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BOILER WATER TREATMENT: LESSONS LEARNED

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FACILITIES ENGINEERING
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BOILER WATER TREATMENT: LESSONS LEARNED

1. Purpose. This Public Works Technical Bulletin (PWTB) transmits the Boiler Water Treatment: Lessons Learned document. The lessons learned improve maintenance, efficiency, reliability, treatment, system life and safety of boiler systems.

2. Applicability. This PWTB applies to all U.S. Army Public Works activities responsible for operating and maintaining boiler, cooling tower and HVAC systems.

3. References.

a. Army Regulation 420-49, Facilities Engineering, Utility Services, April 1997.

b. Technical Manual (TM) 5-650, Central Boiler Plants, October 1989.

c. Technical Manual (TM) 5-642, Operation and Maintenance Small Heating Systems, August 1990.

4. Discussion. Many installations across the country are facing problems with boiler systems related to water treatment. One of the most common problems is difficulty in preventing the formation of scale or the occurrence of corrosion in these heating systems. As a result of these problems, system life, reliability, efficiency and safety are reduced. Many of these problems are preventable through proper boiler water chemistry maintenance and treatment. To assist installation personnel responsible for operating heating systems, a list of lessons learned over the past 15 years has been assembled to indicate the most common problems and their solutions. The Boiler Water Treatment: Lessons Learned document is attached.

5. Point of contact. Technical questions and/or comments regarding this subject, which cannot be resolved at the installation level, should be directed to:

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10 November 1999

BOILER WATER TREATMENT: LESSONS LEARNED

I. INTRODUCTION

a. Purpose of Report

The purpose of this report is to provide installation managers and plant operators with a ready reference to the main boiler water treatment problem effects and causes encountered in Army installations. The lessons learned provide a general solution that can be of value to each installation in improving their performance.

b. Format and Content

This report addresses major water treatment problems that have been identified at various installations and the lessons learned from the action or lack of corrective action taken. For each major problem area, the trouble effect is defined, the cause identified, and a recommended solution described.

This report touches on major problems and is not an all-inclusive Manual. Where installation-specific problems are not clearly identified, it is imperative that the installation contact the US Army Engineering and Support Center (CEHNC) for further guidance and assistance.

c. Background

Enormous amounts of water are used daily in boiler water operations. However, water normally contains various levels of contaminants, dissolved solids (minerals) and dissolved gases. These contaminants cause major operational problems and damage to boilers unless they are removed or controlled on a continuing basis. Correct application of chemical treatment programs can eliminate many problems associated with boiler operations. But other problems can and do impact operations.

This report of lessons learned has segregated the problems into two major areas:

(1) MANAGEMENT CONCERNS: Addresses the administration of sound boiler water operations.

(2) OPERATOR PERFORMANCE: Addresses the hands-on operation of boilers.

II. MANAGEMENT CONCERNS

Introduction

Every installation has its own mode of operation and style of management. Boiler water treatment is but one small area of operations but is so critical that complete base operations may cease if boilers are not operated properly.

Observations indicate that major difficulties found in Army treatment systems can be traced to management actions as follows.

<u>Lessons Learned</u>

1. Inadequate Management Support

A serious problem at many Army boiler plants is the apparent lack of attention from management and/or lack of communications between operating and supervisory personnel. This inattention is reflected in numerous ways:

(a) Inaccurate direction or lack of water chemistry knowledge.

(b) Plants operating without assigned first-line supervisors.

(c) Lack of evidence that base Public Works Managers show a physical presence at the plant, or lack face-to-face communications with operating personnel.

(d) Lack of initial or ongoing training for all levels of managers and operators.

(e) Lack of or inadequate safety program.

(f) Lack of proper maintenance procedures, records, and general order and appearance of the plant.

<u>Suggested Actions</u>

With O&M budgets under constant scrutiny, support functions such as boiler plant operations tend to lack a champion unless the assignment of operations is delegated to one specific manager – a manger who should have a good understanding of the operation and has, or takes, the time to monitor operating performance.

In addition, a training schedule should be established to cover water treatment and operational training for both managers and operators.

2. Lack of Effective Maintenance Programs

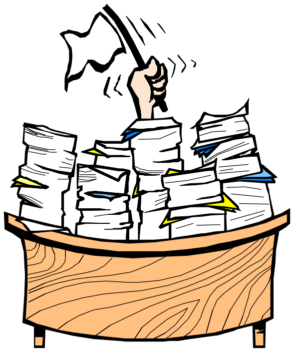
A ready indication of inadequate maintenance programs is the lack of documentation of a planned Preventative Maintenance Plan, poor record keeping, a history of downtime, and/or expensive repair costs.

