THESIS - **BACHELOR'S DEGREE PROGRAMME**
TECHNOLOGY, COMMUNICATION AND TRANSPORT

Planned Annual Inspections & Maintenance of Bubbling Fluidized Bed Boiler

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SAVONIA UNIVERSITY OF APPLIED SCIENCES THESIS
Abstract

Field of Study Technology, Communication and Transport			
Degree Programme Degree Programme in Energy Engineering			
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Title of Thesis Planned Annual Inspections & Maintenance of Bubbling Fluidized Bed Boiler			
Date	20.1.2017	Pages	43
Supervisor(s) Jarmo Pyysalo			
Client Organisation /Partners Andritz Pulp & Paper, Power Plant Services / Ari Korpirinne			

Abstract

Bubbling fluidized bed boilers are applications that are utilized in the energy industry sector. Commonly, these applications are used to produce steam, heat or electricity. Steam powers many other industrial processes that produce goods and services.

Thesis studies the concept of maintenance and boiler performance features from the view of equipment, maintenance project team, plant owner and notified bodies. The results of the literary section summarize the features that are involved in the development process to achieve a safe and reliable plant environment.

The study presents the most common characteristics of biomass utilizing BFB applications, including fouling and typical wear mechanisms. The study focuses on the boiler's most essential internal structures, environmental aspects and the legal requirements that are reviewed to the boiler repair and maintenance work. Maintenance work is usually performed by specialized and qualified workers during the planned boiler shutdown.

The contents were mainly compiled by studying the literature of the field, by interviewing Andritz Oy's engineers and by reviewing the archives from Andritz Oy's database. It was possible to utilize Andritz Oy's extensive maintenance instruction databank and published technical studies of BFB boilers' repair works. Over 40 inspection reports were reviewed in the research process.

Maintenance scheduling and resource planning was the assignment of Andritz Oy's Power Boiler Service department. The plan is eventually an attachment that is left out of public version, but which is still a significant part of the entirety. The task was to create a platform for managing the shutdown related tasks. This gives an opportunity to manage and analyze the project workloads. The schedule and resource plan platform will be developed in the future to cover also case company's alternate and residue fuel boiler applications.

Keywords
BFB Boiler, Shutdown, Resource, Scheduling Inspection, Planning, Maintenance

FOREWORD

An Idea for this thesis started when I was working in Andritz power plant services department as a trainee in 2017. Along with the training, I learned the main components and operating environment of a power plant. During summer training in 2016, I also got once chance to work in the shutdown site as a boiler inspector assistant, which has helped me to perceive a practical foundation for writing this work. The topic of this thesis was therefore linked to my work assignments.

I would like to thank my family, the lecturers of Savonia University of Applied Sciences and the Andritz service team in Varkaus.

Definition of a pressure vessel:

> *"A pressure vessel is a container, piping or other technical entity which has or may develop an overpressure and it has technical units intended to protect the pressure equipment."* (FINLEX, 16.12.2016/1144 §2)

CONTENTS

1 INTRODUCTION

ANDRITZ OY

> *"Andritz is a globally leading supplier of plants, equipment, and services for hydropower stations, the pulp and paper industry, the metalworking and steel industries, and for solid/liquid separation in the municipal and industrial sectors. Publicly listed on the Vienna Stock Exchange, the technology Group is headquartered in Graz, Austria, and currently has a staff of approximately 24,500 employees. Andritz operates over 250 sites worldwide."* (Andritz group intranet 2017)

The operational environment around the boilers is constantly changing and developing. In the energy industry sector, one big challenge is to respond to constantly tightnening environmental directives. These changes lead, for example, to the need for updating current monitoring techniques and mechanical structures. BFB applications are very well suited when retrofitting old boilers and commonly used worldwide when boiler modernization become topical. The conditions inside the boiler are also challenging and create various wear and stress factors for materials. In summary, these factors create an environment where the process must be monitored, maintained and supervised continuously.

The topic of this thesis was assigned by Andritz Oy's Power plant services. The main objective of the thesis was to create uniform shutdown process plan by using Microsoft Project. Plan covers schedule and resource planning and includes info packet. The objective of the literary section is to guide the people who are involved in the maintenance process. Assignment structure is shown in Figure 1.

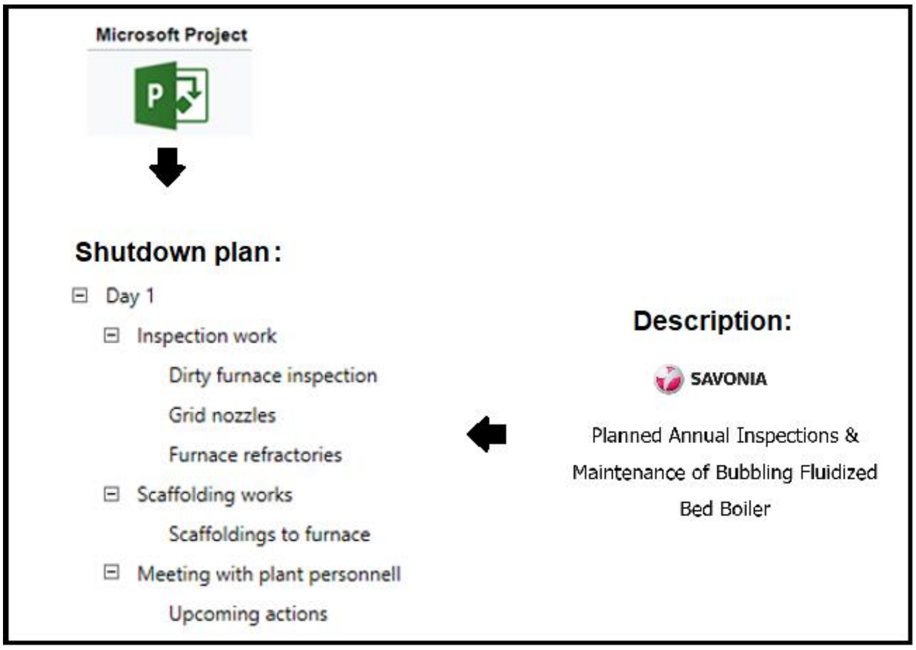


Figure 1. Assignment structure. (MS Project)

Thesis contents were mainly compiled by studying the literature of the field, by interviewing Andritz Oy's engineers and by reviewing the archives from Andritz Oy's database.

The thesis content is very closely inspired from the previous theses made for the Andritz Power Plant Services and therefore it works partly as a development of the previous studies.

Theses made for Andritz Power Boiler Service

Title: Productisation Of Maintenance Business
University: Lappeenranta University Of Technology
Author: Aki Karvonen
Year: 2011
Assignment: BFB Boiler parts' lifetime analysis & replacement intervals

↓

Title: Planning Annual Shutdown Inspection for BFB Boiler
University: Savonia University Of Applied Sciences
Author: Tatu Sorsa
Year: 2014
Assignment: Inspection checklist

↓

Title: Planned Annual Inspections & Maintenance of Bubbling Fluidized Bed Boiler
University: Savonia University Of Applied Sciences
Author: Leo Sevtsenko
Year: 2018
Assignment: Scheduling & resourcing of BFB Boiler shutdown

Figure 2. Theses made for Andritz Power Plant Services.

By developing uniform shutdown routines for the maintenance team, it is possible to achieve many improvements. The best improvement is to achieve safer and more efficient process performance features. Schedule and resource plan platform will be developed in the future to concern also Andritz Oy's alternate fuel and residue fuel concepts. Concepts are shown in

Figure 3

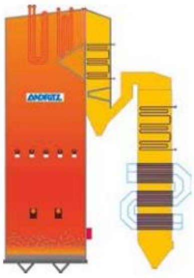
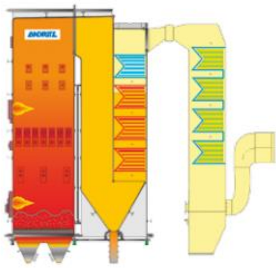
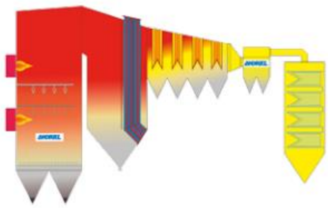
BFB applications	EcoFluid BC Biomass fuels concept	EcoFluid AC Alternative fuels concept	EcoFluid RC Residues and refuse-derived fuels concept
Type			
Size range	40-420 t/h (88-925 klb/hr)	30-250 t/h (66-550 klb/hr)	30-100 t/h (66-220 klb/hr)
Main fuels	Biomass fuels (bark, chips, sawdust), peat	Rejects, sludges, demolition wood, agricultural residues	RDF, rejects, sludge
Secondary fuels	Sludges, demolition wood, agricultural residues, Coal up to 20%, TDF	Biomass fuels	Biomass fuels, demolition wood, agricultural residues

Figure 3. Andritz Oy's BFB boiler applications. (Andritz Oy's archives)

2 BFB TECHNOLOGY, MAINTENANCE AND MONITORING

This chapter presents the main design features and functions of a BFB boiler and how the maintenance and monitoring is implemented in the process.

