of potential upgraded materials that may be used includes:

- 309L Stainless Steel
- Alloy 625
- Alloy 825

### 4.4.4 Special Restrictions

This procedure should be used on recovery boilers when the following criteria are met:

- The area to be overlaid is accessible for welding and inspection is possible.
- The remaining thickness of the pressure containing base material is at or above the minimum thickness required to maintain the structural integrity of the tube (refer to Section 1.4 for base metal dilution considerations).
- The tube surface is free of defects caused by corrosion or overheating.
- If the size of the area to be overlaid is large, consider having water in the boiler to reduce the risk of distorting the tubes during welding.

### 4.4.5 Welding

#### *4.4.5.1 Surface Preparation*

All oxides and foreign substances shall be removed from the surface of the area to be repaired.

This preparation should be extended beyond the extremities of the repair area to ensure no weld contamination occurs. Overlay must be applied in a timely manner to prevent re-oxidation. Alternatively, a weld compatible coating may be applied to prevent re-oxidation.

#### *4.4.5.2 Welding Process*

The recommended welding processes that can be used to perform repairs are the following:

For localized areas:

- Shielded Metal Arc Welding (SMAW)
- Gas Tungsten Arc Welding (GTAW)

For larger areas:

- Metal Inert Gas Welding (MIG)
- Electron Beam Welding (boiler tubes)
- Laser Applied Welding (boiler tubes)

### 4.4.6 In Process Inspection

#### *4.4.6.1 Cleaning and Removing Defects*

All un-fused weld metal, voids, slag, weld splatter, and irregularities shall be removed from each weld bead before depositing a succeeding weld bead. If burn through or melt through is suspected, the tube section should be replaced. A radiograph can be used to verify if burn through or melt through has occurred (see final inspection).

#### *4.4.6.2 Weld Finish*

The surface of the completed weld shall be ground free of abrupt ridges and valleys. The edge of the weld shall merge smoothly into the surface of the tube, but the tube should not be ground under-gauge. All edges of the weld buildup shall be tapered to the existing contour of the tube, at a maximum angle of 45°. Common practice typically utilizes a 3:1 taper. Exercise extreme caution during the tapering action to avoid damage to the base material. A slight crown or reinforcement may remain.

### 4.4.7 Final Inspection

Visual examination is required for all weld overlays. Either wet fluorescent dye penetrant examination (WFPT), or color contrast dye penetrant examination (PT) shall be completed by a qualified inspector. Magnetic particle testing (MT) can be used to evaluate localized repairs that were made to the carbon steel base metal where an electrode similar to the base metal was used to make the repair.

Following NDE, Best Practice after applying corrosion resistant weld overlay to boiler tubes is to perform a pressure test to verify the leak tightness.

### 4.4.8 Documentation

The location, extent, filler materials and base material shall be documented and maintained for future reference.

#### 4.4.9 References

1) American Society of Mechanical Engineers (ASME) Section IX Part QW – Welding
2) National Boiler Inspection Code (Current Edition) Part 2, Section 4 Inspection, Examinations, Test Methods, and Evaluations
3) National Boiler Inspection Code (Current Edition) Part 3, Repairs and Alteration Section 3, Part 3.3 Repairs to Pressure Retaining Items
   a) NBIC 3. 3.3.4.3 Wasted Areas
   b) NBIC 3. 3.4.2 Defect Repairs
4) National Boiler Inspection Code (Current Edition) Part 4, 3 4.4.1 Test or Examination Methods Applicable to Repairs.
5) ASME Repair of Pressure Equipment and Piping, Article 2.11 Weld Buildup, Weld Overlay and Clad Restoration

## 4.5 Plugging Tube in Drums and Headers

### 4.5.1 Introduction

This procedure applies once the need for installing plugs has been determined. Refer to General Welding Foreword (for Sections 3 and 4) and Technical Bulletin 3.7 for guidelines to determine the need for repair. Jurisdictional requirements shall be considered and followed.

It is recommended that, whenever possible, a failed tube should be replaced or repaired rather than plugged. Access or lack of materials may result in the need for removing the tube from service without it being replaced. Tube plugging can be a permanent method to remove the tube from service and still operate the boiler safely.

Tubes may be plugged in the economizer, generating bank, and superheater. Furnace waterwall, rear wall screen, floor, roof, and nose arch tubes must not be plugged. Supply or relief lines to/from headers must not be plugged. Any load bearing tube should be evaluated with the OEM for being left in place to assist in support. Support tubes can usually be identified by support lugs on the tube. Impact on circulation should also be reviewed when plugging tubes.

When tube ends are plugged in the drum, the tube should be removed from the boiler. Otherwise, the plugged tube may dislodge and obstruct gas passages, damage sootblowers, represent a danger to personnel, etc. If the tube is not removed, a pressure relief hole must be put in the tube to prevent over-pressurization due to trapped water. A hole should be put in the tube at the steam drum and another in the tube at the mud drum if the tube is to be left in the boiler. The hole at the mud drum is for leak detection during a hydro.

Any tube circuit left un-cooled in the boiler during operation shall not be returned to service unless it is replaced in its entirety. An un-cooled tube exposed to service conditions may have its integrity compromised.

The procedure for installing tube plugs in headers is typically different than that used for installing plugs in drums. Plugs are typically installed on the outside of headers and installed on the inside of drums.

When plugging with a tube stub, orientation and location should be considered. In high temperature areas, a plugged, vertical tube stub on the top side of a drum or header can result in a steam pocket, and waterside corrosion. For vertical tube stubs plugged on the bottom side of a drum or header, chemicals can be trapped during a chemical cleaning and must be purged of residual chemical. The stub shall be either drained after cleaning by removing the cap or flushed.

Plugging refers to use of plugs, blind nipples or caps.

### 4.5.2 Evaluation

The location of the tube, boiler design criteria and other process demands determine the type of plugging to be used. A map documenting all plugged tubes must be maintained

#### *4.5.2.1 Superheater*

Because of high heat zones in the superheater, all plugging in the superheater should be done as close to the header as possible, and outside the flue gas path. The header will be in the penthouse, so plugs, blind nipples, or caps may be used.

Due to complex superheater circuitry; validate the superheater tube circuitry and support requirements at both ends of the tube to be removed from service to ensure plugging at the headers is proper. Preferably, the tube should be removed at the time of the plug repair. If the tube is not removed at the time of plug repair, damage from falling tube sections may occur.

Considerations after the decision to plug (or after plugging)

Access: For temporary repairs, determine when the damaged tube section can be accessed in a timely manner for replacement or repair without plugging. Access to remove the out of service tube circuit from the flue gas path shall be provided on an urgent basis.

Field Weld location: Recommend that plugging does not remove the existing butt weld near the headers or other suitable documented locations to facilitate a future tube replacement without header stress relief.

Water remaining in tube circuit removed from service: The water should be drained at the lower loops (especially if full after a hydro), and a notification provided to operations that steam may temporarily be present in the penthouse during startup. Steaming from the dead circuit must stop before putting the unit on liquor to ensure steam is not from an actual tube leak.

Loading / Support: Forces acting on header and tubes shall be considered. If the circuit is removed the remaining circuits within the pendant must be secured. If the circuit is not removed, consideration should be given to support all tubes in the pendant in the event the dead circuit deteriorates. Side to Side Alignment within the assembly should be taken into consideration.

Tube Circuit Replacement: Factors for evaluating if a tube circuit replacement should be performed include:

- Tube metal temperature differential on remaining tubes from loop to loop, including stresses and buckling distortion at the ties.
- Radiant heat to newly exposed tubes; newly exposed tubes from inner loops may experience excessive metal temperatures.
- Tube material changes; inner loops may have material that is less corrosion resistant.
- Removal of tubes may have shortened circuits to a point where steam temperatures and therefore metal temperatures are reduced.
- Reduced outlet bulk steam temperature due to surface removal
- Flue gas channeling can result in increased flue gas temperature further back in boiler and fouling in the generating bank.
- Temperature changes in overall circuitry outside the immediate repair area.

Material Compatibility: Materials for plugs used shall be compatible with tubes and headers being plugged and suitable for welding and service conditions.

Instrumentation: If the tube being plugged has a thermocouple attached, the thermocouple should be relocated to another active element in the immediate vicinity. The revised thermocouple installation shall be documented.

Penthouse Penetrations: All openings into the Penthouse, following repair shall be sealed to prevent salt cake intrusion and to maintain gas seal.

#### *4.5.2.2 Generating Bank*

##### *4.5.2.2.1 Single Drum Considerations*

For tube plugging in a single drum generating bank, plug location, unit design (large vs. mini header units), and access must be considered.

Plugging the tube stub with a tapered plug or cap may be quicker than installing a plug inside the header, but acid cleaning and trapped oxygen may cause future problems. Consideration must be made to remove the stub and plug directly inside the headers.

After the tubes have been inspected, evaluated, and the need to plug the tube has been determined, the concentration of plugs (plug density) should be considered. The proximity to the tube plug density threshold should be determined and consider when tube replacements should be planned. Both tube clusters and total number of tubes plugged should be considered in reaching the threshold(s). Because of potential issues with circulation or gas channeling, when clusters of plugged tubes exist, discussions with the OEM should be initiated to establish plugged tube cluster limits.

A map documenting all currently plugged tubes must be maintained.

Accessibility/ Location of Leak: Installing a Dutchman is preferred. If plugs must be installed, access may not allow for plugging external of the header with a tapered plug. If the tube cannot be plugged externally, access through the header may be required for plugging (Figure 4.14). Plugging at the distribution and relief headers is also an option, which would remove the entire platen from service.

Future Chemical Cleaning: If chemically cleaning, special precautions should be utilized taking into consideration the type of tube plugs. Plugs should be close to the header to prevent non-drainable dead legs.