Suggested Actions

Base management should ensure the assignment of single-point responsibility. Specific duties would include development and maintenance of:

- A Preventative Maintenance Plan.
- Accurate records of tests and repair activities.
- A training schedule for personnel.
- A safety program.
- A schedule for general housekeeping activities to be followed.

3. Inadequate Preparation of Statements of Work (SOWs) for the Acquisition of Boiler Water Treatment Chemicals and/or Support Services



High costs of operation, increased repair costs, boiler failures, contract disputes, terminations and, on occasion, litigation can many times be traced to the incomplete or inadequate preparation of requests for services.

The selection of a good chemical vendor is very important to plant operations. Too often the selection is made on the basis of lowest price per pound of vendor chemicals. What this does is reward the vendor that has the most water in their chemical products! The competitive selection of chemicals and vendor should be based on cost to treat 1,000 gallons of boiler feedwater.

Another factor in buying treatment chemicals is whether to buy chemicals with or without service. Most of the companies recognized as boiler water treatment chemical suppliers do not sell chemicals without service. Also, the quality of service provided varies greatly by company and service representative. Service includes monthly plant visits, technical assistance and possibly other services. Conflicts arise because the company may provide advice that results in unnecessary higher chemical use since the company has an interest in selling more chemicals. Typically, chemical products that include service in the purchase price can cost 5 to 20 times more than the generic chemicals.

Suggested Actions

A standard SOW (Public Works Technical Bulletin (PWTB) 420-49-23, Model Scope of Work for Procurement of Industrial Water Treatment Chemicals) has been developed for the acquisition of water treatment chemicals with/without support services. This model SOW provides details on factors to consider when purchasing chemicals and guidance for preparing purchasing documents. Contact Nelson Labbé at DSN 763-1494, (202) 761-1494 (phone) for help in this area.

4. Lack of Effective Safety Programs

Over 7,500 incidents of employee injuries have occurred over the last three years in boiler installations. Common safety problems include simply the lack of a formal safety program, not maintaining the program through regularly scheduled safety meetings, not providing back-up for single-shift operators, and lack of safety facilities such as eye wash basins or shower stalls. Last but not least is the lack of clear, printed warnings on chemicals used in boiler water treatment.

<u>Suggested Actions</u>

Assign a Safety Coordinator for each facility. Schedule regular safety meetings. Document ANY safety violations. Conduct regular inspections and training in the safe use of chemicals and equipment. Develop a standing list of protective clothing and gear for each work location.

III. OPERATOR PERFORMANCE

Introduction

The successful operation of boilers requires accurate analysis of the water that is used, proper treatment to remove corrosive minerals and gases, and careful attention to the controls and procedures for the taking of water samples, their testing, and all required inspections.

The key player is the boiler Operator and, of course, assigned Supervisors. A basic knowledge of boiler mechanics and water chemistry is an absolute requirement – whether through formal training or On the Job Training (OJT). Following are examples of operating problems that occur and are often mis-diagnosed – with suggested actions for the correct solution.

WATER

TREATMENT

Lessons Learned

1. Inadequate Control of Oxygen Is a Major Source of Boiler Corrosion

A common maintenance problem for Army boiler water treatment is a lack of control of corrosion due to oxygen. Mistakes are made in the mechanical removal of dissolved oxygen or the chemical scavenging of oxygen or both. This results in corrosion pitting attack by oxygen on boiler water tubes and feedwater lines which calls for expensive replacement of failed metal and downtime for the boiler.

Suggested Actions

A. Improper Mechanical Removal of Oxygen from Feedwater

Mechanical removal of oxygen is accomplished with a deaerator (DA). The DA works by heating the water to a boil at which point the solubility of dissolved oxygen and other dissolved gasses are at their lowest level. The undissolved gasses are vented to the atmosphere and the deaerated water is used in boiler feedwater. The little remaining dissolved oxygen should be no more than the parts per billion range (ppb) which is scavenged by chemical treatment.

