PRESERVING BOILER EFFICIENCY BY BETTER MAINTENANCE©

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1.0 DESIGN OF AN EFFICIENCY-RELATED BOILER MAINTENANCE PROGRAM

1.1 Introduction

- A complete maintenance program for a boiler plant has to include many items concerned with issues such as availability, safety, warranty requirements, life extension, and operational efficiency.

- This presentation will focus on boiler maintenance items that pertain to operational efficiency, i.e., the fuel or energy consumption to generate a given amount of steam.

- Efficiency-related boiler maintenance can be viewed as a more specific application of the complete boiler plant preventative maintenance procedures. The intent is to identify and correct those items that influence efficiency before the equipment has deteriorated to the point where reliability, capacity, or efficiency is compromised.

- Efficiency-related maintenance items will be defined as those items that, for a selected constant boiler output, have the potential to cause an increase in any of the following parameters.[1]

  1. Stack gas temperature.
  2. Excess air (stack O_2) level.
  3. Carbon monoxide concentration in flue gas, smoke, or unburned carbon in ash.
  4. Convection or radiation losses from the boiler.
  5. Blowdown above that required to maintain permissible boiler water concentration.
  6. Steam and/or hot water leaks.
  7. Auxiliary power consumption, e.g. fans, pumps.

1.2 Setting a Performance Goal

- The first requirement for an efficiency-related boiler maintenance program is to establish the best achievable performance of the boiler over the operating range.

- Starting point should be the manufacturer's predicted performance tabulations and test records containing data taken during testing that followed initial start-up.

- On older units or when above information is not available, baseline data may have to be taken at various outputs over the operating range. On older boilers this should only be done following a major or annual outage that has included control and firing systems tune-up.

- Although, on firetube and watertube boilers without heat recovery, exit gas temperature will normally range between 100ºF and 200ºF above steam saturation temperature, when heat recovery (e.g. an economizer or air heater) has been included as part of the boiler installation, variations in design conditions make it impossible to generalize about exit gas temperature.

- In general, with a well-tuned package boiler, it should be possible to operate at full load with not greater than 15% excess air on natural gas and 15 to 20% excess air on oil firing. On larger, field-erected natural gas and oil-fired units with the proper burners and controls, even lower excess air levels can be achieved. Stoker-fired boilers should not exceed 30 to 40% excess air.

1.3 Performance Monitoring

- The objective of performance monitoring is to document deviations from the established performance goal as a function of time and thus indicate where maintenance is required.

- Data should be taken on a regular basis and at steady load conditions. Data comparison must be made on the basis of similar load conditions.

- In paper-based systems, much of the information that is required would be found in the boiler plant's operating log book. With microprocessor-based boiler controls systems, it is possible to store and/or trend operating parameters and generate reports which can then be used as the basis for "performance" monitoring. Boiler performance-related maintenance can then become part of a preventative maintenance plan which can be incorporated in a Computerized Maintenance Management System (CMMS).

- For an operator collecting data, the list can be reduced to:[1]
  - Steam Pressure and Temperature
  - Feedwater Temperature
  - Steam, Feedwater, and Fuel Flows
  - Fuel Supply Pressure
  - Fuel Supply Temperature
  - Boiler Outlet Gas Temperature
  - Boiler Outlet O_2
  - F.D. Fan Inlet Temperature
  - Stack Appearance

- Flame Appearance
- Windbox Air Pressure
- Windbox to Furnace Air Pressure Differential
- Boiler Outlet Flue Gas Pressure (draft)
- Blowdown Flow
- Unusual conditions or equipment malfunctions

- If a boiler operates in an environment with frequent and/or large fluctuations in load, it may be necessary to schedule a monthly performance check during which time a steady load can be maintained.

1.4 Computerized Maintenance Management System (CMMS)

CMMS are increasingly being used to manage boiler plant maintenance in preference to manual, paper-based systems. The CMMS is an important preventative maintenance tool, along with performance monitoring to track and maintain boiler efficiency.

