महाराष्ट्र शासन

Technical Literature

BOILER INDIA 2024

SEPT 25|26|27

CIDCO Exhibition & Convention Centre

Vashi, Navi Mumbai

BOILER®
INDIA 2024

CIDCO Exhibition & Convention Centre

Directorate of Steam Boilers
Maharashtra State

BOILER INDIA 2024

CIDCO Exhibition & Convention Centre

It gives me great pleasure to extend my best wishes for this important and prestigious 'Boiler India 2024' event. Boiler industry is important for the industrial progress not only of the state but also of the entire country. I hope that 'Boiler India 2024' will bring together industry experts, researchers, innovators and professionals to discuss technology developments, innovations and future challenges.

In my opinion, this program is a model not only of technological progress, but also of maintaining the highest standards of safety in the industry and reducing carbon emissions. Maharashtra has always been committed to industrial safety, efficiency and sustainability, the use of these carbon credits in the boiler industry is an effective measure to protect the environment and reduce carbon emissions. I am sure that Boiler Industry will take advantage of this opportunity for large scale industrial development in Maharashtra.

With the cooperation of all of you, I am confident that we will make this program a success and take this industry to new heights.

With best regards,
Eknath Shinde,
Chief Minister, Maharashtra State

Directorate of Steam Boilers
Maharashtra State

BOILER INDIA 2024
CIDCO Exhibition & Convention Centre

It gives me great pleasure to extend my best wishes for this important and prestigious event ‘Boiler India 2024’. As the Deputy Chief Minister of Maharashtra, it is an honor for me to be a part of this event. The boiler industry is vital for the industrial progress of Maharashtra and the country, and the exchange of new technologies and ideas in this sector is certainly appreciable.

Advances in the boiler industry are an important part of the safety, efficiency and sustainability of the industrial sector. ‘Boiler India 2024’ will be an ideal platform to bring together industry experts, innovators and professionals to share knowledge, skills and experience.

The state of Maharashtra has always been at the forefront of industrial development, and we are always ready to promote technological development, safety, and environmental sustainability in this sector. I am confident that this program will spur both innovation and excellence in the industry.

Using green fuels in boilers can contribute significantly to the protection of the environment. On this occasion I appeal for maximum use of green fuels like Biogas, Biodiesel, Ethanol, Green Hydrogen, Pellets to achieve sustainability and eco-friendliness in boiler industry in Maharashtra state.

Heartiest congratulations to the organizers, participants and technology presenters of this exhibition. There is no doubt that your participation will be important for the industrial progress of Maharashtra and the country.

I am confident that with the cooperation of all of you, this program will be successful and will take the boiler industry to new heights.

With best regards,

Devendra Fadnavis

Deputy Chief Minister, Maharashtra State

Directorate of Steam Boilers

Maharashtra State

BOILER INDIA 2024

CIDCO Exhibition & Convention Centre

It gives me great pleasure to extend my best wishes for this important industrial festival 'Boiler India 2024'. As the Deputy Chief Minister of Maharashtra, it is an honor for me to be a part of this important event. The boiler industry is the backbone of the industrial sector, and technological advancements and innovations in this sector are crucial for the industrial development of Maharashtra.

The platform 'Boiler India 2024' is a unique platform to bring together various experts, entrepreneurs and innovators to share their knowledge, skills and experience. The exhibition will highlight the latest technologies, safety measures, and environment-friendly measures in the boiler industry, which are essential for the bright future of the industry. The state of Maharashtra has always been at the forefront of the industrial sector, and our commitment to promoting safety, efficiency, and sustainability in this sector will always remain strong. Through this programme, I am confident that innovation and technological excellence in the industry will gain a new dimension.

Heartiest congratulations to the organizers, participants, and technology presenters for the successful organization of this event. Your participation will be a valuable contribution to the industrial development of Maharashtra and the country.

I strongly believe that with the cooperation of all of you, this program will be successful and will give a new direction to the boiler industry.

With best regards,
Ajit Pawar
Deputy Chief Minister, Maharashtra State

Directorate of Steam Boilers

Maharashtra State

BOILER INDIA 2024

CIDCO Exhibition & Convention Centre

It gives me great pleasure to extend my best wishes for this important and prestigious industrial event 'Boiler India 2024'. In this series Boiler India – 2020, Boiler India – 2022 as well as Boiler World – 2023 in Kenya and now Boiler India – 2024, the department is certainly proud to organize seminars on "Safe and Efficient Use of Boilers". The boiler industry is an important component of the industrial sector, and progress in this sector contributes significantly to the industrial development of Maharashtra.