##### *4.5.2.2.2 Multiple Drum Considerations*

Number of Tubes Plugged - The number of tubes plugged, or the concentration of plugged tubes, may affect circulation within the generating bank.

Generating bank sidewall tubes should receive special consideration regarding circulation and their role in preventing overheat of sidewall casing and should therefore be considered for repair or replacement rather than plugging.

After the tubes have been inspected, evaluated, and the need to plug the tube has been determined, the concentration of plugs (plug density) should be considered. The proximity to the tube plug density threshold should be determined and consider when tube replacements should be planned. Both tube clusters and total number of tubes plugged should be considered in reaching the threshold(s). Because of potential issues with circulation or gas channeling, when clusters of plugged tubes exist, discussions with the OEM should be initiated to establish plugged tube cluster limits.

A map documenting all currently plugged tubes must be maintained.

Accessibility/Location of Leak: Access will likely require that all plugging will be done from inside the drums. Tapered plugs, caps, or blind nipples may be used.

Drum Hole Design: The type of drum bore influences the plug design. If there is no counter bore, a tapered plug may be used (Figure 4.2). If there is an internal counter bore or the tube end does not extend into the drum, a cylindrical plug with a head or cap should be used and seal welded to the drum. (Figure 4.3).

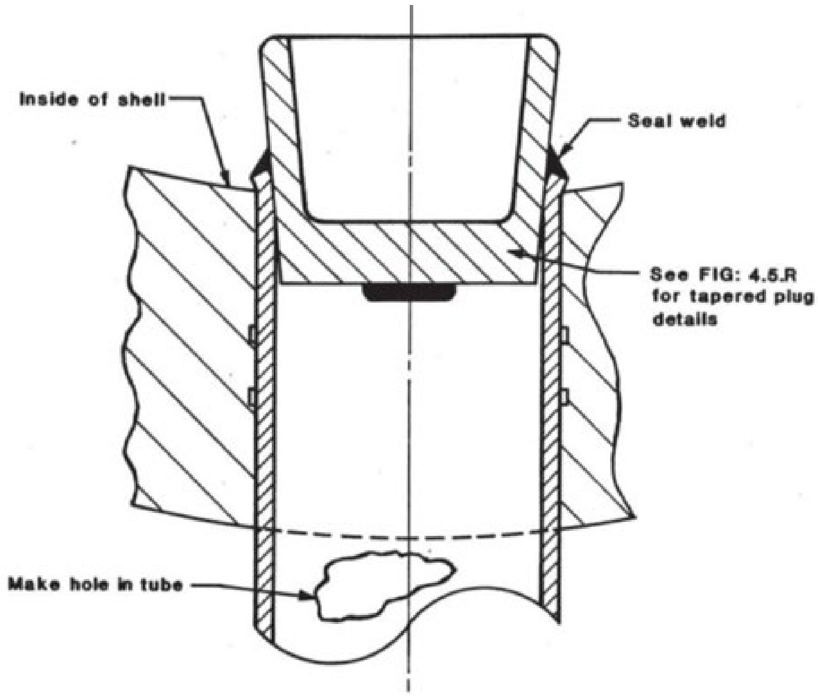



**Figure 4.2: Tapered plug in a drum that does not have counter bored tube holes.**

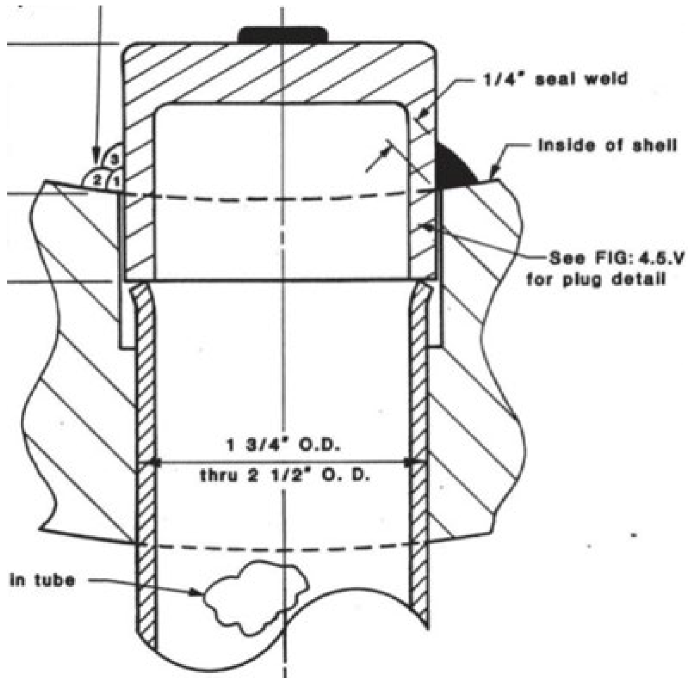



**Figure 4.3: Cylindrical plug in a drum with counter bored tube holes.**

Tube End: The tube end that extends beyond the drum tube sheet. Can be plugged by installing a tapered plug (Figure 4.2) or by removing the tube end, by grinding, and welding the plug to the drum is recommended. Welding the plug to the tube end alone may break the roll seal resulting in an additional leak.

Plug Design: Plugs will be custom made to conform to the ID of the rolled tube joint. If the tube is removed completely, the plug should extend past the OD of the drum to prevent creating a pocket for salt cake accumulation. Refer to 4.5.4 Procedures and Plug Types.

Locating Suspect Tube: Care should be taken to ensure that the leak is correctly identified, and both ends of the tube are identified. Identifying the ends by running a string or measuring tape down the tube, or by using air pressure are a couple of examples of how this can be accomplished.

Material Compatibility: Materials used for plugs shall be compatible with tubes and drums being plugged and suitable for welding and service conditions.

Tube Venting: If the tube is not removed, a pressure relief hole must be put in the tube to prevent over-pressurization due to trapped water. A hole should be put in the tube at the steam drum and another in the tube at the mud drum if the tube is to be left in the boiler. The hole at the mud drum is for leak detection during a hydro.

Adjacent Tubes: If plugs are welded to drum bump rolling adjacent tubes may be necessary,

Removal of Tube: Recommended if access allows. Cut stub as close to drum as possible.

#### *4.5.2.3 Economizer*

For plugging in the economizer, plug location, unit design (large vs. mini header units), and access must be considered. Use of external plugs or caps may be quicker, but acid cleaning and trapped oxygen may cause future problems. If chemically cleaning an economizer, special precautions should be utilized taking into consideration the type of tube plugs that exist in economizer. Plugs should be close to the header to prevent non-drainable dead legs. Consideration must be made to remove the stub and plug directly to the header/drum. Refer to Single Drum Considerations Section 4.5.2.2.1 for mini-header economizers.

### 4.5.3 Materials

Material used to make the plugs must be in accordance with the requirements of the ASME Code for use in boilers.

Plug materials and electrode choices must be compatible with the header/drum/tube material. A cross check on existing equipment should be performed to ensure compatibility.

Materials must have documentation/identification that allows verification of material specifications and origin.

### 4.5.4 Procedures and Plug Types

Plugs and seal-welds are designed for the boiler pressure to be exerted on the head, the seal-weld side, of the plug only. The button weld on the plug is to prevent leakage through the "piping" which can occur at the center of some bar stock.

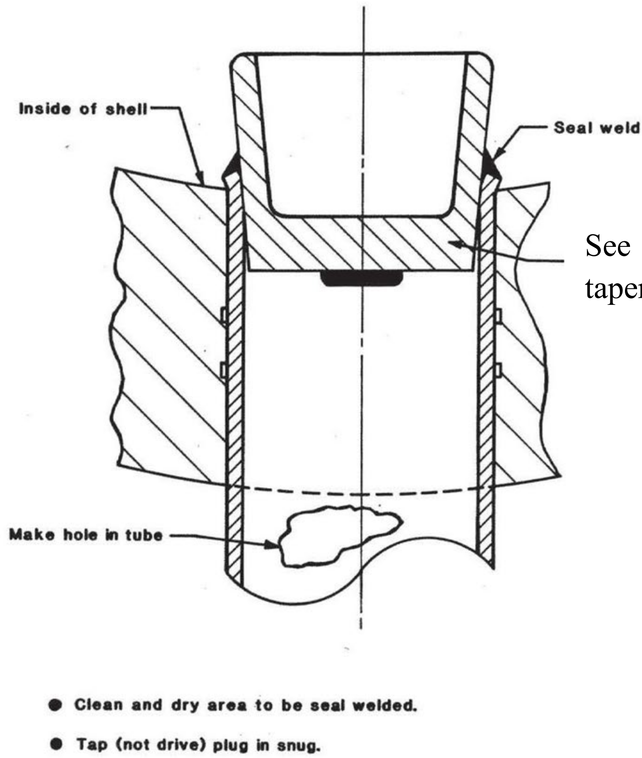
A rolled-in tube leaking at the seat should be removed from its seat; and a new tube rolled in. If a new tube cannot be rolled in, the tube end may be seal-welded to the drum or plugs may be installed and seal-welded to the drum.

Seal-welding of tube ends, tapered plugs or cylindrical plugs to the drum should be done in such a manner as to minimize the heating of adjacent tube seats. Preheating the drum shell for the seal weld is recommended to ensure the seat is dry to prevent pinholes, and to reduce the heat sink effect of the drum shell to prevent cracks in the seal weld. All welders and welding procedures must be qualified as required by the applicable code. It is also the responsibility of the installer to obtain the Authorized Inspector's approval of the repair plan.

If the tube is not removed, a pressure relief hole must be put in the tube to prevent over-pressurization due to trapped water. A hole should be put in the tube at the steam drum and another in the tube at the mud drum if the tube is to be left in the boiler. The hole at the mud drum is for leak detection during a hydro.