Maintenance tends to address general preventative maintenance and scheduled maintenance but often does not address "efficiency-related" preventative maintenance.

A computerized efficiency monitoring maintenance plan for a boiler plant would normally include the items listed below as objectives to be achieved and limitations to be respected:

- Satisfaction of equipment vendor-specified maintenance to ensure validity of equipment warranty, attain expected operational life and obtain desired plant availability and performance.

- The plan should be capable of efficient implementation, control and monitoring of plant maintenance activities and provide overall boiler plant efficiency as well as component efficiency.

- The plan should be able to build an easily-accessible equipment history or record.

- The plan should be able to analyze large volumes of records quickly and evaluate its effectiveness.

- The plan should offer the capability to quickly adjust the maintenance plan as determined by analysis or operating experience.

- Schedule efficiency monitoring and testing as part of preventative maintenance and schedule resultant actions.

- Document and control maintenance procedures and effect of procedure on plant efficiency.

- Schedule calibration and maintenance for gauges and instruments and maintain instrument datasheets.
- Control location and calibration of portable testing equipment.
- Provide fuel, energy savings and replacement cost savings due to maintaining or improving efficiency.
- Provide maintenance budget and cost statistics.
- Provide analysis tools for "maintenance" performance related to efficiency and equipment life.
- The plan must consider size and composition of plant staff and the physical resources available to them, e.g. tools, equipment and shop space, boiler control system monitoring, tracking and report generation capabilities, etc.

2.0 EFFICIENCY-RELATED MAINTENANCE

Boiler efficiency is usually determined by either using the input/output method or the heat loss method which are discussed in many other sources.

In this section we will review factors that affect boiler efficiency that deserve consideration for inclusion in a maintenance program.

2.1 Excess Air

Past studies have shown that reducing excess air is the single most effective method to improve the combustion process and therefore boiler efficiency.

One testing program's findings were that in nearly 75% of the cases where excess air was reduced, industrial boiler efficiency increased by up to 3%; nitrogen-oxides decreased by up to 38%; and particulate emissions dropped by up to 30% on No. 6 oil and 15% on coal.[3]

Lowering the excess air level for combustion provides the following advantages:

- Increases the boiler efficiency by lowering the "dry gas loss."
- Reduces both total emissions due to increased efficiency and specific pollutants such as nitrogen-oxides (NOx) and sulfur trioxide (SO_3) because of less available oxygen.

It is thus obvious that maintaining proper excess air levels (i.e., air/fuel ratio) in a plant's boilers should be an item of prominent focus in a boiler maintenance program, as should all conditions affecting the combustion process. A minimum level of excess air must, however, be accepted as a necessary evil in all boilers due to physical constraints on proper mixing of air and fuel and less than ideal conditions such as maldistribution of combustion air.

As excess air is reduced closer and closer to the theoretical stoichiometric level, a point will be reached where the emission of carbon monoxide (CO) will start to increase significantly or the boiler will start to smoke. The smoke threshold normally applies to coal and oil firing because smoking usually occurs before CO emissions reach significant levels with these fuels. The CO threshold pertains to gaseous fuels.

Smoking or a spike in CO emissions are signs of incomplete combustion. Incomplete combustion is even more damaging to boiler efficiency than excess air. If carbon is only oxidized to CO instead of being fully oxidized to carbon dioxide (CO_2) approximately two-thirds of the chemical energy in the carbon is lost

Trying to operate below the above thresholds is dangerous and could even lead to a furnace explosion! The optimum operating point for excess air will, therefore, always be on the higher side of the above thresholds to ensure complete combustion of fuel and a safe furnace environment. The larger or more rapid the load swings that the boiler is expected to accommodate, the greater will be the margin required between the stoichiometric air requirement and the actual excess air level at which a boiler can successfully operate.

2.2 Firing Equipment

Oil and Gas Burners

- Check to see that the burner diffuser or impeller is not burnt-off, warped or otherwise damaged. Also, ensure that it is correctly positioned with respect to the burner throat and the oil burner tip or gas spuds or orifices.