Proper DA operation requires a vessel pressure of 3-4 psi above atmospheric and a water temperature measured at the storage section of 8°F above the boiling point for water at the installation's altitude. There should be a visible 18-24" steam plume coming from the DA's vent. This contains the unwanted oxygen and other gasses. Three things to check once per shift is 1.) operating pressure, 2.) temperature of water in the storage section, and 3.) an 18-24" steam plume at the DA vent. Oxygen should then be in the 7 to 20 ppb range depending on the type of DA.

B. Chemical Scavenging of Dissolved Oxygen

The deaerator removes most but not all of the dissolved oxygen. The remainder must be reacted with oxygen scavengers such as sodium sulfite. Sodium sulfite is the most common oxygen scavenger.

A common mistake is to overexpose sulfite to air so that it is already consumed before it is applied. This can result from excessive mechanical mixing of sulfite in the mix/feed vessel. A mix/feed vessel should also include a floating lid to minimize it's exposure to air.

Sulfite and other oxygen scavengers should be fed into the storage section of the DA - upstream from the boiler. This allows for it react with oxygen ***before*** the oxygen gets into the boiler and it also helps to protect feedwater lines.

Sulfite should be fed continuously as a function of feedwater flow as opposed to slug dosages. This allows for a proper residual in the operating boiler at all times and avoids conditions of overtreatment and undertreatment swings.

2. Inadequate Treatment of Carbon Dioxide Is a Major Cause of Condensate Piping Corrosion And Boiler Deposits

Carbon dioxide comes from the decomposition of the carbonate and bicarbonate alkalinity that is naturally present in the makeup water. The decomposition occurs in the boiler and the carbon dioxide that is formed is volatile enough to escape with the steam and later condense in the condensate system forming carbonic acid which is acidic and corrosive.

The presence of carbon dioxide can be easily determined by measuring the pH of the condensate. Carbon dioxide lowers the pH. A reading below pH 7.5 indicates corrosive levels of carbon dioxide.

Suggested Actions

A. Reduce the amount of carbon dioxide produced in the boiler.

One method is to reduce the amount of makeup water used. This is accomplished by maintaining the optimal cycles of concentration through proper blowdown and also by recovering as much condensate as possible since condensate combines with makeup water to form boiler feedwater. Cycles of concentration, often measured with conductivity or total dissolved solids readings, should not exceed the point where scaling or carryover occurs. The amount of condensate returned can be increased by eliminating wasted steam and of course repairing condensate leaks.

Another method to reduce carbon dioxide is to reduce the amount of alkalinity (bicarbonate) in the makeup water. Dealkalizers remove alkalinity from the makeup water which is the precursor of carbon dioxide. This is a form of external treatment.

B. Carbonic acid can be neutralized using neutralizing amine treatments which are used to raise the pH to between 7.5 and 8.5.

The proper amine or blend of amines is dependent upon the length of condensate piping runs to be protected. *Morpholine* for example is more effective for short runs of say 800 feet or less. *Diethylaminoethanol* (DEAE) is more effective for runs of up to 1 mile while *cyclohexylamine* is more effective for runs over 1 mile.

Neutralizing amines should be fed directly into the boiler or into feedwater piping. It should not be fed into the deaerator where it can escape via vent piping. For long and complex condensate systems (over 1 mile with multiple locations for steam demands), "satellite" amine feed stations can augment amines being fed at the boiler plant.

Neutralizing amines should be fed continuously as a function of feedwater flow as opposed to slug dosages. This allows for a proper pH in the condensate system at all times and minimizes overtreatment and undertreatment swings.

3. Inadequate Control of Scale And Sludge Impacts Boiler Performance

Scale and sludge can result from mistakes made in: 1) the external treatment to remove the unwanted scale forming minerals or 2) the internal chemical treatment or both. This results in scale and/or sludge that reduces boiler efficiency and even tube failures which calls for chemical cleaning to remove scale or expensive replacement of failed boiler tubes.

External treatment (ET) is designed to remove unwanted minerals before they enter the boiler system i.e. sodium zeolite softeners remove calcium and magnesium hardness. Problems develop when ET capacity is exceeded allowing the unwanted minerals to enter the boiler system. The inadequate capacity can result from improper sizing of ET equipment, excessive makeup water usage, and/or inadequate regeneration. Often scale/scale damage is a result of poor monitoring and control of softeners.

The use of improper internal chemical treatment can result in scale and sludge deposits.