The platform 'Boiler India 2024' provides a unique opportunity to bring together various experts, industry leaders and innovators to share their experiences, knowledge and technical expertise. The event will discuss the latest advancements in boiler technology, safety measures, and sustainability innovations, which will provide an opportunity to take the industry to new heights.

The state of Maharashtra has always emphasized on safety and efficiency in the industrial sector. We have always been committed to worker safety, and I am sure that this program will further boost our efforts in this direction.

Heartiest congratulations to the organizers, participants, and all the wellwishers for the successful organization of this event. Your participation will surely give a new direction to the industrial progress of Maharashtra.

I strongly believe that with the cooperation of all of you, the program 'Boiler India 2024' will be successful and will set a new benchmark for the development of the boiler industry.

With best regards,

Suresh (Bhau) Dagadu Khade

Minister, Labour, Maharashtra State

Directorate of Steam Boilers

Maharashtra State

As Principal Secretary, Labor Department, State of Maharashtra, I recognize the vital role of this sector in promoting industrial growth, ensuring safety and promoting sustainable development. Boiler India 2024 is a flagship program that is a testament to the global potential and innovation of the boiler industry and is followed not only in Maharashtra but across the country and abroad.

The boiler industry is fundamental to the infrastructure of various industries and its progress is directly linked to the progress of the nation. Boiler India 2024 provides a unique platform where industry experts, innovators, business think-tanks come together to showcase cutting-edge technologies and address the evolving challenges we face in this sector.

Safety and efficiency are of utmost importance in boiler operations and the Labour Department is committed to maintain the highest standards in this regard. This program provides opportunities to enhance boiler regulation, promote best practices, and ensure safety of all workers involved in the industry.

The main objective of this workshop is to guide the boiler users in a comprehensive manner on the measures to be taken to prevent boiler accidents, the benefits of using new technology, the efficient use of boilers. This will also helpful to facilitate communication between all boiler and boiler component manufacturers and boiler users and to achieve the growth of boiler industry.

I am confident that Boiler India 2024 will act as a catalyst for further innovation and collaboration and take this industry to greater heights. The exchange of knowledge and expertise in this program will undoubtedly contribute to the continuous improvement of safety standards, operational efficiency and environmental sustainability in boiler technology.

I sincerely appreciate all the organizers, exhibitors and participants who came together to make this event a success. Your collective efforts will not only shape the future of boiler industry but also strengthen the industrial movement of our state and country.

I urge all delegates to take this opportunity to pave the way for a more secure and brighter future.

Smt. Vinita Vaid Singal (I.A.S),
Principal Secretary, Labour Department,
Maharashtra State.

Directorate of Steam Boilers

Maharashtra State

BOILER INDIA 2024

CIDCO Exhibition & Convention Centre

Boiler India 2024 is a premier event bringing together the global boiler industry on a single platform. As Director, Directorate of Steam Boilers, Maharashtra State, I am privileged to be a part of this endeavor, which sets benchmarks in the industry at the confluence of innovation, technology and knowledge-sharing.

Since 2020, Boiler India has set an exemplary example of how to inculcate industrial development and safety as an important and integral element in the industrial sector. The efforts of the organizers is immensely appreciable which showcase the latest advancements in boiler technology, fostering collaboration and addressing challenges faced by the industry.

The Boiler India 2022 event received an unprecedented response from the commercial sector and the Boiler India exhibition has played a fundamental role in making India a global platform for Boiler manufacturing.

This 3rd edition of Boiler India shows a commitment towards excellence in manufacturing, empowerment of users and skilled manpower with a diverse range of exhibitors, insightful seminars and interactive workshops. It is a great opportunity for industry stakeholders to learn new technologies and best practices and interact directly with peers from around the world.

Best Boiler User Competition is organized to encourage Boiler Users to operate Boilers in the safe and efficient manner, to improve the skills of boiler operation and to promote the prevailing best operating practices. The main objective of organizing this competition is to achieve integrated development by promoting and spreading the use of accident free and efficient Boilers. This helps to increase the skills of boiler operation by increasing competition among boiler users.