The following figures have been taken from the AFPA Recovery Boiler Reference Manual (Blue Book) for Owners and Operators of Kraft Recovery Boilers with permission from the API Operations and Maintenance Subcommittee.

Tapered plugs should be used to plug tubes when it is not practical to remove the tube from its seat and there is no internal counter bore (Figure 4.4). These plugs must be tailor-made for each tube diameter and tube wall thickness. Figure 4.5, Tapered Tube Plug Details, shows the details for such a tapered plug.




See Figure 4.5 for tapered plug details

**Figure 4.4: Plugging a Failed Tube with a Tapered Tube Plug**

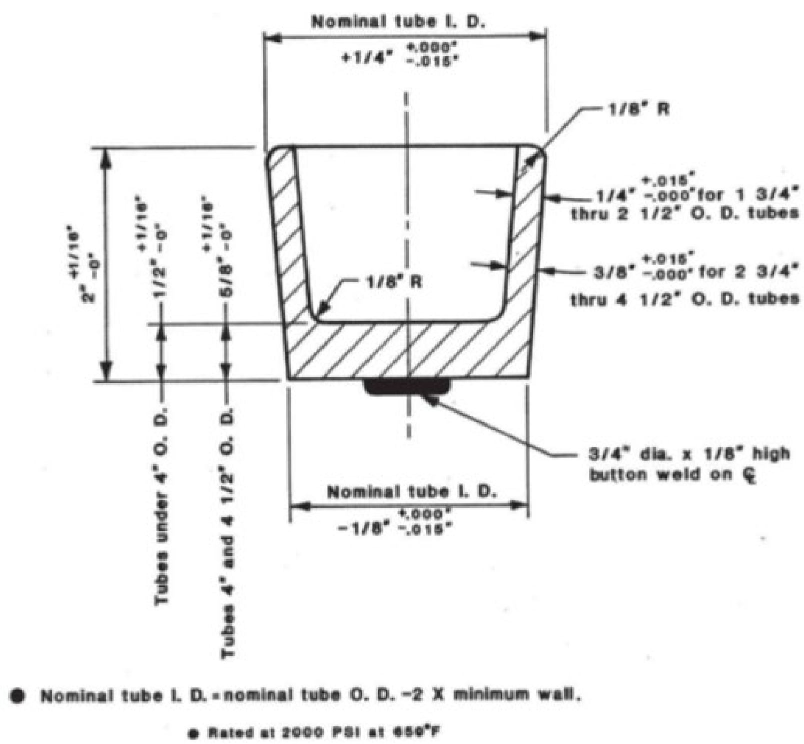



**Figure 4.5: Tapered Tube Plug Details**

In the field, Internal counter bored holes must be plugged with a cylindrical plug when the tube is still in the seat. Some counter bores may be shallow enough to expose the tube ends sufficiently to permit seal-welding to a tapered plug (Figure 4.6). If the tube seat is leaking, then the tube must either be seal-welded to the drum shell or the counter bore plugged with a cylindrical plug and seal-welded. Figure 4.7 and Figure 4.8 show cylindrical plugs in counterbored drums. Figure 4.9 shows the details of such cylindrical plugs.

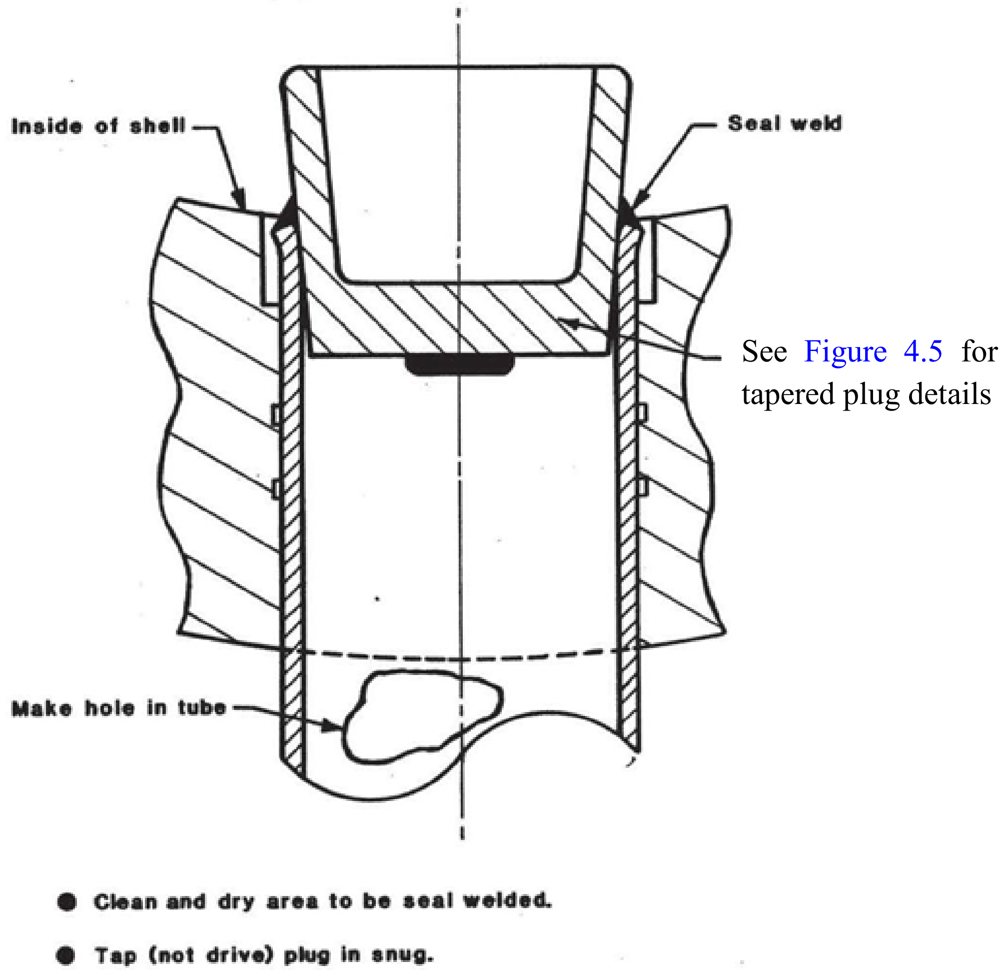
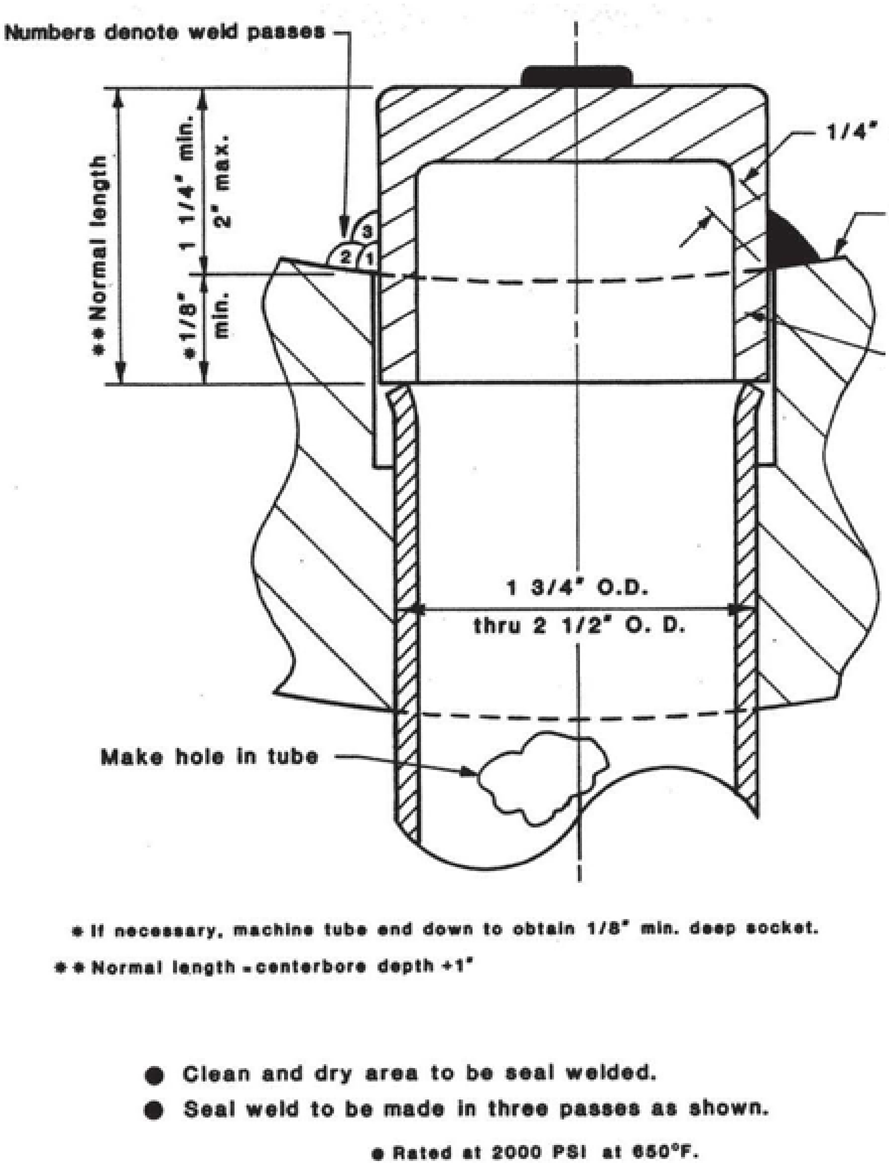