- Inspect the condition of the burner throat refractory and ensure that the oil gun is located in the correct position with respect to the burner throat and draft tube.

- Inspect the oil tip passages and orifices for plugging or coking and clean them of any deposits. Use the proper size drill bit as a “go / no go” test for determination of wear.

- Similarly, on gas burners, check all gas injection orifices for sooting or other blockage. Note that, in some instances, during the original set up and tuning of the burner, some of the orifices may have been deliberately plugged. This should have been documented.

- Verify proper fuel pressure at the burner and in the case of oil, proper temperature as well. Note that because of the decline in residual oil quality in the last decade, higher oil delivery temperatures may be required.

- Verify proper atomizing steam pressure on oil burners.

- Inspect and clean strainers located in the burner fuel train.

Pulverized Coal Burners

- Check for wear and proper functioning of upstream fuel and air delivery equipment including feeders (gravimetric or volumetric), pulverizers, primary air fans and primary and tempering air dampers.

- Clear primary air/coal delivery piping of any coal and coke deposits.

- Check burner parts for any signs of erosion, oxidation, distortion or slagging. Repair and/or replace components as necessary.

Stoker/Grate Firing

- Check grates for wear and signs of distortion or overheating. Replace and/or repair components as required.

- Confirm proper positioning of all air proportioning dampers.

- Inspect overfire air ports for oxidation and slagging or other blockages. Clean and repair as necessary.

2.3 Combustion Controls

- Check calibration of all gauges, differential pressure transmitters, switches, etc. Replace any devices that cannot be properly calibrated.

- Observe movement of fuel control valves, damper positioners and other final control elements to verify proper movements. A smooth response or movement should be observed. The cause of any binding or hunting should be determined and corrected.

- Internally inspect and clean fuel flow control valves.

- Check for excessive play and/or poor repeatability in the combustion control system by selecting a firing rate condition and then approaching this firing condition from both lower and higher firing rates. Ensure that boiler operation has stabilized before any observations are made or readings are taken.

- With "positioning type" of controls, mark the relative position of linkages at the selected firing rate, and then compare position of linkage after this firing rate has been approached from both lower and higher firing rates. With metering controls, record air and fuel flow and excess O_2 if this is also measured.

- Eliminate any play in linkages discovered during above testing. With metering controls, correcting poor repeatability may involve recalibration of sensors, adjustment or repair of positioners or final control elements and tuning and/or modification of air and fuel controller programming.

- Ensure that fuel supply pressures at inlets of pressure regulators are high enough to assure constant regulator-outlet pressure for all firing rates.

- Check, calibrate and record all field instrument settings including confirming that primary element conditions match transmitter range, and control system function blocks are correct prior to the start of the initial testing. Confirm settings on at least an annual basis.

2.4 Fireside and Waterside Cleanliness

- Deposits and fouling on external tube surfaces of water tube boilers or inside the tubes of a fire tube boiler restrict heat transfer and reduce boiler efficiency.

- The best indicator of a change in fireside cleanliness is an increase in stack gas temperature. Ensure that comparisons of stack gas temperatures are made under the same boiler operating conditions.

- As a general "rule of thumb" for oil and natural gas fired boilers, an increase of 40ºF in stack gas temperature will equate to an approximate 1% drop in boiler efficiency.

- The most likely causes for an increase in fireside fouling are a degradation in firing conditions or a degradation in fuel quality. Maintenance of firing conditions and combustion controls has been discussed above. Determining degradation in fuel quality may require obtaining an ultimate analysis from an independent laboratory.

- Although an increase in fireside deposition is more likely to be caused by a degradation in fuel characteristics or firing conditions, it can also be caused by improper sootblower operation. Correct operation of the sootblowers (e.g. sequencing, blowing time, and blowing arc), blowing medium delivery pressure, and condition of sootblower lance and nozzles should be checked.