Suggested Actions

Determine the efficiency of external treatment by comparing the design versus the realized capacity of ET equipment. The design capacity is information supplied by the manufacturer, but can also simply be calculated based on the size of the equipment for resin volume. The run time on a softener is measured by the amount of water it can soften before regeneration is required. A running log of softener capacity will show a trend of softener efficiency. As the realized capacity drops below design capacity, regeneration needs to be performed more often to prevent excursions of hardness or other unwanted ionic species. When the realized capacity is unsatisfactory, regeneration procedures should be reviewed which can include elution studies. Resins may need replacement or replenishment.

Army Technical Manual (TM) 5-650, Central Boiler Plants and Public Works Technical Bulletin (PWTB) 420-49-05 Industrial Water Treatment Procedures define phosphate and dispersants (polymers or tannin) as the accepted treatment for deposit control. Phosphate comes as orthophosphate or various polyphosphates. In the boiler, polyphosphates break down to orthophosphate. Orthophosphate should always be fed directly into the boiler. If fed into equipment and piping upstream from the boiler, it can precipitate in the presence of calcium. Feed polyphosphates and dispersants directly into the boiler through dedicated chemical feed piping or inject into feedwater piping.

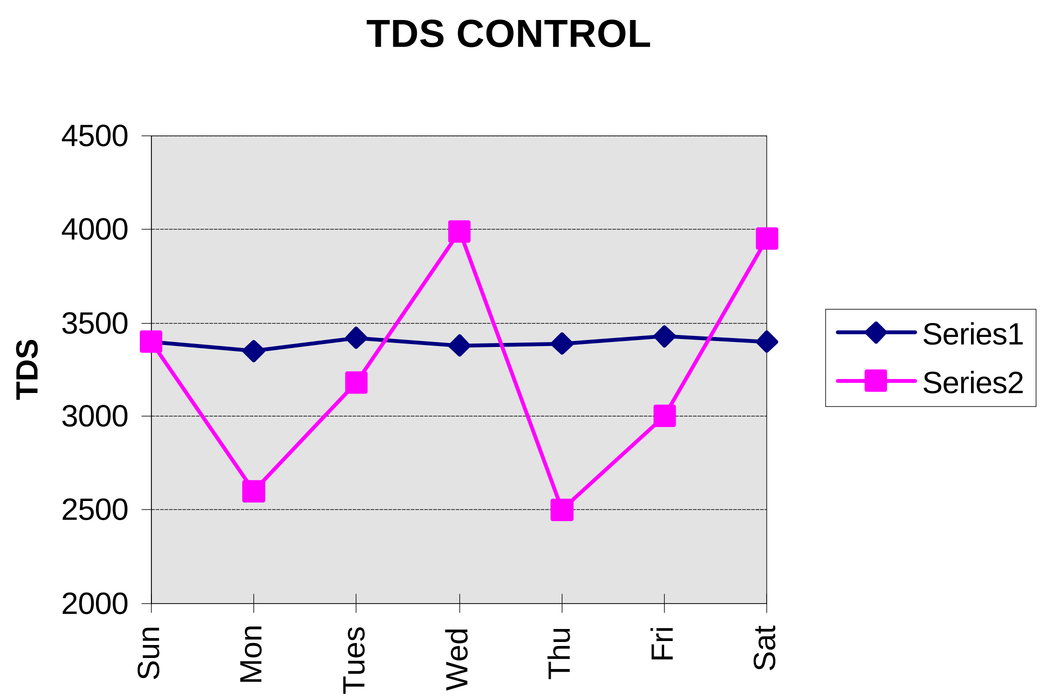
Feed phosphate and dispersant treatments continuously as a function of feedwater as opposed to slug dosages. This allows for a proper residual in the operating boiler at all times and minimizes overtreatment and undertreatment swings.

4. Improper Blowdown Is a Major Cause for Scale Formation and Wasted Energy

Scale and sludge can result even when chemicals are applied at the desired treatment levels when there is insufficient blowdown. In a number of cases, blowdown has been treated as an unrelated procedure to the chemical treatment program, rather than part of an overall treatment plan. At the same time, excessive blowdown wastes energy, water, and chemical treatment. The most common problem is excessive blowdown.

Suggested Actions

Use surface blowdown to control total dissolved solids (TDS) wherever practical. This is achieved with a manual throttling valve or an automated microprocessor blowdown controller. It is better to control blowdown continuously or in small frequent increments rather than infrequent long increments. This avoids wide swings in the TDS level as well as chemical levels.