**Figure 4.6: Plugging a Failed Tube with a Tapered Plug in a Drum with Shallow Internal Counterbores**




See Figure 4.9 for cylindrical plug details

**Figure 4.7: Cylindrical Plug for Internally Counterbored Drum Shells for Tubes 1 3/4" through 2 1/2" O.D.**

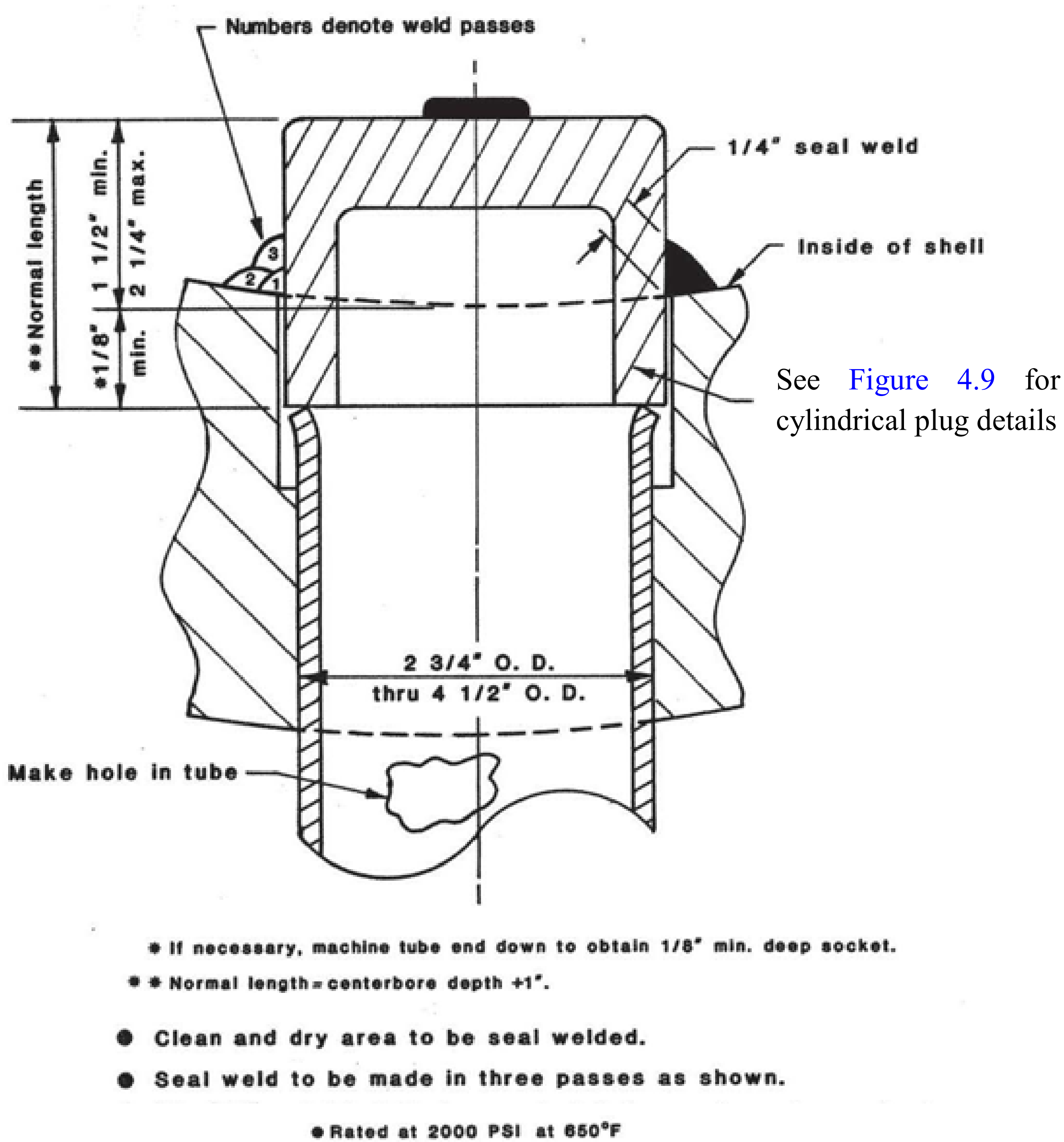
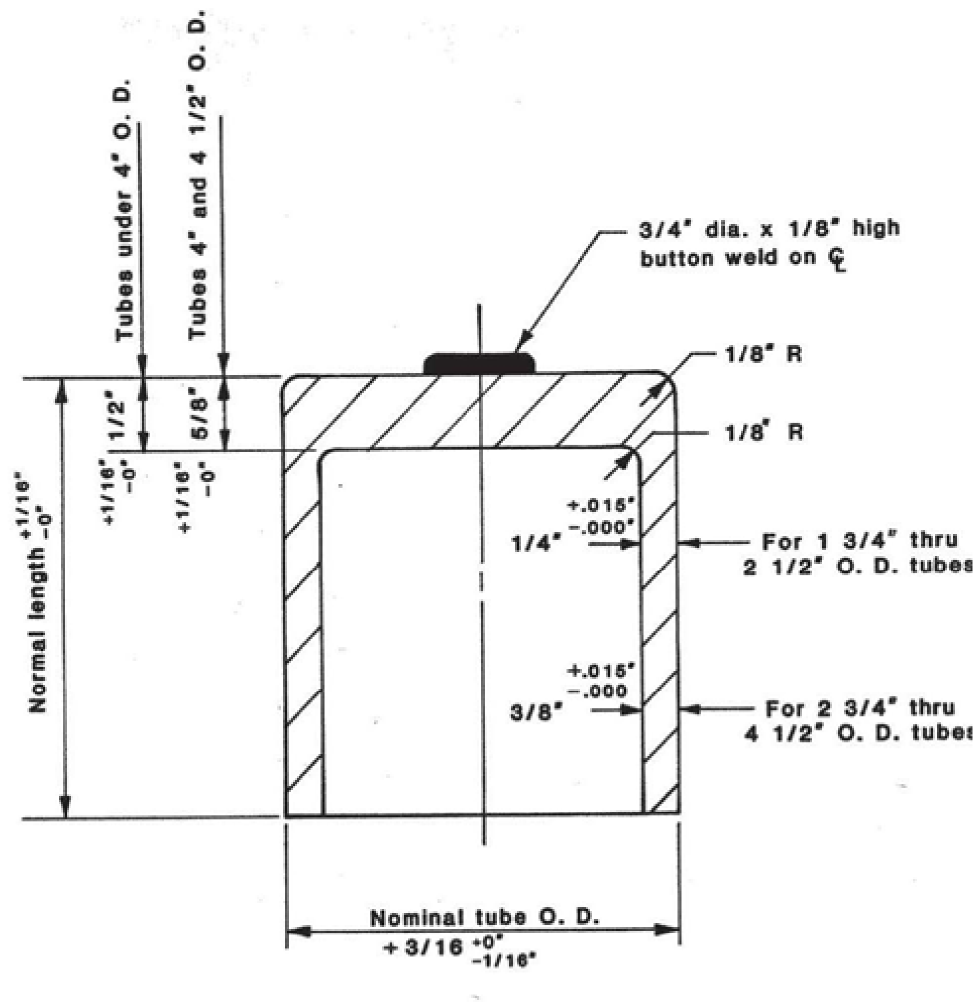


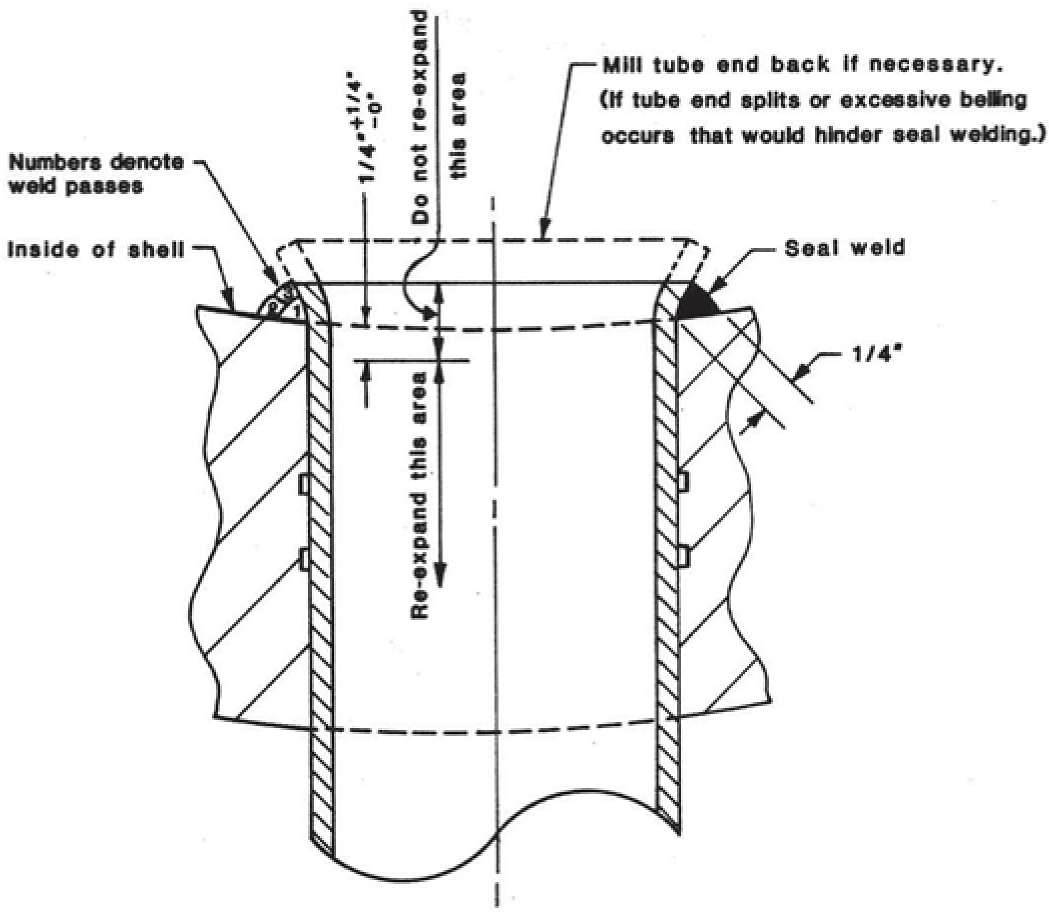

**Figure 4.8: Cylindrical Plug for Internally Counterbored Drum Shells for Tubes 2 3/4" through 4 1/2" O.D.**




- See Figure 4.7 and Figure 4.8 for determining normal
- Rated at 2000 PSI at 650 °F

**Figure 4.9: Details of a Typical Cylindrical Plug for Internally Counterbored Drums**

Seal-welding of a tube to the shell may be used when the tube seat is leaking, and it is not practical to replace or remove the tube and use a rolled stub and plug (Figure 4.10).