2.1 Technology

Energy production by utilizing bubbling fluidized bed technology is commonly used worldwide. Usually BFB boilers utilize mainly renewable bio fuels, such as wood chips, bark, waste wood and agricultural residues, but there are also waste fuel applications that can utilize industrial and municipal sewage sludges, RDF and residues from pulp and paper industry. The main parameters of a boiler design are steam generation capacity, main steam temperature and main steam pressure. (Esa Kari Vakkilainen 2017,15) Andritz Oy's biofuel applications can incinerate 25 to 350 MW_{fuel}, which means 10 to 100 MW_{energy}. Superheated steam temperature is stabilized around 540 - 550 C° degrees. Good and economical corrosion resistant materials above 550 C° degrees are not yet available. The maximum practical pressure for natural circulation units is 19,31 Mpa (193,1 Bars). At this pressure, the density of water has decreased to about one third, reducing the boiler's natural circulation capabilities. For example, compared to the unit where the pressure is 8,27 Mpa (82,7 Bars), water to steam density ratio is 16:1 (Brad Buecker, 2002, 6).

Fuel heating value in biomass is usually in range of 3-20 MJ/kg and the fuel moisture and particle size fluctuate a lot. Bubbling fluidized bed combustion technique is very efficient and suitable for moisture fuels. Fluidizing means that the inert bed material is mixed constantly. Bed sand, which is fluctuated by the speed of 0,7 - 2,0 m/s, captures the heat and releases it to wet biomass and evaporates water from it quickly. Relatively low furnace temperature (700 - 900 °C), air staging and SNCR or SCR systems in flue gas channel enable low NO_x, –emissions. SO2 control is achieved with calcium carbonate injection or, for example, with flue gas scrubber technique. Lower part of the furnace is protected with refractories to avoid abrasive erosion of the bed sand. Coarse bed material is removed by conveyors located below the bottom ash hoppers. Flue gas flow is conducted to electronic precipirator or bag filters, where the dust components are captured before flue gas enters the stack. Flue gas flow is achieved with the help of flue gas blowers. After flue gas treatment, cleaned flue gas is released to the atmosphere. Flue gas properties are shown in chapter 3, Table 1. (Esa Kari Vakkilainen 2017,15; Huhtinen M., Kettunen A., Nurminen P., Pakkanen H. 2000, 36 - 37.)

Boiler functions are secured by safety related systems (SRS), which are based on automation system and process measurements. These automatic functions protect the boiler from unwanted process conditions, which may lead to hazards. Therefore, the condition and functioning of the measurement sensors and devices are the key for a coherent process. Implementation of systematic quality measures such as design reviews, inspections, acceptance tests and commissioning tests enable a long lifetime and high availability for the boiler. (Andritz Oy's archives)

The basic structure of a BFB Boiler is presented in Figure 4.

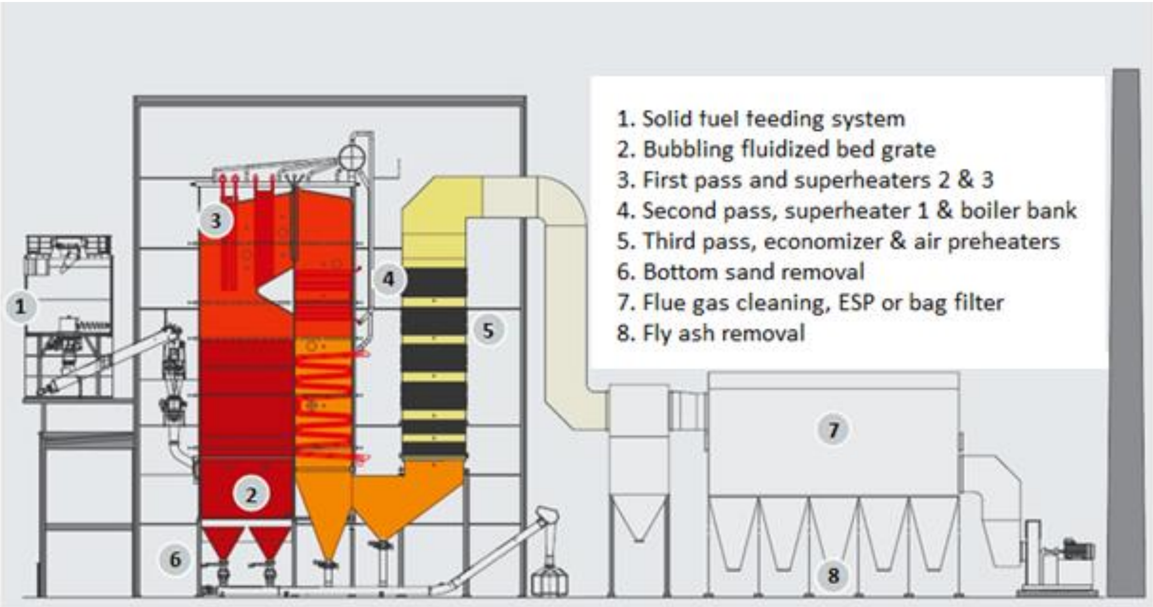


Figure 4. The basic structure of a BFB boiler. (Andritz Oy's archives)

2.2 Maintenance & Monitoring

The concept of maintenance is wide ranging. It covers malfunction correction, preventive and continuous maintenance, inspections and monitoring. Neglected maintenance routines may cause harm to people, to the process equipment and to the environment. Shutdown periods district heat producing power plants are usually scheduled for the summer season when the steam demand seasonally drops at its lowest, but in pulp and paper industry sector the demand is to operate as long as possible between the shutdowns.

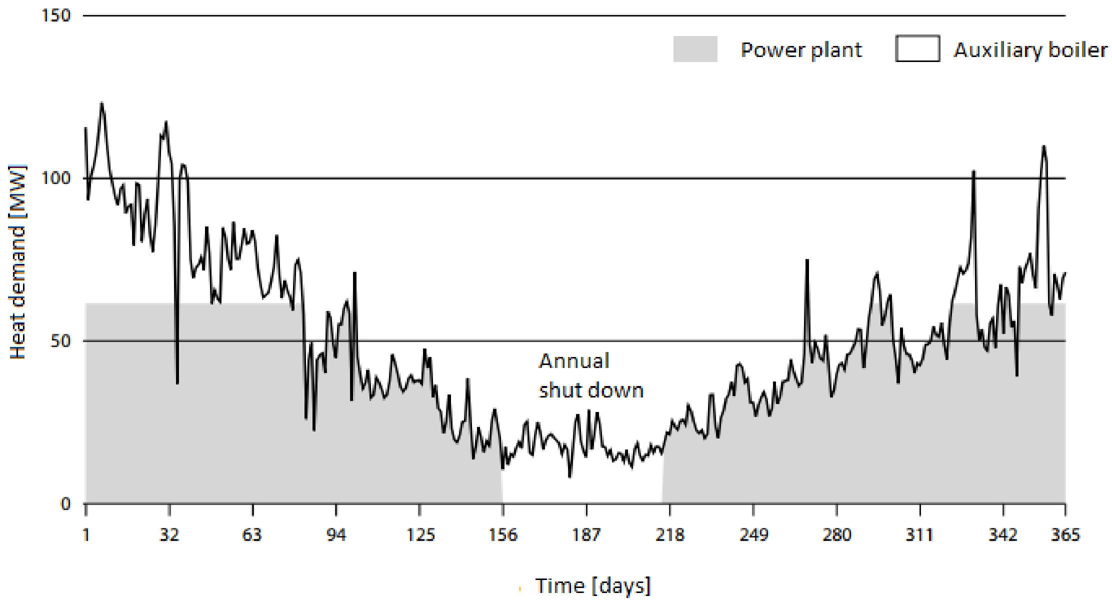


Figure 5. Possible shutdown period time range for a district heat plant. (Voimalaitostekniikka 2008, 12)

The plant owners' interests are that the production losses are minimized and process interruptions are as short as possible. Shutdown maintenance costs are concidered to be high. Therefore, the whole maintenance process, which is inevitable for the continuity of operations must be efficient and well planned.

$$\text{Availability} = \frac{\text{Plant's running time}}{\text{Year (8760 hours)}}$$

Figure 6. Availability (Hannu S. Laine 2010, 240)

The prevailing fact is that the unplanned repair work hour costs five times more than the planned repair hour (Hannu S. Laine, 2010, 51). In first hand, the plant owner is responsible for the implementation of planned maintenance and inspection works. The power plant's annual maintenance tasks employ specialized and qualified workers for several days during the shutdown. In case the shutdown schedule is tight, work may be performed in two shifts, day and night. The length of a shutdown period for each plant varies, depending basically on the plant's mechanical condition and size.

Collecting boiler data is one way to collect information about the condition of the process. Deviations in running parameters can be usually linked to a certain area of the boiler. The benefits of the data system will only be usable, if the data is regularly collected, saved and measurement practices are not neglected. Preventive control of parameters can possibly extend the life expectancy of tubes and other process devices. Collected data is analyzed and corrective actions can be taken on the basis of the results. For example, vibration measurement of electrical motors can be performed regularly and therefore the upcoming malfunction can be detected before it is too late. (VTT, 2016, 36.) Motor manufacturers will normally give clear instructions for measurements to be carried out during motor maintenance. Development of a bearing break is shown in Figure 7. The clear case of a bearing damage caused by frequency converter drive was found in both bearings.