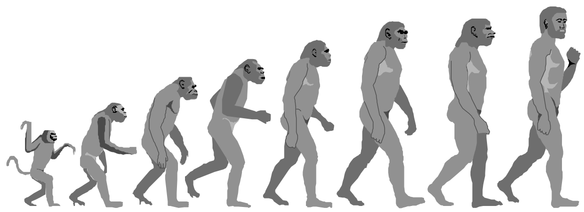


Series 1 depicts continuous or frequent small incremental blowdown.
Series 2 depicts manual, infrequent large incremental blowdown
Control Range: 3,500 - 5,000 ppm TDS for this example. Above 5,000 ppm risks scaling and carryover. Below 3,500 ppm is wasteful of energy, water, and chemical treatment.

Use bottom blowdown to remove sludge. It is not used to control TDS unless it is the only blowdown option available. The frequency of bottom blowdown depends on feedwater quality and the type of treatment program being followed. Boiler load also impacts blowdown requirements. The heavier the load, the more frequent bottom blowdown is required.

Excessive blowdown is a common problem with Army boiler operations. The general attitude is that blowdown will avoid trouble. However, the cost in wasted energy, water, and chemicals along with the possible replacement of boiler elements can be significant. Proper blowdown is achieved when adjustments are made to match boiler load changes, while maintaining the specific control ranges for TDS, alkalinity, and/or silica.

5. Inadequate Sampling And Testing Procedures Result in Improper Chemical Treatment



We have come a long way from the old days!!!

Inaccurate gathering and analysis of water samples can result in losing control of the treatment program. This can lead to a higher cost of chemical treatment, misapplication of treatment, reduced efficiency, and even boiler failure.

Chemical test results are only as accurate as the sample collected. Therefore the sample collected must be truly representative of the system conditions. A poor sample will yield results that call for unwarranted or insufficient adjustments to the program.

Suggested Actions

Specific rules apply to good sampling and test procedures:

Sample Point

Boiler samples should be collected at the continuous surface blowdown line using a sample cooler for operator safety and to prevent flashing (water converting to steam). If there is no continuous blowdown line then a sample can be collected from the water column beneath the sight glass which again should be cooled.

Sampling Technique

Sample lines should be flushed thoroughly to minimize contaminants from stagnant water in the lines. Sample containers should be clean prior to taking a sample. Containers should be dedicated for sample type i.e. boiler, feedwater, condensate etc. Heavy duty, high temperature, polypropylene, wide mouth bottles are recommended over glass

Tests for trace metals like iron and copper require special preparation. The sample needs to be preserved with acid to bring the pH down to 2.0 or less. This is necessary to prevent the trace amount of metal from being absorbed into the walls of the container.

Interval Between Sample Collection and Analysis

For some constituents in boiler water it is critical that the interval between sample collection and analysis be as short as possible. Long intervals may allow some chemicals to continue reacting so that smaller than actual amounts will be found. An example of this is sulfite which continues to react with oxygen from the atmosphere over time. Different constituents in boiler water have different degrees of stability. Some must be tested immediately after removal: sulfite, hydroxide, and pH. Others can last indefinitely when properly contained. The order of testing should be as follows: 1.) sulfite, 2.) causticity and pH, and 3.) all others.

General Laboratory Technique

Laboratory glassware and testing vials should be clean when starting to run tests. Rinse glassware and test equipment thoroughly between different tests and different samples to avoid cross contamination. This is particularly important when measuring conductivity of condensate samples which are relatively pure compared to boiler water samples.

Problematic Testing

The problems that often rise in boiler water testing is the lack of consistency in following correct procedures and /or interpreting results. The following are some examples:

Phosphate Testing

The first step for determining a free phosphate residual is to filter the boiler water sample with 0.45 micron filter to remove phosphate that has reacted with calcium. An excess of a polymer can cause some of the reacted phosphate to pass through this filter yielding an erroneously high result so it is important to keep polymer dosage within control limits which may need to be verified by a lab. The free phosphate is measured by comparing the resulting blue color in the prepared test sample with a comparator block - a series of various shades of blue color standards. Color can be judged visually or with a spectrophotometer. Tannin or rust can interfere with the visual determination in which the case the sample can be decolorized using a special grade of a decolorizing filter.

Conductivity and Total Dissolved Solids Testing of Steam Boiler Water Samples

Blowdown is generally controlled as a function of total dissolved solids (TDS) which is calculated from neutralized conductivity measurements. Excessive blowdown causes TDS to be too low resulting in waste of energy, water, and chemical treatment. Insufficient blowdown results in excessive TDS and risks the deposition of scale on boiler tubes and carryover of boiler water into the steam.