- Clean and dry area to be seal welded.
- Seal weld to be made in three passes as shown.
- Re-expand tube in tube seat after seal welding as shown above.

**Figure 4.10: Seal Welding a Rolled Tube Joint**

Figure 4.11 shows a top hat style plug which can be used if the end of the tube does not protrude into the drum (counterbored tube hole or the tube has been ground off flush with the drum ID).

Figure 4.12 shows several types of plugs welded directly to the drum shell.

Figure 4.13 shows the remnants of a top hat style plug during the plug removal process, after the cap has been gouged away to reveal the stem remaining in the tube hole. The stems are typically easy to knock out of the hole once the hat has been removed.

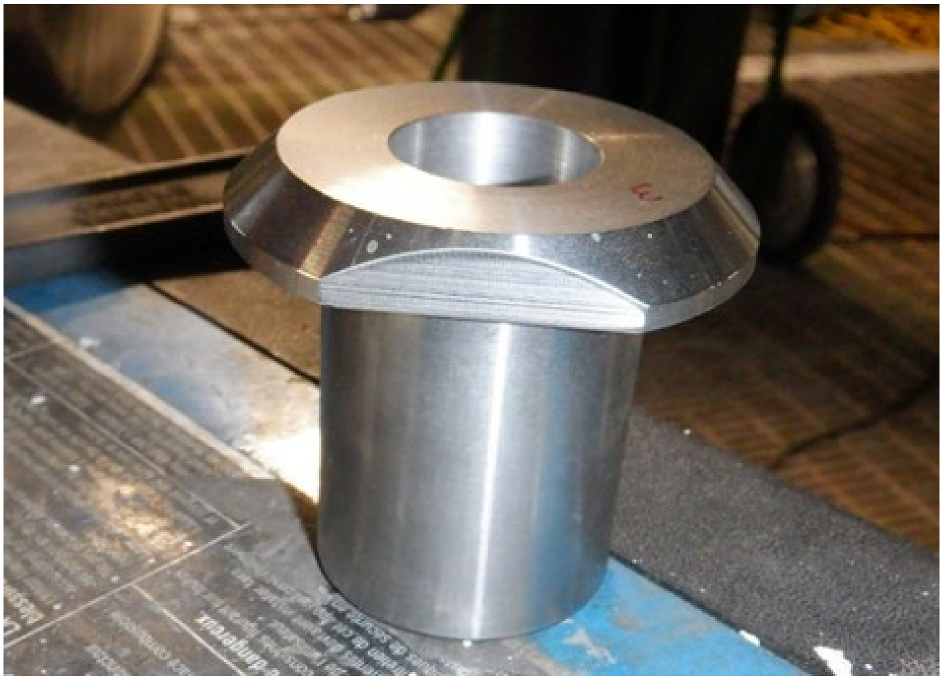


**Figure 4.11: "Top hat" Style Tube Plug to be used in Drums after Tube Stub has been Removed**

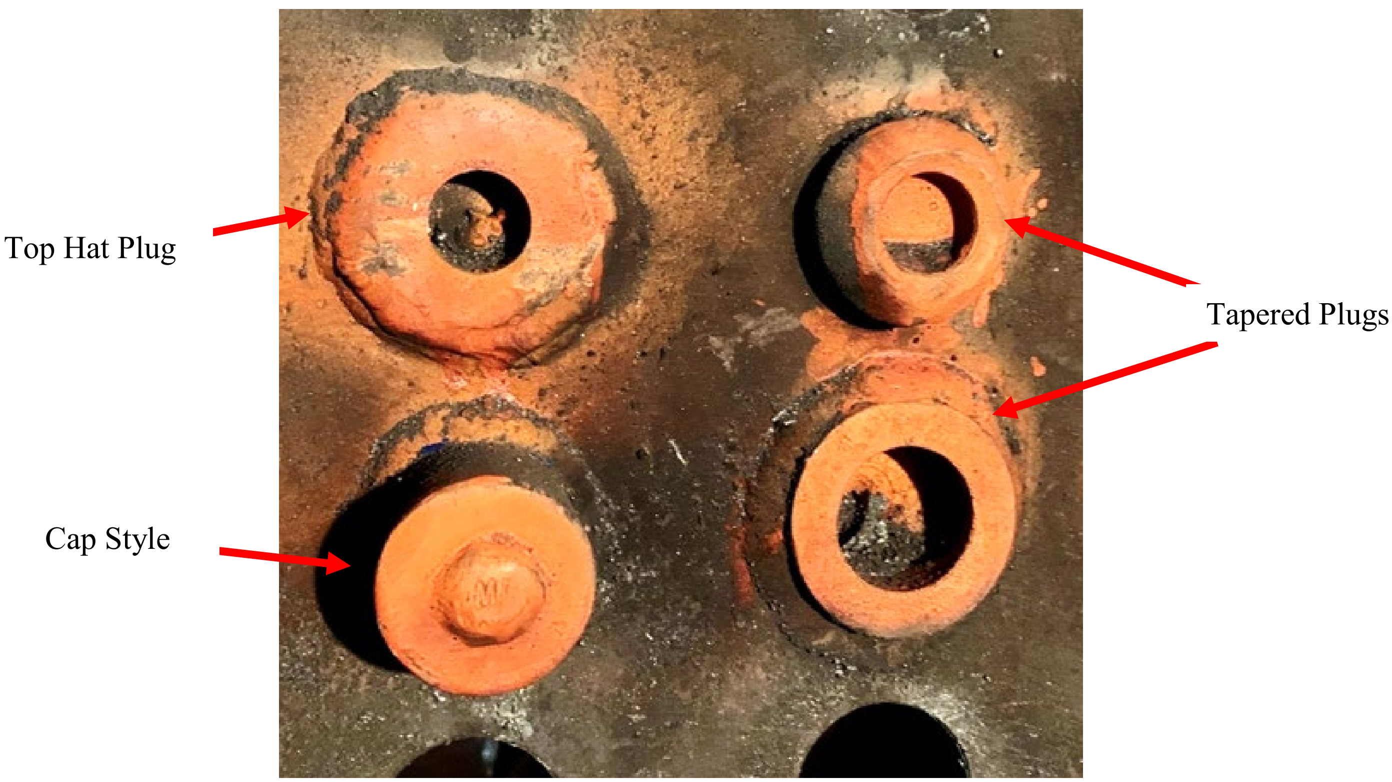



**Figure 4.12: Several Types of Plugs Seal Welded Directly to the Drum Shell**

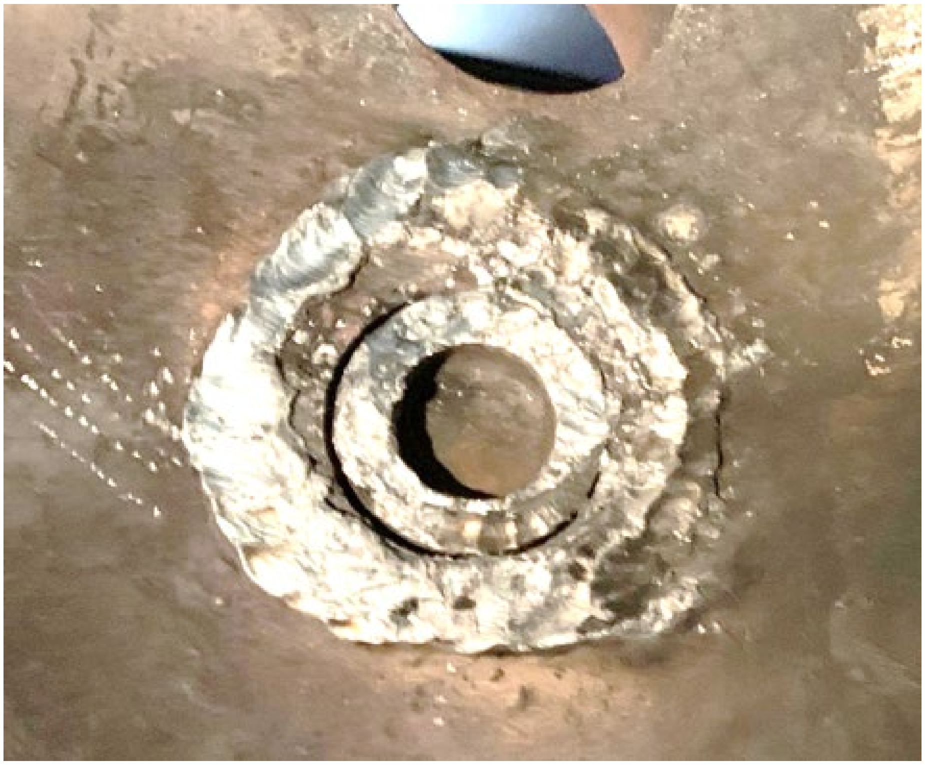


**Figure 4.13: "Top hat" Style being Removed**

Figure 4.14 shows plugging tubes inside the header on long flow economizers or generating banks'