I extend a warm welcome to all the participants, exhibitors and delegates. I believe that Boiler India 2024 will contribute significantly to the progress of our industry and will certainly stimulate new opportunities in the industrial sector.

Let's all make this program a grand success, leading the industry to a safer, more efficient and sustainable future.

Jai Hind! Jai Maharashtra!

Dhawal Prakash Antapurkar,
Director, Directorate of Steam Boilers,
Maharashtra State

CONTENTS

Full Name: Onkar Singh Saini

Company Name: Thermax Babcock & Wilcox Energy Solutions (TBWES) a Thermax Ltd. company

Designation : Group Head- After Sales Support

Educational Qualification: B.E. (Electrical); PGD Business Management

Education Institute Details: Nagpur University, Symbiosis University

Current Job Profile: Heading After Sales Support function for TBWES

Experience : 23+ years of experience in power plant

Achievements:

a. Development of Single button start & stop logic for FBB boiler reducing dependence on operator

b. Development of IoT solution for the boiler

c. Development of Fuel Cost Calculator

BOILER FUNCTIONAL SAFETY MANAGEMENT: ADHERENCE TO STANDARD OPERATING PROCEDURES (SOP) DURING SHUTDOWN AND CHEMICAL CLEANING

Introduction

Boilers are critical components in various industrial processes, providing the necessary thermal energy for operations such as power generation, heating, and manufacturing. Boilers are also inherently complex and potentially hazardous systems hence the management of functional safety in boiler operations by adherence to standard operating procedures (SOPs) is paramount to ensure the protection of assets, continuity of operation, the environment, and human life.

This topic focuses on following of Standard Operating Procedures (SOP) during shutdown and chemical cleaning of the boiler.

Importance of SOPs during Shutdown and Chemical Cleaning

- **Safety:** SOPs provide step-by-step guidance, minimizing the risk of human error and accidents.
- **Efficiency:** Adherence to SOPs streamlines processes, reducing downtime and improving overall efficiency.
- **Compliance:** SOPs often align with industry regulations and standards, ensuring compliance.

Shutdown Procedures

The shutdown of a boiler system must be conducted methodically to prevent any hazardous situations. The process typically involves the following steps:

1. Gradual reduction of load and firing rate.
2. Isolation of the boiler from the process by closing valves.
3. Shutting off the fuel supply and ensuring the cessation of combustion.
4. Depressurization of the system.
5. Draining of the boiler and associated piping.

Allow the boiler to cool down to a safe temperature before starting any cleaning activities.

Chemical Cleaning

Chemical cleaning of a boiler is performed to remove scale, corrosion products, and other contaminants that can impair the boiler's performance and safety. The procedure usually includes:

1. Selection of appropriate chemicals for the cleaning process.
2. Preparation of the boiler by removing safety valves and ensuring the system is isolated from the process.
3. Circulation of the cleaning solution through the boiler.
4. Rinsing and neutralization of the cleaning chemicals.
5. Restoration of the boiler to operational status.

Safety and Compliance

Throughout the shutdown and chemical cleaning process, it is imperative to follow the SOPs to maintain safety. This includes:

- Regular monitoring of the boiler's parameters.
- Ensuring all safety devices are functional.
- Strict adherence to the manufacturer's guidelines and industry standards.
- Documentation of all procedures and any deviations from the SOPs.
- Training of personnel in the proper execution of the SOPs.

How to develop effective SOP's??

1. **Risk Identification and Assessment**

- **Hazard Analysis:** Identify potential hazards that could arise during boiler operation, shutdown, and cleaning.
- **Risk Evaluation:** Assess the likelihood and impact of these hazards to prioritize safety measures.

2. Safety Protocols and Procedures

- **Standard Operating Procedures (SOPs):** Develop and implement SOPs for all boiler-related activities, including emergency procedures.
- **Safety Controls:** Install and maintain safety controls such as pressure relief valves, alarms, and automatic shutdown systems.

Key contents of SOPs for Shutdown and Chemical Cleaning

1 **Shutdown Procedures:**

- **Isolation**: Ensure isolation of the boiler from the steam distribution system to prevent steam leaks.
- **Cooling**: Gradually cool the boiler to prevent thermal shock and damage.
- Pressure Relief: Ensure safe venting of residual pressure.
- **Lockout Tagout:** Implement proper lockout procedures to prevent accidental startup.