- If firing equipment and sootblowers are verified to be in good condition and proper functioning and tuning of controls has also been determined but fireside fouling persists, then water washing of the fireside should be investigated. Ensure that the wash is followed by a neutralizing rinse.

- An increase in stack temperature can also result from deposition on the waterside of tubes, which would also impede heat transfer. However, before a significant drop in efficiency is noticed, a potentially more serious problem is likely to be encountered, i.e., tube bulging or failure due to overheating. Strict attention to maintenance of proper boiler water/cycle chemistry is one of the more important duties of operations and maintenance staff.

2.5 Other Boiler Energy Losses

- Deteriorated casings on boilers will lead to casing leakage. On balanced draft boilers, the leakage will be inward and will lower boiler efficiency. On pressurized furnaces, the leakage will be outward and while it may not have a significant impact on boiler efficiency, it has definite personnel safety concerns, i.e. air quality and potential for thermal burns! Repair casing leaks quickly to protect personnel safety and prevent further insulation and casing damage.

- With the boiler out of service, test for casing leakage by way of a "smoke bomb" test using the forced draft fan to pressurize the furnace.

- Many older boilers have refractory or metal baffles in their boiler banks that were designed to ensure "crossflow" or "longflow" of flue gases. Inspect and repair these to maintain the desired gas flow pattern. If flue gas is bypassing a portion of the heat transfer surface in the boiler bank, stack temperature will increase and boiler efficiency will decrease.

- Air heater leakage can affect boiler efficiency as well as auxiliary power consumption due to increased loading on fans. Air heater leakage can be verified by measuring oxygen concentration in flue gas at entrance & exit to the air heater.

- Leakage in a tubular air heater is normally not significant. However, cold end corrosion due to sulfur containing fuels and low gas exit and/or low inlet air temperatures can occur.

- Rotary regenerative air heaters have seals located between stationary and moving parts, to prevent leakage from the air side to the flue gas side. The normal leakage is in the 7~15% range, but improperly adjusted or worn seals can double the amount of leakage.

- Excessive blowdown will lead to unnecessary heat loss. On many smaller boilers, blowdown is controlled by a manual valve that may have been inadvertently opened too wide. Before any reduction in blowdown is made, however, a thorough examination of boiler water quality records (which should be consistently maintained) and consultation with the provider of the boiler plant chemical treatment program should be conducted before any decision is made to reduce blowdown.

- Depending on size of boiler plant and amount of blowdown required, it may be economically justifiable to consider heat recovery from blowdown through the use of a flash tank connected to a lower pressure steam system or an exchanger that would use blowdown to heat a process stream.

- Missing or loose insulation increases heat loss in the plant and should be inspected for and repaired on all boilers, flues, ducts, heat recovery equipment (e.g. economizers and air heaters) and piping.

- Internal boiler leaks, if they are small, will be hard to detect with the boiler in operation. Larger leaks can be recognized by such things as by noise of escaping steam, vapour plume in stack gas or increased make-up water flow. To prevent steam or water cutting of adjacent tubes, leaks should be repaired promptly.

- Along with boiler maintenance and efficiency monitoring, maintenance and monitoring of other components and systems should also be performed including feedwater pumps, fans, oil pumping and heating system, etc.

2.6 Steam Leaks

- Although not part of boiler energy losses, steam leaks from pipe joints, flanges, valves, unions, etc. are an obvious waste of energy in the boiler plant, which should not be accepted as "a fact of life."

- In addition to the thermal energy lost in the leaking steam, the quantity of steam leaked must be replaced by make-up water. This make-up must undergo mechanical and chemical treatment before it becomes part of the boiler feedwater. Increasing make-up thus increases energy and chemical consumption. Further, increasing make-up will require an increase in boiler blowdown, which wastes more water, chemicals, and thermal energy.

- Less visual steam leaks occur with malfunctioning steam traps, i.e., a trap that is blowing steam, can be a large energy loser. As an example, about 210,000 lb of steam per month will be wasted with a leak equivalent to a ¼-inch orifice at a 100 psig differential[5]. A bi-annual or tri-annual trap-testing program should be established to check for malfunctioning traps. Testing methods can include visual observation, temperature (infrared), acoustic and electronic.