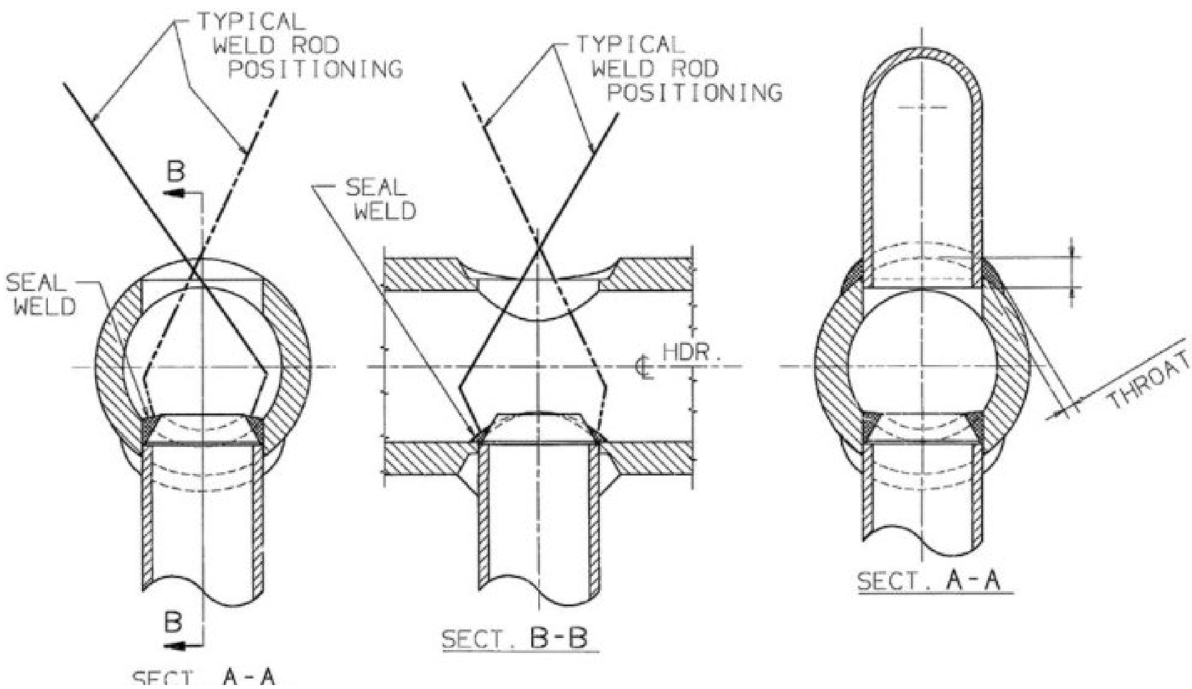
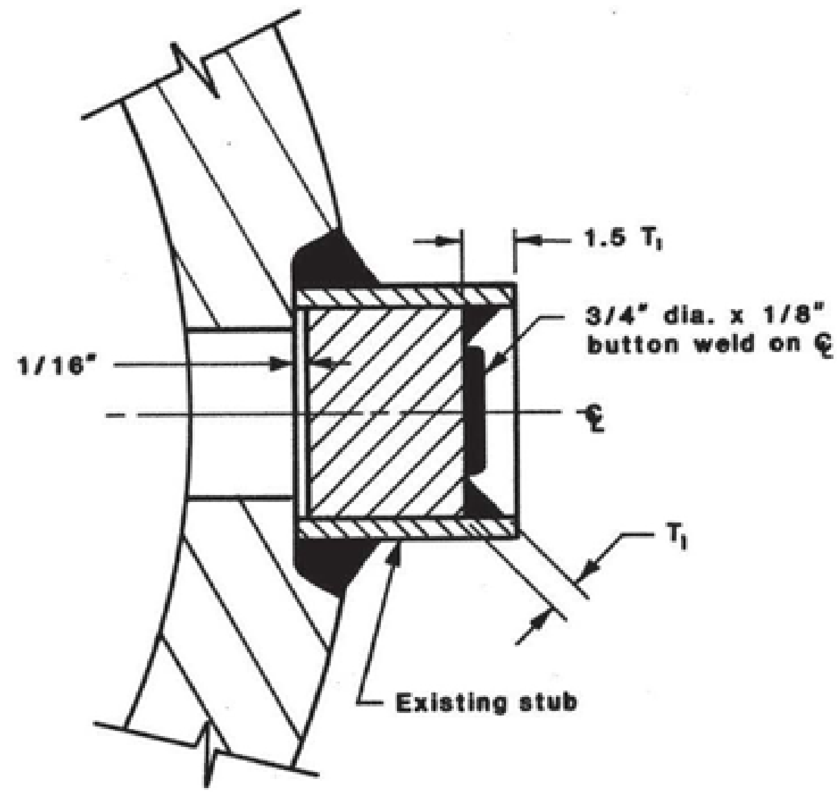



**Figure 4.14: Plugging a tube in a "bottle header" on a long flow economizer or generating bank (Illustration Courtesy of B&W)**

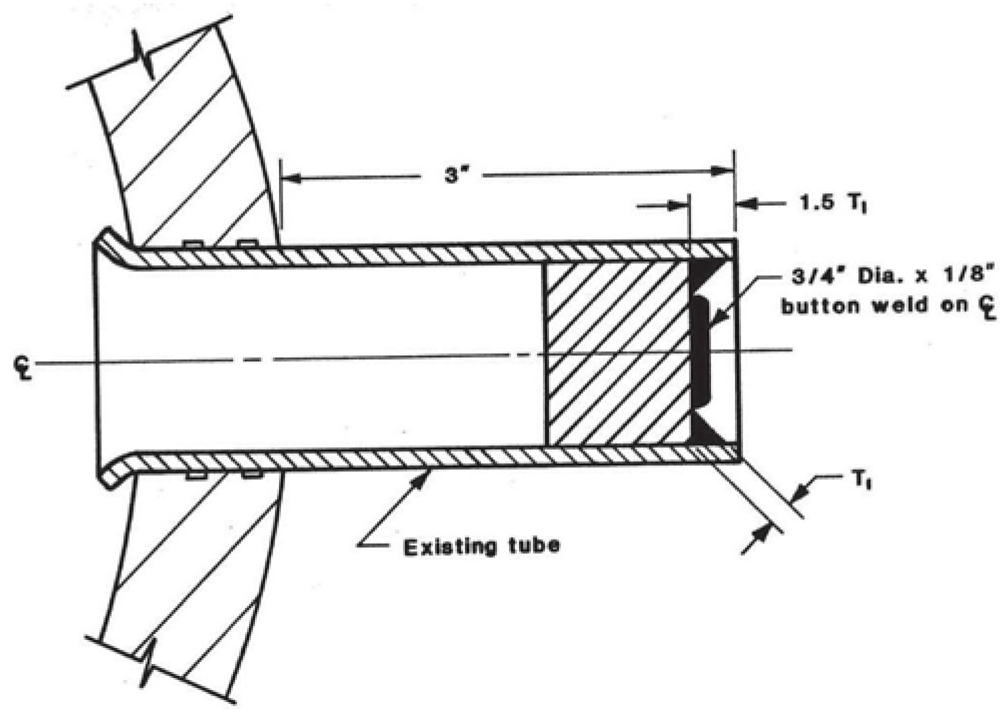
Economizer and superheater headers may be plugged as shown in Figure 4.15. Figure 4.16 shows plugging a superheater or economizer tube stub that is out of the gas stream or where only external access is available and the conditions shown on the figures are met. If those conditions cannot be satisfied, tube replacement is recommended. In these figures, the pressure is on the internal end of the plug and is restrained by the external strength weld.

Care should be taken to avoid the type of repair that would create a cavity which would be subject to chemical attack especially during acid cleaning.




- Plug diameter = nominal tube I. D. minus 3/32".
- Plug length is 1" up thru 4 1/2" O. D. tube.
- $T_1$ is the greater of 1.25 x nominal tube wall or 3/16".
- Cut failed tube off leaving stub as shown.
- Clean and dry area to be welded.
- Insert plug in stub.
  - Use for plugging economizer headers in or out of the gas stream. Use for plugging S. H. headers out of the gas stream. Rated at 2000 PSI max.

**Figure 4.15: Plug for Economizer and Superheater Headers**




- Plug diameter = nominal tube I. D. minus 3/32".
- Plug length is 1" up thru 3" O. D. tube. Over 3" O. D. tube use 2" length.
- $T_l$ is the greater of 1.25 x nominal tube wall or 3/16".
- Cut failed tube off leaving stub as shown.
- Clean and dry area to be welded.
- Insert plug in stub.
- The welding should be done in such a manner as to minimize the heat input to the tube seat.
- Use this plug for headers not in the gas stream.
- If header is in gas stream use new rolled stub with a shoulder and seal welded plug inside header.

**Figure 4.16: Plugs for Headers not in the Gas Stream**

### 4.5.5 Removing Tubes from Drums, Headers, and Tube Plates

The removal of tubes from their seats must be done very carefully to prevent damage to the tube seats. If the tube seat is severely damaged, it may be impossible to ever roll another tube in and make a tight seal. Gouging of the tube seat could also affect the ligaments between tube holes and the integrity of the shell. Refer to AFPA Recovery Boiler Reference Manual (Blue Book) for Owners and Operators API Operations and Maintenance Subcommittee.

### 4.5.6 Acceptance

Visual examination followed by Dye Penetrant Examination (PT) or Magnetic Particle Examination (MT). PT is generally preferred because MT will not pick up rounded indications such as porosity (steam blow holes). Examination should be performed by properly qualified technicians. These inspections should be followed by a hydrostatic test.

### 4.5.7 Documentation

A map documenting all currently plugged tubes must be maintained.