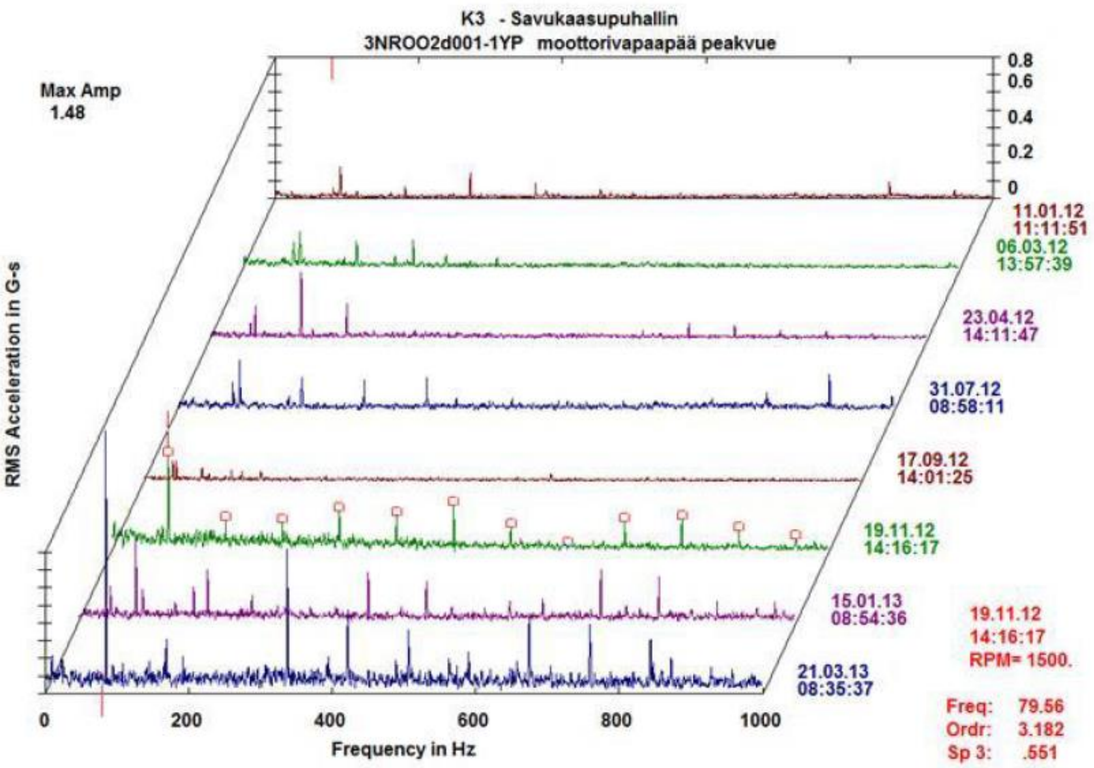


Figure 7. Development of a bearing break in flue gas blower. (VTT 2016, 36.)

Monitoring gives an opportunity to perform maintenance before the actual malfunction occurs. Simplified steps of maintenance and monitoring are shown in Figure 8.

1) Performing the right maintenance work at the right time: (Condition monitoring, inspection, maintenance)

2) Qualifications of the authors are ensured: (Operators, maintenance labor, services)

3) Clear process descriptions and work instructions.

4) Maintenance is recorded in the system database.

5) Operating experience is recorded in the system database.

6) Information is analyzed regularly and maintenance program is updated based on the experience.

Figure 8. Simplified steps of maintenance and monitoring. (Hannu S. Laine 2010, 39.)

It is essential to determine that monitoring is a guiding operation. Operating model needs information flow between condition monitoring and maintenance. Operating model is presented in Figure 9.

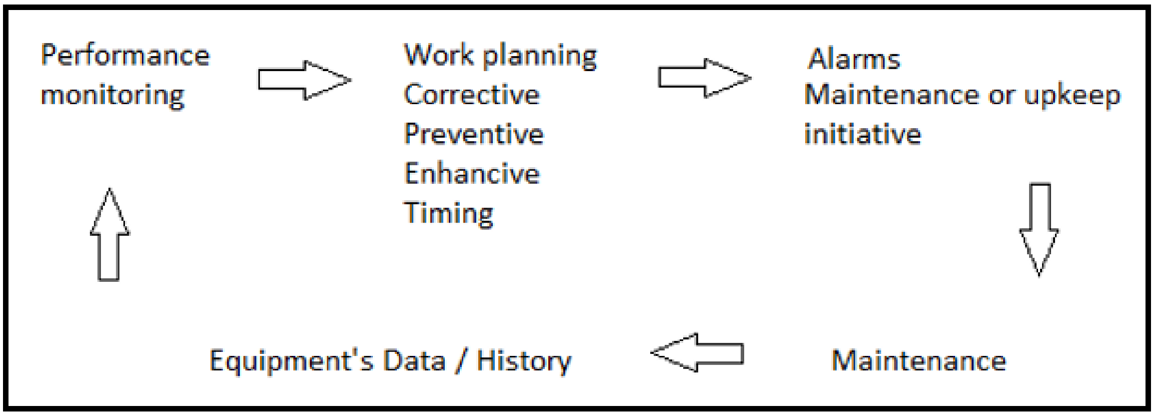


Figure 9. The operating model between condition monitoring and maintenance information systems. (Kunnossapitoyhdisys ry, 2004, 36)

Other common measurements are, for example, flow rates, temperatures and pressure measurements at various points in the process and voltage analyses. The results give an opportunity to compare the calculated and actual process efficiencies. (Kunnossapitoyhdisys ry, 2004, 17-23).

3 HEALTH, SAFETY AND ENVIRONMENT

3.1 Occupational health and safety

Occupational Health and Safety issues are part of a company’s management system. Industry field based organisations are increasingly concerned with HSE related risks. The safety factor is therefore increased to the top priority of all actions.

> *“The pressure equipment must be designed, manufactured, handled and used and inspected so that it does not endanger anyone's health, safety or property.” (FINLEX, 16.12.2016/1144 §5.)*

When a boiler operator is performing maintenance works with various subcontractors and various work labor, it is necessary to write contracts about who takes care of the work safety issues on the site and how the co-operation of the various parties is implemented. From the point of view of occupational safety, it is imperative that the various activities are timed correctly and that the communication between the organizations is functioning well. It is often appropriate to establish an occupational safety organization for a large site with the participation of as many as possible of the construction site working groups. During the projects, reviews and audits are held to assess the performance of safety practices. Standard requirements can be objectively audited. The aim is to detect hazards and take corrective and preventive actions. The organisation management shall demonstrate their commitment and ensure that persons in the workplace are also responsible for all the aspects. Appropriate education and training for personnel must be held to avoid risks. (BSI / OSHAS- Requirements 18001:2007.)

OSHAS 18001:2007 will be replaced by ISO 45001 standard during the year 2018.

OH&S management system model for this OHSAS Standard

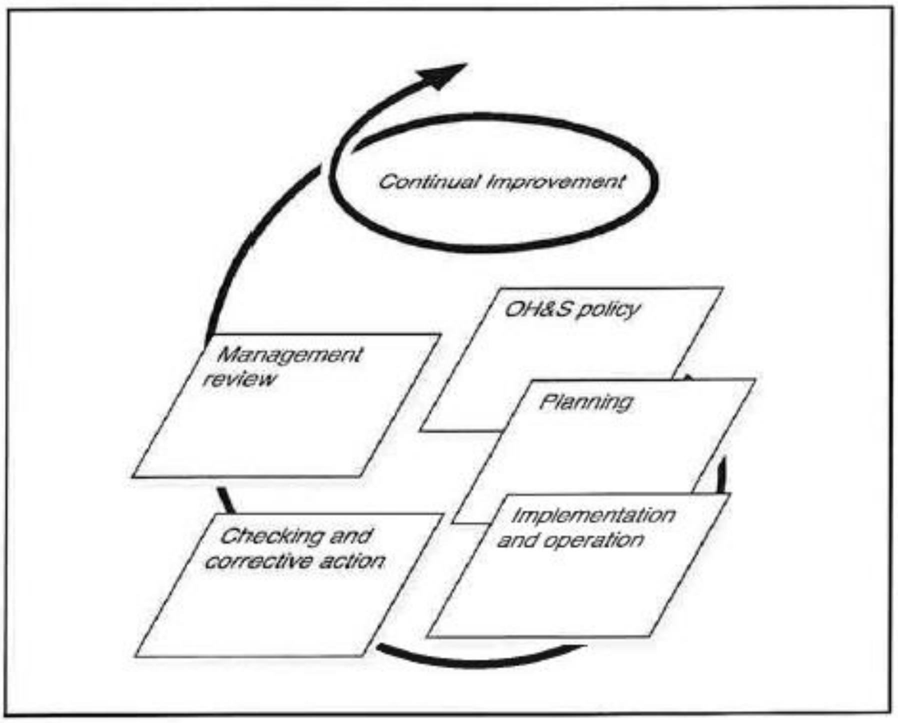


Figure 10. PDCA methodology (BSI / OSHAS- Requirements 18001:2007)

> *"Continual improvement has become also one major element in ISO 9000 quality standards"* (Hannu S. Laine 2010, 260).