3.0 RETROFITTING NEW AND IMPROVED BURNER MANAGEMENT SYSTEMS, BURNERS AND COMBUSTION CONTROLS

The reasons for pursuing a burner and/or controls retrofit can include the following:

- Previously, the efficiency and emissions advantages of maintaining excess air levels were described. A desire to improve even further on these items by installing a low excess air burner and associated controls would, therefore, be a major reason for a burner and controls upgrade.

- A control systems upgrade would provide the opportunity to automate the collection, analysis and reporting of plant and component efficiencies, if planned properly during the purchase of the system.

- An increase in plant safety level may be afforded by a new Burner Management System with advances in hardware (including flame scanners) and software.

- An increase in boiler plant availability may also be a benefit gained by retrofit of modern burners and controls.

- A desire or need to achieve greater fuel flexibility (e.g. a decision to change from a firm supply to an interruptible natural gas supply) may require a retrofit.

- An upgrading of other plant controls may afford the opportunity to upgrade boiler controls. It may also require upgrading of boiler controls if present controls cannot interface with new plant controls.

- Although not as likely to be a primary reason for retrofit, a benefit that may ensue is a savings in space where relay panels are replaced by microprocessor or PLC-based controls or where burner management functions are combined with combustion controls in the same cabinet.

3.1 Upgrading and Retrofitting Burner Management System (BMS)

- The BMS ensures that a safe environment for trial ignition has been established in the furnace and monitors furnace safety indicators following ignition. If, at any time, an unsafe indication is detected, the BMS will stop all fuel flow (energy input) to the furnace.

- The BMS, therefore, does not affect boiler efficiency; it only safeguards burner operation.

- The BMS does have to interface with the boiler's combustion (modulating) controls to ensure proper positioning of the forced draft fan variable inlet vanes, variable speed drive or damper, and the fuel flow control valve for burner light-off.

- A very common approach today is to have the sequential logic performed by a Programmable Logic Controller (PLC), but to retain hardwired inputs from field devices to relays for the safety interlocks. This will likely change in the future with relays being replaced by redundant processors.

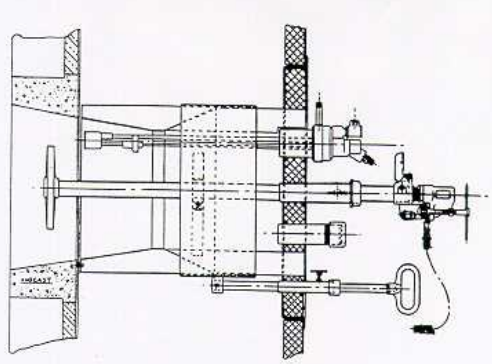
- As opposed to a separate BMS panel, it is also possible to have the BMS logic contained in the same cabinet as the combustion controls, such as when there is a Distributed Control System (DCS) for other plant systems and to have only a small panel local to the boiler to initiate a burner start.

3.2 <u>Upgrading Burners</u>

- Most modern low excess air burners are of the "axial" or "parallel flow" type rather than of the older "register" (high swirl) design and originate from research conducted by the former Central Electricity Board (CEGB) in the U.K. in the 1960's. This research showed that in fact the high turbulence and pressure drop introduced into the air stream as it passed through the registers did little to promote good mixing of air and fuel in the furnace.