Records and documentation for repairs should be maintained as required by the Code and Jurisdictional Requirements. Materials must have documentation/identification that allows verification of material specifications and origin

### 4.5.8 References

1) AFPA Recovery Boiler Reference Manual (Blue Book) for Owners and Operators API Operations and Maintenance Subcommittee
    a) AFPA cite The Recovery Boiler Reference Manual for Owners and Operators of Kraft Recovery Boilers. pp 4-63-72. Figures used with permission of AFPA.
2) NBIC

# 5 (PREVIOUS SECTION 3) MATERIALS

## 5.1 General Materials Foreword

Recovery boiler operation at higher pressures, temperatures and liquor solids has resulted in increased corrosion and deterioration of furnace tubes and boiler components. Examples of significant new materials introductions in the past 30 years to resist recovery boiler corrosion are composite and chromized tubes, weld overlaid tubes and different thermal metal spray coatings. Likewise, new refractories and nonmetals have been introduced in efforts to protect fireside components, and for application in specialized use areas such as smelt spouts. Duplex stainless steels have been more recently used to provide resistance to stress corrosion cracking of tanks and vessels.

The BLRBAC Materials and Welding Subcommittee provides a format to review areas where materials applications have been successful, as well as where there have been failures. This is done using the combined expertise of the subcommittee membership – personnel representing OEM's, owner-users, repair contractors, insurance and consultants.

The subcommittee has also initiated surveys to evaluate current materials practices, and the relative success of these practices. The objectives of the surveys are to assist the subcommittee in defining damage mechanisms, causes, operating issues and materials solutions. Examples have been surveys on materials for black liquor nozzles, smelt spouts and smelt spout steam shatter jets.

The Materials and Welding Subcommittee welcomes comments and suggestions for new materials' applications, or ideas where materials may be better used for solving old and arising recovery boiler problems.

## 5.2 Survey Results: Black Liquor Nozzle Wastage

### 5.2.1 Scope

A survey was conducted to identify the common causes and solutions to corrosion of black liquor nozzles and piping.

### 5.2.2 Corrosion Characteristics

Wastage of black liquor nozzles and piping have been reported to have the following characteristics:

- Corrosion at the top of the 45° elbow before the nozzle
- Corrosion of the nozzle body
- Corrosion of the splash plate

### 5.2.3 Causes of Corrosion

The following were reported to be suspected causes of corrosion of black liquor nozzles and piping:

- Extension of nozzle too far into the furnace
- Plugging (scaling) of piping and subsequent overheating
- Small liquor gun port size and subsequent minimal cooling air flow

- Insufficient port cleaning and subsequently reduced cooling air flow

### 5.2.4 Operating Issues

The following operating issues were found to be directly related to the occurrence of liquor nozzle and piping corrosion:

- Excessive carryover and the adoption of suspension firing caused smelt to flow down the furnace walls and onto the liquor nozzles.
- Increasing the black liquor solids from 68% to 76% resulted in liquor nozzle corrosion.

### 5.2.5 Mechanical Solutions

- Retract liquor guns closer to the furnace wall
- Rod/clean liquor gun ports more frequently
- Position liquor gun at the center of the port to achieve even air flow around gun
- Increase secondary air flow

### 5.2.6 Materials Solutions

The following materials were reported to provide satisfactory life of liquor nozzles and piping in order of decreasing effectiveness:

- Allstel (55 % Cr / 45 % Ni)
- 50% Cr/ 50% Ni
- Stellite
- Duplex (example 2205)
- Inconel
- Type 316 stainless steel
- Type 304 stainless steel

Black liquor nozzle life was reported to range from two months to 12 months using stainless steel. The life of stainless steel black liquor piping was reported to be in the range of three months to two years.

## 5.3 Survey Results: Smelt Spout Materials

### 5.3.1 Scope

A survey was conducted to identify common materials and operating solutions for addressing corrosion of carbon steel smelt spouts. The specific form of corrosion being addressed involves wastage of the spout at the smelt exit end near the steam shatter jets.

### 5.3.2 Corrosion Characteristics

The smelt spout wastage is characterized as affecting as little as the lower six inches of the smelt spout trough to as much as 75% of the trough length. Corrosion can also affect the discharge lip of the spout, the bottom of the outer trough, end plate and any cooling piping located near the smelt exit. The corrosion does not necessarily affect all smelt spouts on the boiler to the same degree.

**Figure 5.1: Picture of Smelt Spout Wastage**

### 5.3.3 Causes of Corrosion

The following were cited as possible causes of corrosion of smelt spouts at the smelt exit end:

- Low cooling water temperature
- Condensation of vapors within the smelt spout enclosure
- High dissolving tank level resulting in excessive vapor formation
- Inadequate venting through the dissolving tank vent stack
- Splashing due to excessive smelt shattering
- Misalignment of the smelt shatter jets and splashing on the spout
- Splashing of weak wash onto the spouts

### 5.3.4 Materials Solution – Weld Metal Overlay

The following materials applied in the form of weld overlay were reported to be successful in resisting corrosion and provide a minimum service life of twelve months.

- Austenitic Alloy Steel (18% Cr)
- Austenitic Alloy Steel (25% Cr)
- Inconel 625 (8 % Mo)
- Inconel 622 (12 % Mo)
- Hastelloy C276

- Alloy 72 (40 % Cr)

Weld overlay should be done from 3:00 to 9:00 positions on the spout to cover the tide line; overlay can be done over one foot at the discharge tip of the spout, and should cover the end plate, and wrap around to cover the bottom one inch of the outer trough. The transition inside the trough should be ground to provide a smooth transition of the different materials, or it can be applied the entire length of the spout trough.

The following material(s) applied in the form of weld overlay were reported to perform satisfactorily in some cases but not in others:

- Hastelloy C

The following material(s) applied in the form of weld overlay were reported to perform poorly:

- Inconel 600

Erosion at the transition from an eddy effect can cause early failure if a smooth transition is not prepared.

#### 5.3.5 Materials Solutions – Miscellaneous Forms of Corrosion Protection

The following forms of corrosion protection were reported to perform satisfactorily in some cases but not in others:

- Thermal spray coating (45CT)
- Chromizing

### 5.4 Survey Results: Smelt Spout Steam Shatter Jet Materials

#### 5.4.1 Scope

A survey was conducted to identify materials solutions for wastage of smelt spout shatter jets and associated piping/assemblies.

#### 5.4.2 Corrosion Characteristics

Wastage of smelt spout shatter jets and associated piping/assemblies have been reported to have the following characteristics:

- Wear of steam holes
- Wastage on top of shatter jet assembly
- Wastage of steam feed piping

#### 5.4.3 Causes of Corrosion

The following were reported to be suspected causes of corrosion of steam shatter jets and associated piping/assemblies:

- Erosion of steam holes due to high velocity
- Smelt corrosion

- Insufficient cooling due to smelt pluggage

The survey showed that steam shattering systems are operated in the range of 60 – 165 psi and 310 – 400 °F. There was no relationship between the occurrence of corrosion and the pressure or temperature of the shattering steam.

### 5.4.4 Materials Solutions

Type 304L stainless steel was reported to be effective in minimizing corrosion of steam shatter jets and associated piping/assemblies. Type 304L stainless steel was reported to perform satisfactorily when used as a monolithic and as a weld overlay over carbon steel.

316 can be used in nozzle designs to preserve attachment welds.

## 5.5 Thermal Spray Coatings (Initial) for Boiler Fire Side Waterwall Tubes

**Description:** Identification, Selection and Application of thermal spray coatings for boiler fireside water wall tubes.

**Potential for Exposure:** Non-Critical but if not corrected could lead to critical potential for exposure. This bulletin is for the application of thermal spray coatings on boiler tubes that have not thinned below the minimum allowable thickness for continued pressure containment.

**Details/Causes:** Mechanical erosion, waterside deposit conditions, general and localized corrosion

**Boiler Areas Affected:** Any areas where tubes are subjected to the erosive and/or corrosive conditions of the boiler environment and are readily accessible for thermal spraying. Areas of typical field application are water wall tubes in the lower furnace.

**Recommended Inspection:** Perform initial visual inspection to identify areas of localized erosion and/or corrosion. Perform routine UT inspection of the boiler followed by more thorough inspection of areas that show evidence of thinning to determine the scope of the coating application.

Tube wall thickness should be above minimum by sufficient amount to account for loss of material during surface preparation (blasting). Coating thickness measurement should be performed after installation of the thermal spray to ensure desired coating thickness.

Inspections should be made during subsequent outages to monitor coating integrity and the need for coating repair.

If tube material is removed for replacement it is recommended to perform destructive testing of samples to determine mechanism of thinning as the cause may be associated with water side conditions of the tube.

**Recommended Actions:** Compare current thickness data versus historical tube thickness data to determine the timeline for reaching minimal wall thickness. Several thermal spray coating options and processes exist for managing this challenge after historical data and the next inspection date are considered.

1) If corrosion is not severe, it is possible to make no coating application and revisit during the next inspection date.

2) If it is determined that action needs to be taken before the next scheduled inspection date, the tubes may be protected with the following typical coatings and processes:
   a) 50 Chromium: 50 Nickel Power using the High Velocity Oxy Fuel (HVOF) Process
   b) 44Chromium: 51 Nickel: 3Titanium wire using the High Velocity Continuous Combustion (HVCC) process.
   c) Alloy 625 wire using the High Velocity Arc Spray (HVAS) process
   d) Etc.
3) Replace tubing in kind or with appropriate corrosion protection

The thermal spray process has hazards associated with it that will restrict work and an appropriate safety plan should be developed.

Appropriate steps must be taken when replacing coated tube sections to avoid contamination during welding activity.