The first step in obtaining an accurate reading is to have a conductivity meter that is properly calibrated for the range that is being tested. One would not want to use a 300 micromhos calibration standard for a reading that is expected to be measured in the thousands micromhos range or vice versa. Some conductivity meters have “built in” calibration, but these must always be verified against an external standard. Comparing one calibration standard against another independently prepared standard, gives some idea if the standards are in agreement and therefore correctly prepared.

The next step in measuring boiler water conductivity is to properly neutralize the sample using an organic acid like gallic acid. This neutralizes the contribution of hydroxide ions which we do not wish to include in the estimate of TDS. The sample’s conductivity is also affected by temperature so all readings should be done on samples that have cooled to room temperature for consistency.

Finally the neutralized conductivity measurement is used to calculate boiler water TDS. Neutralized conductivity times the factor 0.7 = ppm TDS. The factor changes slightly if tannin is used as a dispersant as shown below:

Tannin Number	Factor
0	0.7
1	0.8
2-3	0.9
4-5	1.0

Polymer/Phosphonate/Chelant Testing

Many boiler water treatment programs are getting away from phosphate and moving toward all polymer, phosphonate, and/or chelant programs. Specific test procedures are available to test for these, however it is recommended to send samples to an outside lab for analysis to verify results obtained at the plant.

6. Poor Records Cause Ineffective Boiler Operations

Well documented logs of water testing results are necessary to indicate the current status and trends of chemical treatment and general boiler operations. Records are particularly valuable for preventing boiler failures or determining the cause of failures that do occur. Well maintained records can predict the condition of the boiler before inspections are performed.

Suggested Actions

Maintain log records that are organized and easy to read or they are not useable. Many operations use computer generated spreadsheets and databases that they create on their own or use from their water treatment service company. Records worth keeping can include:

Makeup Water	water meter readings, hardness, conductivity
Feed Water	water meter readings, hardness, alkalinity, iron, silica, pH, conductivity
Boiler Water	sulfite, phosphate, causticity or pH, alkalinity/causticity, chloride, silica, polymer, conductivity
Condensate	pH, conductivity, iron, hardness
Chemical Treatment	dosages, chemical pump settings

Records should be reviewed by supervisory personnel to see if that all parameters are within specified control limits. If they are consistently out of the control range, then corrective action is required.

Test results should be periodically verified by an independent testing laboratory to make sure that accuracy is being achieved.

Army Boiler Water Quality Assurance

The Army has a quality assurance program to provide an independent audit of chemical testing and overall water treatment program effectiveness. Each base is required to submit to the approved laboratory - one boiler and condensate water sample for each high pressure (greater than 100 psi) boiler plant. This is to be done once per month. Samples of condensate and makeup water should also be sent in for analysis to allow for complete system review. Chemical test results are compared for accuracy and control. The contractor then provides comments and recommendations on how best to improve operations.

7. Inspections Are Invaluable for Boiler Operations

Boiler inspections are necessary to document the effectiveness of the water treatment program. Proper chemical treatment application and record keeping can allow one to predict the condition of the boiler, however the inspection documents the condition. Proper documentation allows for comparison to previous inspections to see if the condition of the boiler has changed for the better or worse. Photos and videos should be used wherever practical.

Please, please, please let it look good! I promise I'll be good from now on.

Suggested Actions

Obtain documents from the previous inspection if applicable, to serve as a reference for the present condition of the boiler.

Inspect the watersides of the boiler. In many cases the view will be limited especially for water tube boilers. Fiber optics video inspection equipment is useful for this purpose. Note the presence or absence of deposits. If present, note the thickness of the deposit and obtain a sample for laboratory analysis. Good control of external treatment, chemical treatment, and blowdown will prevent deposits from forming.

Inspect the watersides for corrosion control effectiveness. The metal should have a thin layer of magnetite (ferrous-ferric oxide), a self-limiting form of corrosion that is a protective film. Magnetite has a grayish/brown appearance. It's presence is indicative of good pH control. The metal should not show any pitting due to oxygen corrosion attack.

Inspect the mud drum of the boiler. There should be no significant accumulation of sludge which indicates that adequate bottom blowdown control has been accomplished.

Safety inspections are above and beyond those described above which are to be done by operators. For those seeking safety inspections, installations can obtain them individually or through the Army's central boiler inspection contract.