2 **Chemical Cleaning Procedures:**

- **Chemical Selection:** Choose appropriate cleaning chemicals based on boiler type, scale composition, and operating conditions.
- **Concentration:** Prepare the cleaning solution at the correct concentration to avoid over- or under-cleaning.
- **Circulation:** Ensure proper circulation of the cleaning solution to ensure thorough cleaning.
- **Personal Protective Equipment (PPE):** Ensure all personnel wear the necessary PPE, such as gloves, goggles, and protective clothing.
- **Ventilation:** Maintain adequate ventilation to prevent the buildup of hazardous fumes.
- **Monitoring:** Continuously monitor the chemical cleaning process to detect any leaks or abnormal conditions.
- **Neutralization:** Neutralize the cleaning solution to prevent corrosion and ensure safe disposal.

3 Post-Cleaning Procedures

- **Inspection:** Conduct a thorough inspection of the boiler to ensure all cleaning residues are removed and there is no damage.
- **Testing:** Perform necessary tests to confirm the boiler is safe to return to service.
- **Documentation:** Document all procedures, inspections, and tests for future reference and compliance purposes.
- **Recommissioning**
- **Reassembly:** Carefully reassemble any parts that were removed during the cleaning process.

- **System Checks:** Conduct comprehensive system checks to ensure all components are functioning correctly.
- **Gradual Start-Up:** Gradually bring the boiler back online, monitoring for any signs of issues.

Ensuring SOP Adherence

Training and Competency

- **Personnel Training**: Ensure all personnel are trained in safety procedures and understand the risks associated with boiler operations.
- **Competency Checks:** Regularly assess the competency of personnel to handle safety-critical tasks.

Documentation:

- Maintain clear and up-to-date SOPs, making them easily accessible to all relevant personnel.
- Maintain detailed records of all safety procedures, inspections, maintenance activities, and training sessions.
- Regulatory Compliance: Ensure all safety practices comply with relevant regulations and standards.

Verification:Implement a system for verifying SOP adherence, such as checklists or regular audits.

- **Emergency Procedures:**
  - Emergency Plans: Develop and practice emergency response plans to handle potential incidents like leaks, explosions, or chemical spills.
  - Safety Drills: Conduct safety drills to ensure everyone knows how to respond in an emergency.
- **Continuous Improvement**
  - **Feedback and Review:** Regularly review safety practices and incorporate feedback to improve safety measures.
  - **Incident Analysis:** Analyze any incidents or near-misses to identify root causes and prevent recurrence.

By strictly following SOPs during shutdown and chemical cleaning, boiler operators can significantly improve safety, efficiency, and compliance. It is essential to continuously review and update SOPs to reflect changes in technology, regulations, or operating conditions.

Conclusion

The successful management of boiler functional safety during shutdown and chemical cleaning hinges on the strict following of SOPs. This ensures not only the safety and efficiency of the boiler system but also compliance with regulatory requirements. Regular training and audits of the procedures can help maintain high standards of safety management in boiler operations.

Typical SOP for safe Shutdown:

1 Reduce boiler load at the rate established by the turbine until the turbine is at itsminimum load point or as per process requirement.

2 During the period of load reduction, operator should maintain continuous steam flow through the super heater

3 Reduce fuel feeding as well as air flow.

4 The air flow should not be reduced below the purge air flow rate.

5 Bring the boiler down by shutting off the fuel feeding. For boilers with burners, follow BMS

[Burner Management Systems (BMS)

A key element in ensuring the functional safety of boilers is the Burner Management System (BMS). A BMS is an automated safety instrumented system that includes sensors, logic and final control elements. Its primary function is to safely manage the start-up, operation, and shutdown of the combustion process in boilers and other combustion equipment.]

6 Follow boiler depressurization curve for pressure reduction. Natural cooling is preferred. Do not force cool the boiler. Force colling may result in thermal stresses in boiler.

7 If the unit is to be stopped for maintenance, positively isolate the fuel.

8 The operator should adjust the startup vent to provide at least 20% steam flow to protect the super heater from overheating.

9 When drum pressure drops below 2 kg/cm2, open vents

10 Stop the pollution control equipment. For units with ESP, switch off the ESP whenever the backend temperature drops below 125 C but rapping system should be continued.