3.2 Hazards in a power plant environment

One employee accident on a construction site costs about 8500 euros for the employer. Accidents at work cause absenteeism, or even life-span injuries. (Markkanen, Jussi 2011, 6). To avoid hazardous situations that may result serious injury or death, it is extremely important that everybody understands and follows all the safety instructions of the plant. The person who is performing maintenance for equipment, must read and understand the equipment's operation and maintenance manual. (Andritz archives, 2012).

In plant rules, it may be defined that the safety training must be completed, before entering the plant area. When entering the boiler, it must be certain that it is safe. Slag formations from upper boiler sections may fall suddenly and without any warning. Going in must be considered on a case-by-case basis and one person must be guarding at the door always. No one should ever enter the boiler alone and all access doors should be kept open during the shutdown. Access door sealings should be replaced at regular intervals. Poor sealings should be noticed during shutdown inspections.

De-Energizing and Lockout/Tagout equipment

> “The operations and maintenance of the electric devices should be assigned only to qualified personnel. Equipment motor disconnects and/or circuit breakers must be locked in the open (off) position. Shut-off, de-energize (bleed off pressure) and lock out all pneumatic and hydraulically operated components, steam systems and electrical circuits supplying power to control functions. De-pressurize all vessels and chambers associated with or connected to the equipment. Rotating elements and other moving parts must be firmly blocked to prevent unintended motion. The individuals performing the maintenance or inspection works shall personally place key-style padlocks on the equipment disconnects. Locks shall be utilized in a manner to guarantee the de-energized condition. Lock keys shall be retained only by the person placing the lock on the disconnect equipment.” (Andritz Oy’s archives, 2012).

Scaffolding

A significant part of the accidents at construction sites is caused by working from scaffolding. The scaffolding may only be erected, dismantled or modified by persons who are trained to operate them correctly and safely. The work area should be isolated from the environment. The access of third parties should be prevented by prohibition and warning labels. It should be ensured that all the required parts are available and that they are undamaged. Scaffolding workers’ work gear includes protective gloves, a helmet, eye protectors, safety harnesses and safety goggles as well attention vests. The base ground must be clean and flat. Commission inspection must be performed after erection together with the site representatives and a scaffolding card must be attached. (Laitinen Heikki, 2009).

Hot work

> “Working with ignition sources near flammable materials is referred to as "hot work." Getting a hot work permit before performing hot work is just one of steps involved in a hot work management program that helps to reduce the risk of starting a fire by hot work in areas where there are flammable or combustible materials.” (OSH, 2017).

Hot boiler parts are usually covered with insulation wool and cover plates that prevent burns from hot equipment parts. The insulation layer must be replaced when the insulation is damaged.

Chemicals

> "In order for a chemical to harm a person's health, it must first come into contact or enter the body, and it must have some biological effect on the body. There are four major routes by which a chemical may enter the body" (OSH, 2017).
>
> - Inhalation (breathing)
> - Skin (or eye) contact
> - Swallowing (ingestion or eating)
> - Injection

Some occupational hazards for the plant workers are shown in

Figure 11. Hazards for the plant workers. (OSH, 2017)

- Exposure to hazardous substances such as: lead, sulfur dioxide, asbestos, mould, adhesives, solvents, solder, and other toxic or carcinogenic substances.
- Exposure to biohazards including raw sewage when working on sewage pipes or septic tank outlets
- Working in awkward positions, or performing awkward manual tasks which increases the risk of musculoskeletal injuries.
- Lifting heavy or awkward objects.
- Exposure to electricity, extreme temperatures, or noise.
- Working in confined spaces.
- Risk of eye injury from flying particles.
- Slips, trips and falls, especially when working in wet environments.
- Burns from hot equipment parts, steam lines, and the release of hot water or steam.
- Working with various tools (both hand tools and powered tools).
- Stress.
- Shift work or extended work days.
- Working alone.

Figure 11. Hazards for the plant workers. (OSH, 2017).

The form in Figure 12. Presents possible hazards and key points to be noticed during daily plant actions.

RISKS AND ACTIONS:

- ☐ Confined space (work permit, measurements, isolation)
- ☐ Hot work (work permit, fire extinguishers, protection)
- ☐ Energy source isolation (LOTO)
- ☐ Gas leaks (detectors, ventilation)
- ☐ Slipping (washing, drying)
- ☐ Falling (railing harness)
- ☐ Electrical shock (isolation, grounding)
- ☐ Traffic (area isolation)
- ☐ Lifting (accessories, area isolation, lifting position)
- ☐ Scaffoldings (scaffold data card, fall arresters)
- ☐ Chemical spilling (isolation, protective equipment)
- ☐ Working on lower/uppers side (protection, working sequence)
- ☐ Radioactive radiation (equipment isolation)
- ☐ Constricting (supports)
- ☐
- ☐

PERSONAL PROTECTIVE EQUIPMENT:

- ☐ Helmet
- ☐ Safety glasses
- ☐ Safety shoes
- ☐ Ear protectors
- ☐ Visor
- ☐ Harness
- ☐ Cut protective gloves
- ☐ Chemical protective gloves
- ☐ Respirator mask
- ☐ Oxygen equipment
- ☐ Reflective vest
- ☐
- ☐

IN CASE OF EMERGENCY LOCATION OF:

- ☐ Emergency shower
- ☐ Eye shower
- ☐ Emergency stop button
- ☐ First aid kit
- ☐ Fire extinguishers
- ☐ Nearest worker
- ☐ Escape routes
- ☐
- ☐

Figure 12. A hazard identification form for the plant's daily actions. (Andritz Oy's archives).

3.3 Hazards to the environment

The main emissions for the environment that are formed in power plant applications are flue gases, noise, transportation of the fuel and ash, waste heat and waste water. Noise and emissions are generated both from the process itself and from the transportation. Typically for wood-based fuels, the economic transport distance is no more than 50 – 150 km. (Esa Kari Vakkilainen 2017, 59).

Table 1. Typical emissions from the combustion of woody biofuel, [mg/m^{3}n] (Esa Kari Vakkilainen 2017, 47).

Emission type	Bubbling fluidized bed combustion
CO_2	150,000 – 200,000
CO	100 – 250
H_2S	1 – 20
SO_2	30 – 150
NO_x	250 – 450
N_2O	4 – 8
HF	1 – 5
HCL	5 – 30
Dust, ESP	10 – 20
Dust, Fabric filter	1 – 5
Dioxins and furans	<0.0001

If biomass is burned efficiently, including wood, it is generally defined to be a “CO2 neutral” energy source. The natural growth cycle of all plants, including trees, fixes environmentally available CO2 within their cellular structure. When woody plants are burned, the recently stored carbon is released back into the “active” environment. Additional CO2 emissions are created as part of the fuel supply chain when the wood is processed and hauled to the biomass system. (Harald H. Welling, Thom J. Shaw, 2007, 10-11).

Boilers need to adhere to the EU Industrial Emission Directive (IED). (Esa Kari Vakkilainen 2017, 59).

4 INSPECTION METHODS

The reason for excess wall thinning can be found by combining the information from NDT-inspections, knowledge of different corrosion mechanisms and examined tube samples. Necessary information about the used fuel, air distribution, temperatures, water chemistry etc. is needed to find a solution on how to control the lifetime of the boiler. (VTT, 2016).

4.1 Non-destructive testing

NDT, Non-destructive testing is an inspection method, which is used for examination of metal structures, castings and welds without damaging the product.

Usually used NDT inspection methods are:

- Visual examination

Visual inspection is basic condition monitoring on accessible areas without any measurement tools.

- Radiographic inspection

“There are two different radioactive sources available for industrial use; X-ray and Gamma-ray. These radiation sources use higher energy level, i.e. shorter wavelength, versions of the electromagnetic waves. Because of the radioactivity involved in radiography testing, it is of paramount importance to ensure that the Local Rules is strictly adhered during operation.” (Twi-global).

The X- and gamma rays have ability to penetrate, travel through, and exit various materials such as carbon steel and other metals. (Andritz Oy’s archives).

- Ultrasonic inspection

Ultrasonic inspection techniques are based on the propagation of ultrasonic waves in the object. With the ultrasonic inspection method, it is possible to measure thicknessess and also to detect volumetric flaws. UT testing cannot detect creep damage. (VTT, 2016).

- Magnetic particle inspection

"Magnetic particle testing, or electromagnetic testing is the process of inducing electric currents or magnetic fields or both inside a test object and observing the electromagnetic response. If the test is set up properly, a defect inside the test object creates a measurable response." (International Journal of Scientific & Engineering Research)

The magnetic particle method is primarily used for carbon and other low alloyed ferritic steels. (Andritz Oy's archives).