Perform post-repair nondestructive evaluation to assess the condition of the repair

Additional Information & References:

1) TAPPI:
2) OEM & Service References:
   a) The AF&PA Recovery Boiler Reference Manual Volume II maintenance and Repair Analysis: repair Guidelines and Practices 4.5.5.4
3) NBIC:
4) ASME:

# 6 (PREVIOUS SECTION 4) TEMPORARY REPAIRS (FUTURE)

# 7 (PREVIOUS SECTION 5) REFERENCE SECTION

## 7.1 OEM and Service Providers

1) Babcock and Wilcox
2) Alstom Power
3) Southeastern Mechanical Services
4) George Bodman, Inc

## 7.2 Technical Sources

1) AF&PA
2) API
3) ASME
4) ASNT
5) TAPPI
6) BLRBAC
7) NBIC
8) NACE

# 8 (PREVIOUS SECTION 6) MISCELLANEOUS

## 8.1 Smelt Spout Installation Traveler

*UNIT #* ______________________ DATE: ____________
*LOCATION* ______________________
*TYPE OF BOILER* ______________________
*NUMBER OF SPOUTS* ______________________

| A. REMOVAL OF OLD SPOUTS | HOLD POINT YES | HOLD POINT NO | | APPROVAL |
|---|---|---|---|---|
| 1. REMOVE SPOUT HOODS | | | 1. | |
| 2. REFERENCE THE SPOUT POSITIONS | | | 2. | |
| 3. MARK THE INLET SUPPLY | | | 3. | |
| 4. MARK THE OUTLET DRAIN | | | 4. | |
| 5. REMOVE SMELT SPOUTS | | | 5. | |
| 6. REMOVE REFRACTORY SEAL | | | 6. | |
| 7. INSPECT THE TUBES IN SPOUT OPENINGS | | | 7. | |
| UT | | | | |
| PT | | | | |
| VT | | | | |
| MLO AND COPPER SULFATE | | | | |
| 8. CLEAN / REPLACE INSERT SHOWERS | | | 8. | |
| 9. EVALUATE WEAR AND INTERNAL CORROSION | | | 9. | |
| 10 EVALUATE SEAL BOX CONDITION | | | 10. | |

| B. INSTALLATION OF NEW SPOUTS | HOLD POINT YES | HOLD POINT NO | | APPROVAL |
|---|---|---|---|---|
| 1 PRESSURE TEST NEW SPOUTS | | | 1 | |
| 2 INSTALL THE NEW SPOUTS AND SEALS | | | 2 | |
| 3 VISUALLY INSPECT SPOUTS FOR DAMAGE | | | 3 | |
| 4 POSITION SPOUT IN BOILER OPENING | | | 4 | |
| 5 SET SPOUT ELEVATIONS | | | 5 | |
| 6 CHECK FOR DISSOLVER INTERFERENCES | | | 6 | |
| 7 INSTALL REFRACTORY; RECORD TIME | | | 7 | |
| 8 CONNECT AND VERIFY COOLING WATER SUPPLY | | | 8 | |
| 9 CONNECT COOLING WATER DRAIN | | | 9 | |
| 10 PT ALL WELDS ON SUPPLY AND DRAIN | | | 10 | |
| 11 WATER TEST COOLING WATER LINES | | | 11 | |
| 12 INSTALL INSERT SHOWERS | | | 12 | |
| 13 INSTALL SPOUT HOODS | | | 13 | |
| 14 INSTALL SHATTER JETS AND CHECK FOR LEAKS DRY AND CURE REFRACTORY | | | 14 | |

C. SMELT SPOUT REPLACEMENT APPROVED BY ______________________

**Figure 8.1: Smelt Spout Installation Traveler**

## 9 (PREVIOUS SECTION 7) DEFINITIONS AND ABBREVIATIONS

The BLRBAC Materials and Welding Subcommittee will try and utilize Standard Welding Terms and Definitions as outlined in ANSI/AWS A3.0 and definitions from The National Board Inspection Code (NBIC) and the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code; however, there may be times that the committee inadvertently uses non-standard terms.

The following definitions and abbreviations may be used within the document:

**A**

| | |
|---|---|
| AF&PA | American Forest and Paper Association |
| AI | Authorized Inspector-For purposes of our document, an inspector commissioned by a jurisdictional agency or the National Board for new construction, for repairs, or for in service inspection. |
| Alteration | Any change in an item described in the original Manufacturer's Data Report which affects the pressure containing capability. Nonphysical changes such as an increase in the maximum allowable working pressure (internal or external), increase in design temperature, or a reduction in minimum temperature of a pressure-retaining item shall be considered an alteration. |
| ANSI | American National Standards Institute |
| ASME | American Society of Mechanical Engineers |
| ASNT | American Society of Nondestructive Testing |
| ASTM | American Standard for Testing Materials |
| Authorized Inspection Agency | New Construction: An Authorized Inspection Agency is one that is accredited by the National Board meeting the qualification and duties of NB-360 |
| AWS | American Welding Society |

**B**

**C**

| | |
|---|---|
| Copper Sulfate Test | Fifty –Percent (50%) Solution of water and copper sulfate to identify carbon steel. The Copper sulfate solution reacts with the iron in carbon steel and results in a bronze/brown color change if carbon steel is detected |

**D**

**E**

**F**

| | |
|---|---|
| Flow Accelerated Corrosion | Internal thinning of carbon steel piping in water and/or steam with water present. Thinning is a function of flow, metallurgy, pH, temperature and dissolved oxygen. |

**G**

**H**

**I**

| | |
|---|---|
| Inspector | Individual identified to perform tasks associated with evaluation of equipment condition and suitability for intended service. |

**J**

| | |
|---|---|
| Jurisdictional Authority | The body that enforces boiler and pressure vessel laws and rules within its jurisdiction. |

**K**

**L**

**M**

| | |
|---|---|
| Magnetic Lift Off (MLO) | Nondestructive examination used to determine the thickness of a non-magnetic material coupled to a magnetic material. MLO uses the reduction of magnetic attraction as the distance between the probe and the ferromagnetic substrate is varied. |
| Magnetic Particle Testing (MT) | Nondestructive method for detecting surface discontinuities in ferromagnetic materials by detecting disruptions in a magnetic field. |
| Metal Inert Gas Welding (MIG) | Alternate and accepted term for Gas Metal Arc Welding (GMAW) |
| Minimum Wall Thickness (MWT) | Minimum required wall thickness for the maximum allowable working pressure as defined by the ASME Boiler and Pressure Vessel Code |

**N**

| | |
|---|---|
| National Board | The National Board of Boiler and Pressure Vessel Inspectors. |
| Nondestructive Testing (NDT or NDE) | Evaluation that does not destroy the specimen |

**O**

**P**

| | |
|---|---|
| Penetrant Testing (PT) | Nondestructive method for determining surface discontinuities using a dye and capillary action. May be Fluorescent, Visible, or a dual sensitivity. Also referred to as liquid dye penetrant. |
| Post Weld Heat Treatment (PWHT) | The applications of heat to an assembly after welding to normalize stresses. |
| Preheat | The applications of heat to a minimum temperature in the base metal immediately prior to welding. |

**Q**

**R**

| | |
|---|---|
| Radiographic Testing (RT) | Also known as X-ray or gamma ray. A radiation source is used for examination of surface and subsurface defects. |
| Repair | |
| Major | Repairs that require in-process involvement by the Inspector and stamping by the “R” certificate holder. |
| Routine | Repairs which the requirements for in-process involvement by the Inspector and stamping by the “R” Certificate Holder may be waived. Refer to the National Board Inspection Code for requirements. |
| Temporary | Situational repair that meets code requirements for service but shall be evaluated on or before the next scheduled outage for final resolution. |

**S**

| | |
|---|---|
| Stress Assisted Corrosion (SAC) | Corrosion and stress, residual or applied that results in ID fissures under combined action in an aqueous solution under certain chemical conditions. The condition is known as “corrosion fatigue” in the power generation industry. |

**T**

| | |
|---|---|
| TAPPI- | Technical Association of Pulp and Paper Industry |
| Tungsten Inert Gas (TIG) | Alternate term for Gas Tungsten Arc Welding (GTAW) |
| Traveler | A document that lists the sequence of operations, weld procedure specification, inspection, examination, and testing. |

**U**

| | |
|---|---|
| Ultrasonic Testing (UT) | Nondestructive method of detecting, locating, and evaluating internal discontinuities and thickness in metals by directing a high frequency sound beam. |

**V**

| | |
|---|---|
| Visual Inspection (VT) | Examination with the eye. Usually the first and most important Nondestructive testing methods |

**W**

| | |
|---|---|
| Welding Procedure Specification (WPS) | A document providing the required welding variables for a specific application to assure repeatability by qualified welder and welder operators. |

**X**

**Y**

**Z**

## ANNEX A: DOCUMENT REVISION HISTORY

### A.1 APRIL 2013

- Added Section 3.4 – Thermal Spray Coatings (Initial) for Boiler Fire Side Waterwall Tubes
- Added Section 6 – Miscellaneous and Section 6.1 – Smelt Spout Replacement Traveler
- Added Section 7 – Definitions and Abbreviations

### A.2 FEBRUARY 2012

- "Notice of Disclaimer of Liability" added to page 2.
- Section 1.3, Repair of Pressure Boundary Material in Tubes, revised to clarify PT is only useful for detection of cracks and copper sulfate must be used to detect base material exposure.
- Section 1.4, Corrosion Resistant Weld Overly Applications on Tubes, and Section 1.5, Repair of Composite Materials on Tubes, revised to add:
  - Detail regarding the impact of dilution of base material
  - The selection of approved weld procedures should consider weld technique to minimize penetration and potential compromise of base material code Minimum Wall Thickness
- Added new Section 2.4, Corrosion Resistant Weld Overlay on Boiler Tubes.

### A.3 OCTOBER 2010

- "Recommended Good Practice" deleted from document title. This document is a "Guideline".

### A.4 APRIL 2009

- First publication of document.