11 Stop the steam supply to the deaerator.

12 Stop HP / LP dosing.

13 Close the CBD valve.

14 Close the sample lines.

15 Maintain normal drum water level throughout colling of the boiler.

16 Verify the IBD valve is closed.

17 Stop all the Fan as per Fan shut down SOP

18 Confirmed space permit to be issued only when temperature is suitable for human entry.

19 Before issuing confirmed space permit, Oxygen and flammable toxic gases level to be checked.

20 Electrical isolation for working on equipment.

21 Proper ventilation to be ensured.

22 Dust mask to be used, if the environment is dusty.

23 Harness to be used while working on height. All PPEs to be used.

Emergency Handling: Emergency shutdown is initiated as a result of equipment failure OR due to MFT conditions. Four types of major emergencies are discussed in this section:

Major Emergency Situations

1 Loss of Feed water supply - Boiler feed pump(s) system is not available.

2 Loss of draft – FD/PA/ SA fans and/or induced draft (ID) fan is not available.

3 Loss of both water supply and draft - Black plant with the boiler trip and isolated from the power grid. This is the most critical emergency.

4 Loss of solid fuel feed to furnace- If draft and feed water supply equipment remain in service, this situation may be resolved quickly enough to prevent emergency shut down.

Emergency Response Action:

1 The fuel should be immediately stopped

2 The goal is to maintain safe water level, if not in the normal operation range, at least up to the minimum visibility of drum direct level gauge glass.

3 Ensure ID Damper should be at stay put conditions to facilitate evacuation of gases from the furnace.

4 FD/PA /SA damper shall also be kept at stay put condition.

Typical SOP for Chemical Cleaning:

1 **INTRODUCTION-** The objective should be mentioned here.

2 **SCOPE-** Should cover the scope of current job- piping & pressure parts covered.

3 **OBJECTIVE-** To remove dirt, oil, grease, mill scale, preservatives, rust, weld slags etc

4 **PROPOSAL-** The description of systems covered and different circuits

5 **SERVICES REQUIRED-** Details of services required- DM water, Power, Service Air, Lighting, Disposal Pond etc

6 **SAFETY PRECAUTIONS-** Use of PPEs during chemical cleaning. First aid kits

7 **EMERGENCY PROVISIONS-** Safety showers or eye wash stations; First aid treatment rooms

8 **FIRST AID TREATMENT-** What should be done for splashes of eye or for irritation of skin

9 **GENERAL-** Should cover any general clause like cordoning of the area or restricted access.

10 **SAFETY OF PLANT-** What steps to be taken for safety of plant/equipment- like what to do is boiler is not started after cleaning. Temperature limitations during different stages of cleaning

11 **EMERGENCY PROCEDURES-** The procedures, the team performing cleaning should be aware of.

12 **STATE OF THE PLANT-** What should be state of different equipment / instruments during cleaning like permanent instruments, BFP, CEP, flow orifice, control valves, MOVs deaerator etc. Status of temporary piping, sampling points, circulation pumps etc. Provision of auxiliary heating steam; provision of vinyl sheet covers for protecting equipment from chemical splash; Backfilling and isolation of Superheaters from cleaning circuits. Installation of orifices in downcomers if required.

13 **METHOD –** Detail method shall be covered here

14 **COMPLETION CRITERIA-** What are the acceptable completion criteria for each stage of cleaning

15 **REFERENCE DOCUMENTS-** Mention all documents referenced in procedure

16 **ANNEXURES-** Schemes, Drawings, Log sheet etc.

METHOD:

1.0 ACID CLEANING PROCESS

1.1 Chemical cleaning shall be carried out by circulation method using adequate capacity and head pumps for removal of iron oxide, copper scales, water borne deposits and corrosion products from internal surfaces. The cleaning shall be carried out in two stages.Firststage for copper removal and second stage for copper and iron deposits.

2.2 In general, acid circulating pumps will take suction from chemical mixing tank and discharge is connected to the feed water line inlet to economizer. The return from boiler is taken from lower water wall headers (inspection caps) to the chemical mixing tank, so as to achieve a closed circulation circuit. **Necessary plugs in the saturated steam pipe and orifice in down comers shall be provided.**

1.3 The following sequence of operations shall be carried out for complete removal of various post - operational deposits such as iron oxides, copper oxides, siliceous and other water side impurities.

1.1.1 **Temporary erection:**

Temporary piping system shall be erected and connected with the boiler before the acid cleaning process.

1.1.3 **Tightness Test:**

Filling the entire system under cleaning with DM water for tightness test using temporary circuit.