- Liquid penetrant testing

"Liquid penetrant inspection is based upon capillary action, where low surface tension fluid penetrates into clean and dry surface-breaking discontinuities. Penetrant may be applied to the test component by dipping, spraying, or brushing. The penetrant may be applied to all non-ferrous materials and ferrous materials; although for ferrous components magnetic-particle inspection is often used instead for its subsurface detection capability." (International Journal of Scientific & Engineering Research)

- Replication

Surface replication is a NDT technique that can be used in the detection of both creep and graphitisation. This technique is limited to detecting only surface damages. For the purpose of detecting creep, it has been proven that replication is adequate – sometimes (where possible) deeper grinding is required in order to establish a more accurate picture of the damage profile. (Van Zyl, FH. 1996.)

When performing NDT inspections, it is advisable to also consider that:

- NDT test equipment is maintained and calibrated.
- NDT procedures meet the requirements.
- PED requirements are taken into account when the results are interpreted.

(Andritz Oy's archives).

4.2 Destructive testing

Destructive testing (DT) includes methods where the material is scattered in pieces so that the internals of the material can be examined. Destructive tests are usually used together with non-destructive methods. A combination of both methods gives the best information on materials and welds. (Studymode).

Benefits of Destructive Testing:

- Verifies properties of a material
- Determines quality of welds
- Helps to reduce failures, accidents and costs
- Ensures compliance with regulations (Studymode).

Destructive testing is also performed as part of failure examinations. Possible tube samples of removed and replaced tubes should always be inspected.

5 SCHEDULING & RESOURCES

A project is a time-bound entity. Time and resource management are closely tied together, a change in the other factor affects another. A good project design saves time, resources, and provides opportunities to avoid many problems. The clearer the project objectives can be opened and communicated to the work involved groups, and the better the project design can be implemented, the more likely the project will succeed. The project is typically due to the fact, that it does not have the right resources at the beginning of the project. To avoid this, each task should be assigned so that one person is also responsible for it. In the management of human resources, it is important to target the right, knowledgeable people to the right tasks and to provide them with the appropriate tools in a timely manner. Resources can be, for example, employees of own organization, subcontractors, machines, tools or repair components. Necessary labor resources and other tools should be reserved in advance to avoid any delays in actual shutdown. It is also possible, that resources are available too much, resulting in unnecessary costs for the project. In case of shutdown of a BFB boiler, the participation of other personnel, authorities and representatives of an insurance company or inspection organization must be ensured prior any actions are performed. (Mikko mäntyneva 2016, 41-56)

The following figure shows the components that are involved in scheduling and resourcing process.

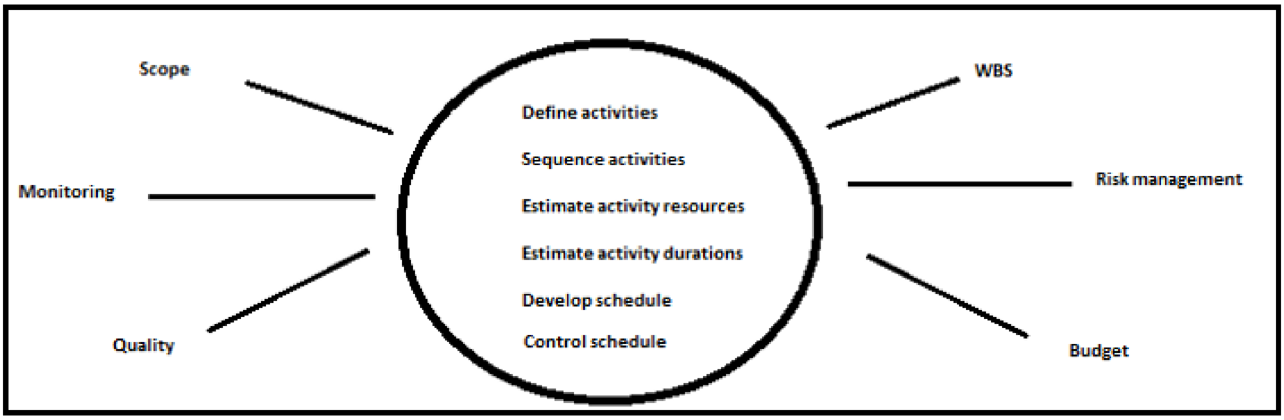


Figure 13. The main components of a project.
(Modified from Project management institute, 2008, 129).

It is most practical to make the spare part plan by categorizing parts by in criticality, therefore critical parts will have a higher availability priority. For the mill, the availability is best when the spare part is in its' own stock. (Hannu S. Laine 2010, 143.)

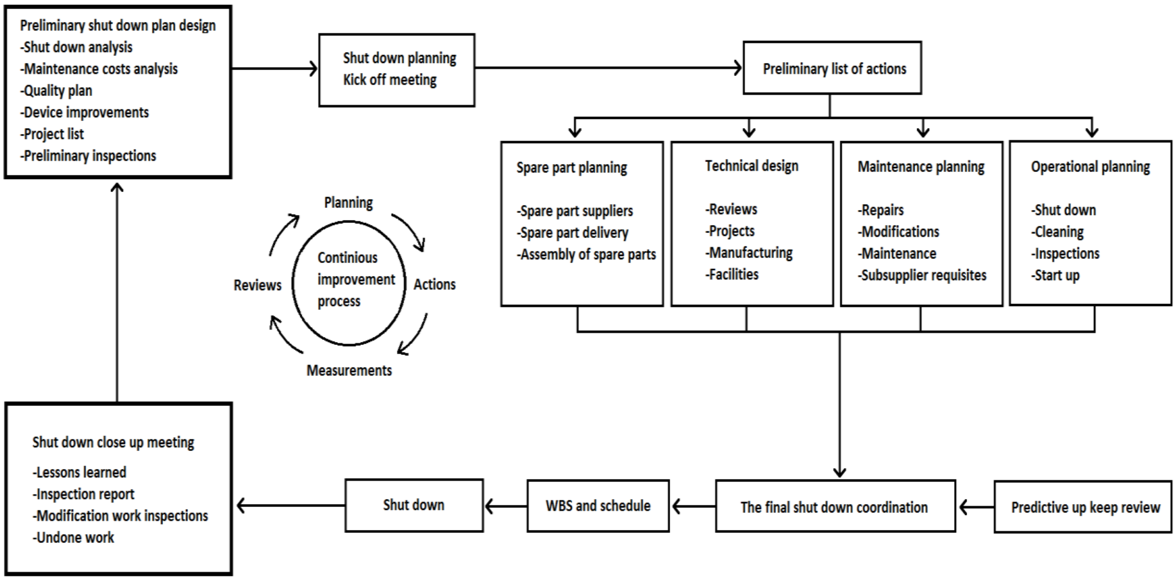


Figure 14. Shutdown planning process. (Hannu S. Laine 2010, 163)

6 BOILER INSPECTION & WEAR MECHANISMS

6.1 Boiler inspection preworks

Annual shutdown inspections include all the most urgent areas at that time. Special attention should be paid for especially for the areas that are expected to be problematic. In case worn parts were found during inspections, repairing actions are planned beforehand for the next year's shutdown. In case, the wear has already gone too far and malfunction is expected to appear in the near future, correcting actions must be performed within the prevailing time and resources. In this case the main focus is to keep the boiler running until the next possible shutdown. Correction may also be temporary. Case-by-case, it must be discussed with plant personnel, when it is possible to perform the next shutdown.

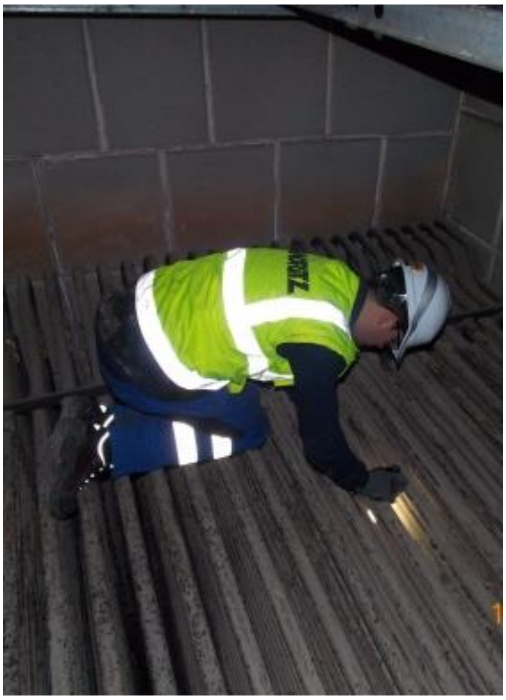


Figure 15. Visual inspection of tubes. (Andritz Oy's archives).

Visual inspections concern the mechanical condition of the heating surfaces and the main structure. When finding signs of mechanisms that may indicate to wear, it is recommended to use a systematic method when selecting the measurement points. Measurement results should be saved in a specific data collecting system. Inspection planning starts from analyzing the previous years' inspection results and overviewing the issues that have been the plant's main challenges during the last operational season. Prior to boiler inspection, when the boiler is cooled down, the bed material must be taken out from the furnace.

Removal of bed material

Bed material has to be taken out from the furnace, when temperature conditions allow. Bed material is taken out through bottom ash hoppers by using screw conveyors, located below the boiler. Furnace grid is emptied from sand and ash. The final cleaning of furnace grid can be done by industrial vacuum cleaner.