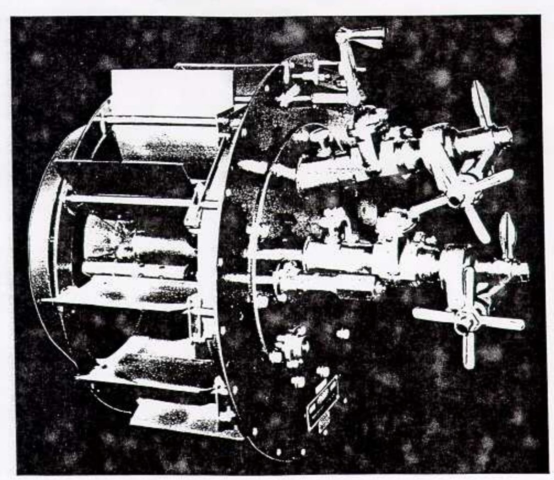
- Parallel flow burners do not incorporate the movable air doors that were the distinguishing feature of register-type burners. Instead, the opening to the burner air or draft tube is completely unobstructed, usually of a bellmouth configuration.

Figure 1
Typical Parallel Flow Burner Illustration



(Extracted from Reference 7)

Figure 2
Typical Register Burner Illustration



(Extracted from Reference 6)

- In a number of manufacturers' designs, the air tube is fabricated as a Venturi section. Where there are multiple burners in a windbox, each burner is normally equipped with an air slide or sleeve that slides over the end of the air tube opening to provide the ability to isolate burners when they are out of service. If it is a single burner installation, the air slide is deleted.

- Parallel flow burners typically require a deeper windbox than register burners.

- Parallel flow burners may require a higher windbox to furnace pressure drop than register burners. This may require a retrofit or replacement of the forced draft fan.

- The flame from a parallel burner is typically longer and larger than that from a register burner. The physical dimensions of the furnace, therefore, have to be considered in any retrofit.

- For low NOx operation, particularly with natural gas firing, it is common to use Flue Gas Recirculation (FGR) to reduce the "thermal NOx component. On packaged boilers, this typically takes the form of Induced Flue Gas Recirculation (IFGR) where flue gas is induced into the inlet of the forced draft fan and enters the burner along with the combustion air. On larger boilers, forced FGR is employed whereby a separate gas recirculation fan is used to force flue gas into a plenum located on the burner air tube.

- With FGR, typical emission guarantees that are offered by burner manufacturers for burners installed in packaged boilers are:

Pollutant	Natural Gas	No. 2 Fuel Oil
NO_x (lb/mmbtu)	0.05 (40 ppmv)	0.09 (72 ppmv)
SO_2 (lb/mmbtu)	0.0	0.41
TSP (lb/mmbtu)	0.005	0.05
CO (lb/mmbtu)	0.15	0.15
NMHC (ppm)	10	10
PM-10 (lb/mmbtu)	0.005	0.05
Opacity % (Cont.)	10	20

- On packaged boilers, excess air levels that are typically offered are 12% on natural gas and 15% on oil. On large field-erected boilers, it is not uncommon to be at one-third of these levels.

3.3 Upgrading Boiler Combustion Controls

- Installing a low excess air burner in a boiler without the proper combustion controls is a pointless exercise.

- Ideally, a fully metered (i.e. both air and fuel flow is measured and their respective quantities are fed back to the air and fuel controllers) combustion control system should be utilized.

- An oxygen (O_2) trim control loop is a must for low excess air operation. This can be applied to single point positioning and parallel positioning controls as well as fully metered controls. The O_2 trim control loop provides a trimming effect or refinement to the air flow control signal based on the actual oxygen content measured in the flue gas.

- The oxygen analyzer must be located upstream of air heaters so that it will not see air heater leakage that would otherwise be misinterpreted as a larger than actual excess air condition in the furnace. This could lead to control actions resulting in an air-deficient furnace, which would be dangerous.

- Sophisticated control systems use multi-parameter trim where O_2 trim is augmented by trim parameters such as carbon monoxide (CO). The CO level is used to confirm that airflow has not been trimmed too low.

- Due to oxygen trim control loop dead time, which is a combination of boiler lag (gas transit time from burner to probe) and response time of oxygen probe, an "adaptive" trim control loop instead of a standard feed back loop may be required to obtain real benefit from oxygen trim control.[1]

- As indicated previously, a modern combustion control system can provide data collection, analysis, reporting and archiving of many boiler functions including plant and component efficiencies. These capabilities should be included in any control system retrofit or upgrade.

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