Scaffolding

Scaffolding installation usually takes 1-2 work days. Work time is based on actual size of the boiler. If scaffolding is not set, it is impossible to clean or inspect any areas above normal reach range. Scaffolding should be installed at each superheater section to the roof tubes, at the rear wall screen and at the vertical part of the boiler bank tubes. Furthermore, scaffolding can be installed in the ash hoppers and in the 2nd and 3rd pass. When scaffolding is set, the inspector and plant personnel must ensure that it is safe to operate. Boiler's lower part can be visually inspected before setting the scaffolding and the upper part when scaffolding is set. After the shutdown, when the scaffolding is being removed, all magnetic material and debris must be cleaned from the furnace. This must be done prior to start-up.

Cleaning of the boiler

It is highly recommended to reserve enough time for the visual inspection of a dirty boiler prior to cleaning. Visual inspection of a dirty boiler gives a good picture of the boiler operation and gives a possibility to monitor the slagging tendency. Cleaning is done by sand blasting, water wash is not suitable. If the superheater elements are very dirty and big boulders are hanging in between the elements, one possibility is to use an explosion method while the boiler is still running. 3rd pass cleaning should be scheduled for the last, because if the cleaning is performed vice versa, the latter parts will be dirty again afterwards and the result will be unwanted (The flue gas fan conveys a dirt towards the stack). After sand blasting, sand and ash are vacuum cleaned. (Modified from interview of Aki Karvonen, Andritz Oy)

6.2 WBS based operations

The following chapter presents some typical wear and fouling mechanisms and focuses on the internal structures of biomass utilizing BFB boiler.

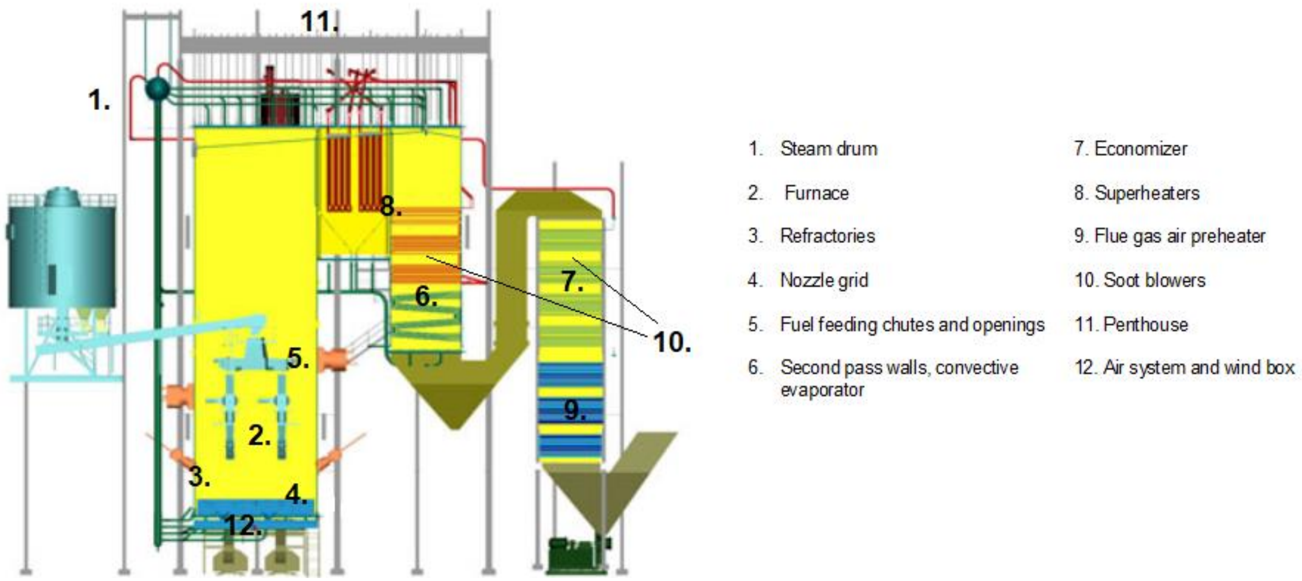


Figure 16. Areas that are presented in the following chapter. (Andritz Oy's archives)

Steam drum

Steam drum is the place where the physical separation of water and steam occurs. The steam exits trough the main steam line at the top of the drum. Boiler water and condensate flow trough unheated downcomers to the boiler wall headers. (Brad Buecker, 2002, 6) The steam drum doors can be opened for inspection when the inside temperature is around 70 °C degrees. Ejectors may be installed to speed-up the cooling process. The internals of the drum can be inspected, when the inside temperature is suitable for going in. Nothing should be dropped into downcomers and they should be covered to prevent this. The passive layer in the drum shell should be covered by a grayish magnetite layer. The color of the internals may be also reddish. The inspector seeks for deposits. A damaged magnetite layer may be due to a too fast boiler start up. Rusty areas in the drum internals can be a result of changes in water chemistry during operation or preservation. In that case, it is recommended to pay attention to the boiler's water oxygen content and pH - value. (Andritz Oy's archives)

Furnace

The inspection in the furnace area focuses on analyzing the burning conditions. Tubes may wear due to corrosion, erosion, or their interaction. Too far advanced wear will reduce the tube material and eventually this will become a pipe leak and result in a boiler’s unplanned shutdown. If any scratches, erosion or abnormality is noticed, the reason must be clarified. All boiler wall openings and start-up burners should be inspected visually. The condition and the remaining lifetime of refractories around the openings can be estimated and reported.

Bed sand particles or unburned material from the fuel mixture combined with high air velocity is one major factor in wearing tendency. Bed sand particle size may vary between 1,0 - 3,0 mm. A bigger particle size means more impacts towards tube surfaces (Abrasive erosion) and increased air demand for fluidization. Smaller sand particle size reduces the ability to keep the furnace temperature stable and may cause overheating.

Normally, boilers have extra oxygen to help fuel burning. This oxygen will also protect surfaces against corrosion by forming a protective oxide layer. Certain fuel mixtures or boiler operations may cause reduction in oxidation reaction locally. The protective oxide layer will break by reduced oxygen and heat-surface material begins to react with flue gas components. Corrosion detection due to deposits on tube surface is difficult and even impossible. (Buecker B. 2002, 106).

In the furnace area, corrosion may also be caused by ammonium. Ammonium corrosion can be noticed usually first beside the ammonium openings. Ammonium corrosion looks like scratches that are caused by mechanical impact, seen in figure Figure 17.

Figure 17. Ammonium corrosion. (Andritz Oy's archives)

Wear mechanism: Creep

Upset in burner operation, rapid load increases, poor design, and other factors will affect the boiling process and may induce a “departure from nucleate boiling” (DNB) that alters the cooling effects of the boiler water. Areas are affected under higher temperatures than originally designed. “Creep” may then set in with eventual tube failure as a result. Internal tube deposits also restrict heat transfer and may cause similar tube failures. (Brad Buecker, 2002, 29).

> “Creep is the primary life limiting mechanism on high temperature and pressure components. Creep evaluation is currently achieved by surface inspection of microstructure (replicas) during maintenance.” (VTT, 2016).

Boiler tubes, supports and other components are designed to withstand creep, and when equipment is kept clean and in good condition, creep is usually not serious. Obviously, as temperature increases, metal strength decreases. Consequently, stress and temperature changes may cause deformation in structures, even though the steel grades have been alloyed with additives to withstand such conditions. The other typical wear mechanism is fatigue. During boiler start-ups and shutdowns, the boiler metal expands and shrinks. Over time, these cycles can cause failures in such locations as boiler buckstays and tube supports. (Brad Buecker, 2002, 105-106).

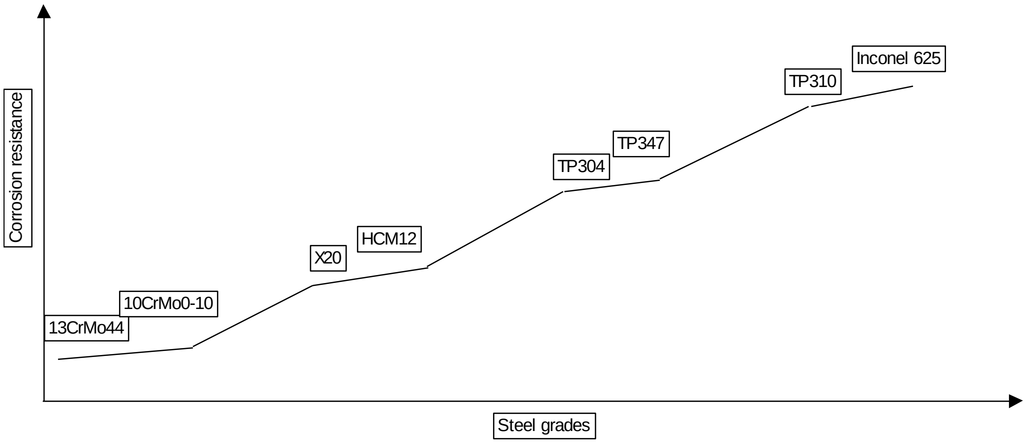


Figure 18. Corrosion resistance of materials. (Pasi Makkonen, VTT).

Tube materials with high chromium content ensure good resistance to corrosion and erosion caused by aggressive fuels. The price of the tube materials increases likely in the Figure 18. Inconel welding, seen in Figure 19 is done for abrasion and corrosion reasons.

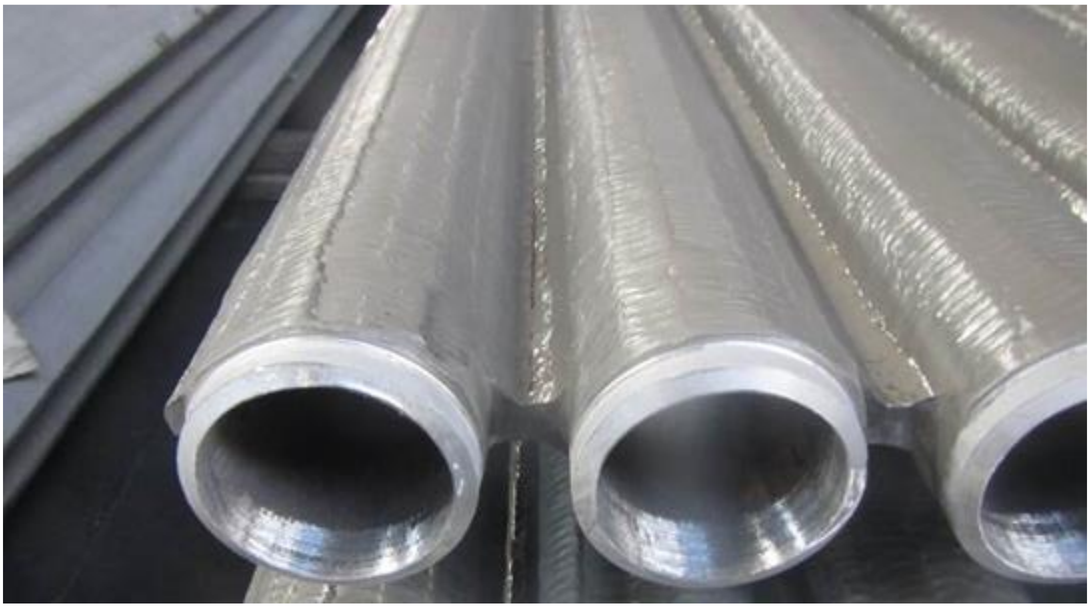


Figure 19. Overlay welded tube wall element.
(Andritz Oy's archives).

Welding presents also one potential problem, especially where two different metals are joined. The two metals have different coefficients of expansion, which places stress upon the weld during temperature changes. (Brad Buecker,2002, 107). The boilers are designed so that thermal expansions in general are taken into account. The boiler is usually hanging from the suspension rods and there is free space around it for expansion, also critical duct connections are made flexible.

Fouling mechanism: Slagging

Slag formation is directly influenced by the fusability properties of ash. The combustion zone of the boiler is the highest heat area, and ash is often molten in this region. (Brad Buecker, 2002, 74). The changes in sand consumption may indicate boiler slagging tendency. Boiler's sand consumption divided by to fuel input megawatt hours can be calculated. Usually the higher the sand consumption is the less slagging there will be. If there are changes in the used fuel, the existing gradient might not be sufficient, which will result in increased slagging.

Figure 20. Slag formations on boiler wall tubes. (Andritz Oy's archives).

Refractories

BFB boiler's lowest tube sections are protected with refractory blocks to minimize the erosion effect of the fluidizing bed sand. The inspector checks the main condition of refractories. Minor cracking is normal and does not cause any actions. Bigger crackings may let the block loose. Sand may push in between the blocks and wall tubes. Areas where cracks are the widest, can be patched. The boundary line between refractories and wall tubes may be the spot to find erosion marks.

Nozzle grid

The Inspector seeks for sintered pieces, damages or signs of erosion from air nozzles, clocked air holes or slag around them. Clogging of the nozzles may also cause problems. Because of the reduced flow area, the velocity of air must be increased. In-leakage of sand into the Hybex beams can be caused by damaged or missing heads of the air nozzles. The condition of temperature elements should be noticed. Replacement is required, if the probe is damaged. Deviations in grid condition can be detected by analyzing the pressure load curve of the fluidizing air.

Fouling mechanism: Sintering

Alkali metals (Na, K) in the fuel react in the boiler and sand particles form alkali silicates. The surface will become sintered, particles will stick together. It is necessary to keep the bed temperature in combustion operation below the melting point of the ash to avoid sintering. The melting point of ash varies depending on the composition of the fuel. Depending on fuel transport and treatment, a large part of the biomass ash can be contaminated by soil that entered the furnace along with the biomass fuel. Silica content is dependent on the level of soil within the fuel. (Esa Kari Vakkilainen, 2017, 36,187)

Figure 21. Sintered material. (Andritz Oy's archives).

Fuel feeding chutes and openings

The fuel chutes should be emptied and cleaned prior to the inspections to enable proper examination. The Inspector should pay attention to the worn inner bottom plates and walls of the fuel chutes. Minor deformations are typical. Refractories around the fuel feeding openings may gather some slag formations, but the main concern is that refractories are not damaged.

Second pass walls and convective evaporator

Second pass walls must be inspected visually. The inspector notes the mechanical condition of the tubes and the thickness of the slag layer. If any scratches, erosion or abnormality is noticed, the reason should be clarified. Special attention should be paid to the areas where the flow of flue gas is changing. For example, sand leaks may be found. Sand leaks can be caused by thermal stresses and thermal expansions of the joints.

The condition of convective evaporator's and second pass walls' inlet and outlet headers should be inspected visually as well.

Economizer

Economizer is used to extract additional heat from the flue gas and transfer the energy to the feed water. Economizer tubes may be finned to provide additional heat transfer, although the fins increase the potential for fly ash accumulation. (Brad Buecker, 2002, 15). Economizer packages and headers should be inspected visually during the boiler inspection. Inspector seeks for any signs of damage. Tubes are usually covered with a layer of dust or even a slight slack layer. If any wear due to erosion is found, thickness measurements can be performed.

Superheaters

Superheaters are a series of tubes placed within the flue gas path of the boiler, the purpose of which is to heat the boiler's steam beyond saturated conditions. The common method of steam temperature control is attemperation from a spray of feedwater introduced directly into the steam. Two general categories of superheaters are radiant and convective. Radiant superheaters are exposed to radiant energy in the furnace, while convection superheaters sit further back in the gas passage and are shielded from radiant heat. (Brad Buecker, 2002, 11-14). During the boiler inspection, the superheater elements' condition is visually inspected. Superheater elements must be straight and aligned and properly fastened to the claws. Soot blowing shields should be firmly attached. Broken ties can be repaired during the shutdown. Tube surfaces are usually covered by a slag layer. In case any clean areas are found on tube surfaces, erosion may occur. Running the boiler at higher load increases the volume of flue gas, which also has a lower density due to the higher outlet temperature. The result is increased flue gas velocities that can cause erosion. The reduction in material thickness can be monitored and recorded. Hot corrosion is a typical wear mechanism for superheaters.

Fouling of superheaters

Fouling means the reduction of heat transfer when tubes get covered with ash deposits (Esa Kari Vakkilainen, 2017, 182). Fouling is most prominent in the convection pass of the boiler, primarily in the superheater and reheater areas. Fouling is caused by the deposition of fly ash particles on tube surfaces. Combustion generates volatile alkali compounds of sodium and potassium, which condense on tube surface and ash particles, giving them much stronger adhesion tendencies. Ash fouling of superheater tubes is a major concern during the operation of a boiler, it reduces heat transfer efficiency. Typical sticky alkali compounds are alkali silicates or salts (primarily chlorides). These alkalis vaporize during the combustion process and form the oxides Na_2O and K_2O. The fouling tendency can be decreased by boiler designing, the tube spacing should be wide enough. Too tight superheater spacing may lead to clogging. Efficient and frequent soot blowing possibility should be provided. Also adding chemicals to flue gas is one possibility. (Brad Buecker, 2002, 79)

> "Boilers that incenerate solid fuels have a high fouling tendency, whereas those that burn liquid fuels (particularly refined oils) have a low fouling tendency. Maintaining the boiler at peak efficiency requires keeping the boiler surfaces as clean as possible. Tests show that a soot layer just 0.8 mm thick reduces heat transfer by 9.5 % and a 4.5 mm layer by 69 %. As a result, the flue gas temperature rises – and so does the fuel consumption, which will affect to energy costs." (NRCan's)

Wear mechanism: Hot corrosion

> "Hot corrosion is formed so that the aggressive elements of the fuel react with the ash and form low melting point compounds. When the ash smelts, the oxide layer protecting the heat surfaces are destroyed and the corrosion-promoting components will react to the heat surface material." (Outokumpu, 2009.)

Figure 22. Hot corrosion on SH tube surfaces. (Andritz Oy's archives)

Flue gas air preheater

Flue gas air preheater piping may be contaminated by sand and ash. Air preheater's cold end tube surfaces should be inspected. In this area, low temperature corrosion may be the problem. To prevent this, cold end material temperatures should be raised above the acid dew point temperature.

Wear mechanism: Low temperature corrosion

> "Low temperature corrosion is a corrosion form, that occurs in the flue gas temperature below the dew point. The sulfur in the flue gas transfers from a gaseous form to sulfuric acid droplets that condences to the tube surface causing corrosion." *(Huhtinen M., Kettunen A., Nurminen P., Pakkanen H. 2000).*

Soot blowers

Soot blowers are used to clean the boiler walls, superheaters, economizers and air pre-heaters during the boiler operation. Soot blowers can cause erosion, if they are adjusted to feed too high pressurised steam or used too often. Condensate draining faults may cause erosion as well. Tube surfaces near the soot blowers are usually equipped with soot blowing shields. Soot blowing shields should be attached firmly on their place. Inspector ensures soot blowers' right alignment and operation.

Penthouse

The inspector seeks, for example, ash leakages. The bolts of pipe's hanger rods should be attached tightly. Ash leakages and porosities can be fixed by welding during the shutdown. Penthouse should be vacuum cleaned and kept clean.

Air system and wind box

Primary air duct below the boiler should be inspected visually. The general condition of the wind box and the vanes that guide the primary air to the wind box should be ensured. Scrap material from the duct should be removed. Wind box should not have sand inside. If the sand occurs, the reason for a leak must be detected and prevented.

After the inspection

Reporting means examination of the observations and writing the actual inspection report for the plant owner. Reporting gives a good overview of the boiler condition, and it is also a part of planning the actions to be done for next shutdown. It contains recommendations for daily operations and maintenance actions that should be taken into account.

7 LEGAL REQUIREMENTS FOR PRESSURE VESSEL REPAIR WORK

7.1 Repair work in general

The power plant process devices should be selected based on satisfactory expected life span and acceptable maintenance costs. The process devices must be placed so that it is accessible for inspection and repair. (Esa Kari Vakkilainen, 2017). Proper packing and lifting instructions of spare parts should be clarified. If component is planned to be preserved somewhere near site, the conditions (weather, safety etc.) must be taken into account. When choosing a right company for pressure part manufacturer, it must be ensured, that the company has sufficient expertise and qualifications including conformity Insurance with CE mark basics. Operational instructions should be translated to local language and technical documents should be included to the delivery. (Andritz Oy's archives)

7.2 Notified body

A notified body (NoBo or the 3rd party) is an organisation designated by an EU country to assess the conformity of certain products before placing them on the market. These bodies carry out tasks related to conformity assessment procedures set out in the applicable legislation, when a third party is required. The European Commission publishes a list of such notified bodies. (Notified Bodies; Consultation on Regulations and proposed technical parameters). Repair, installation or modification work of pressure equipment may be performed, if the manufacturer's instructions are followed and welding procedures are provided and If NoBo approves it as a safe work. NoBo supervises the implementation of the system and makes the agreements of the inspections and evaluates the risk factors with the owner. The purpose is to meet the legal requirements. (FINLEX). The most practical way to prove the conformity is to follow EN-standards. The most common standard in Finland is SFS-EN. Conformity assessments are to be made by NoBo every time, when Pressure part's characteristics are changed from the original. All spare part manufacturing processes must follow the European Pressure Equipment directive's (PED) instructions.

Documentation of repair is to be sent to the 3rd party – to get approval of a declaration of conformity for the project is:

- Repairing report and photographs
- 3rd party inspection reports
- Validation of welding chemicals – test report
- Welder qualification test certificates
- NDT inspector certificates
- Welding procedures

Approved documents will be forwarded to the customer.

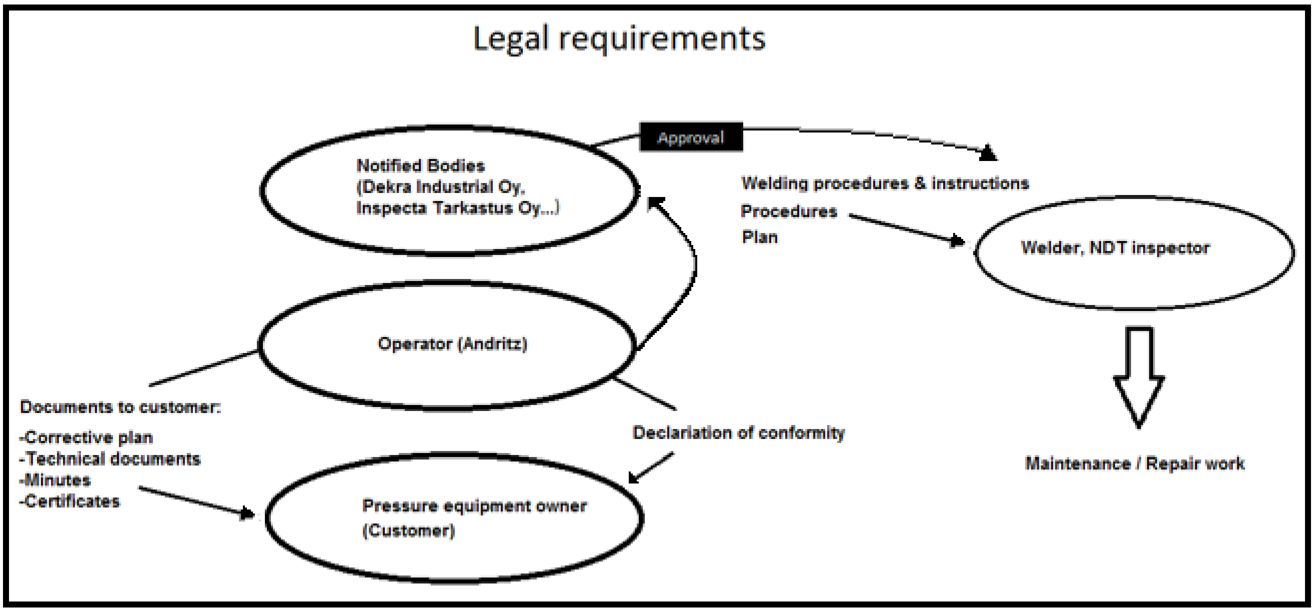


Figure 23. Legal requirements of pressure vessel repair work.

7.3 Specification of welding procedure

Welding Procedure Specification (WPS) is a document that describes how welding is to be carried out in production. Company's welding coordinator is responsible for welder's qualification and good welding practice is based on a company's quality management system. Qualifications for welders and welding methods must be ensured prior to any actions. An approved plan and welding instructions must be including to pressure equipment's design data. The technical content of welding instructions must follow the standards. This rule can differ from individual cases, for example emergency works. (Itis Welding Procedure Specification Services ; Inspecta ISO).

8 CONCLUSIONS

The main objective of the project was to create a project controlling tool. It was possible to utilize Andritz Oy's extensive maintenance instructions and published technical studies of BFB boilers' repair works. Over 40 inspection reports were reviewed in the research process. Development for procedures was therefore achieved by combining results of published studies. Plan gathers together all necessary variations, that can be customized to meet the requirements of up coming shutdown. Making the lists of maintenance related tasks was necessary. BFB boiler's equipment lists and parts' individual lifetime replacement plan was presented by Aki Karvonen in 2011 (Master's thesis was made for Andritz Oy: Productisation of maintenance business, Lappeenranta university of technology).

It has been very instructive to work in co-operation with engineers for the past two years in the case company. In my opinion the need for changing the current operation methods in the case company is not really needed. The established practices have worked for a long time and the quality management system is already on a professional level. Still developing the performance and safety features is necessary (Continious improvement steps). The thesis included only biomass boiler applications, but in the future, the case company's plan is to expand the scheduling and resourcing plan to concern also the alternate and the residue fuel concepts. It would be interesting to see how effective the planning can really be in practice. At least unnecessary working hours and idle time could be avoided. In shutdown maintenance, it is necessary to estimate the loss of production caused by one shutdown day delay. Shortening the shutdown by a day could save a lot of money. Secondly, trying to perform a boiler start up rapidly after the shutdown, can cause serious damage to the boiler internals. In this case, the saving in time is not a saving in money. The more critical the time goal for the project is, the more careful planning and scheduling must be performed.

The plant's down time could be minimized by designing the shutdowns in a way that there are enough professional labor resources reserved for maintenance actions and by making sure that every single spare part and tool is available right from the beginning. Management of the project controlling is a key for successful site operations. By following the uniform and standardized working practises and ensuring the information flow for all representatives and parties involved, it is possible to keep also hazards on an accepted level.

The same subcontractor companies that are involved in shutdown actions repeatedly will learn the needs and practices of the commissioning organization, therefore it is possible to reduce subcontractor guidance. Whenever each subcontractor and supplier is required to make separate assignments and contract negotiations, a lot of working time is required. If the co-operation agreements are already concluded with subcontractors, substantial working time will be saved. (Mäntyneva M, 2016)

The management of maintenance operations is mainly based on knowledge of the methods of faults. Identification of most common failure types enables the correction of faults before it is too late. Weak or problematic areas will usually be found after a few years of plant operation. Coherent treatment cannot be performed for every plant because every plant is tailormade and therefore has its own operational characteristics.

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