1.1.4 **Water washing / Hot and Cold:**

Flushing of the system with DM water for removing loose dirt and water-soluble impurities till clear water is observed.

1.1.5 **Degreasing:**

Degreasing shall be carried out using 0.3 % Tri-sodium Phosphate; 0.05% Sodium Hydroxide at about 60 deg.c. The circulation of this solution is continued for about 4 hours or till alkalinity values are constant. Thereafter the system is drained and flushed thoroughly till alkalinity reduces to traces.

1.1.6 **Copper Removal (1st stage)**

Copper removal shall be carried out using solution of 1 % Citric acid, 1.0 % sodium Nitrite at 60 deg.c. maintaining pH value of solution 9.5-10.0. Circulation shall be continued till copper content is constant on the basis of analysis or maximum for (4) hours whichever is earlier. Draining under atmospheric pressure and DM water rinsing shall be carried out thoroughly till clear water is obtained.

1.1.7 **Acid Pickling (2nd Stage)**

Acid cleaning shall be carried out by using recommended chemicals (based on the deposits to be cleared) solution in DM water at 60 to 65 deg.c. The circulation of chemical solution will be continued till the total iron / acidity content stabilizes on the basis lab analysis or maximum four (4) hours whichever is earlier. Thereafter thesystem shall be drained under nitrogen pressure.

1.1.7.1 **DM Water rinse (1st)**

Rinsing of the boiler with DM water shall be done by circulating at 50 deg.c. for half an hour to one hour and then draining under nitrogen pressure.

1.1.7.2 **DM Water rinse (2nd):**

2nd DM rinsing of the boiler shall be repeated till conductivity of outlet water is less than 100 microsiemens/cm then drained under nitrogen pressure.

1.1.8 **Citric Acid Rinse** :

Citric acid rinse shall be done with (0.2%) citric acid maintaining pH 3.5 to 4.0 by addition of ammonia for complexing residual iron at temperature of 55 deg.c. for two (2) hours and afterwards system is drained under nitrogen pressure.

1.1.8.1 **DM water Rinse :**

DM water rinsing of the system will be carried out and repeated, if necessary, till iron content is achieved less than 50 ppm and pH around 6.0 system draining is done under Nitrogen pressure.

1.1.9 **Neutralisation with sodium carbonate :**

1 % sodium carbonate treatment shall be carried out for system neutralisation at 80 deg.c. for four (4) hours and afterwards system draining is done under atmospheric conditions by opening all vents.

1.1.10 **Passivation (1st stage) :**

Passivation of the acid cleaned surfaces shall be carried out using Hydrazine (200ppm) and ammonia maintaining 9.5 to 100 at 70 deg.c. and circulating for20 hours and drain the system under atmospheric conditions by opening all vents

1.1.11 **Neutralisation:**

The spend acid in the above operations shall be fully neutralized using caustic soda dye during final disposal to nearby neutralizing pit / drain.

1.1.12 The method of acid cleaning and passivation, ("the temporary circuit") and chemical control in all the operations, shall be followed as per the widely accepted and proven methods and according to the system requirement.

Full Name: Narpendra Singh

Company Name: Incosteam International Private Limited

Designation: Chief Executive Officer

Educational Qualification: BE Mechanical

Education Institute Details: University of Pune

Current Job Profile:

Having three decades of experience in steam engineering and understanding Requirements of the modern industry, pain points of the customers along with there need of the hour to be highly competitive and cost effective in their operations alongwith plants having highest reliability in their operations, are the key drivers which motivates me as an entrepreneur to bring solutions to the Industry which addresses there pain points and there needs in real cost effective manner.

My passion for Steam Engineering drives my current role as an CEO, I am responsible for developing, planning and implementing the Company's long term vision, operational and strategic functions driving towards customer needs and all stake holders of the Company.

My job profile also includes:

- Implementing, improving, and enforcing policies and procedures that will help in delivering High quality products, operational excellence, customer satisfaction and highest level of HR Policies for the company.
- Overseeing complete performance of Company in accordance with the direction established in the strategic plans.
- Providing strategic input and leadership on decision-making issues affecting the Company.
- Mentoring and interacting with top level executives and staff members at all levels to foster growth and encourage development among the senior executive team and staff members.
- Ensuring Brand Building of the company through Great Customer services, good quality Products And finally seamless transactions which automatically ensures Brand image.

Experience: 32 Years in Steam engineering

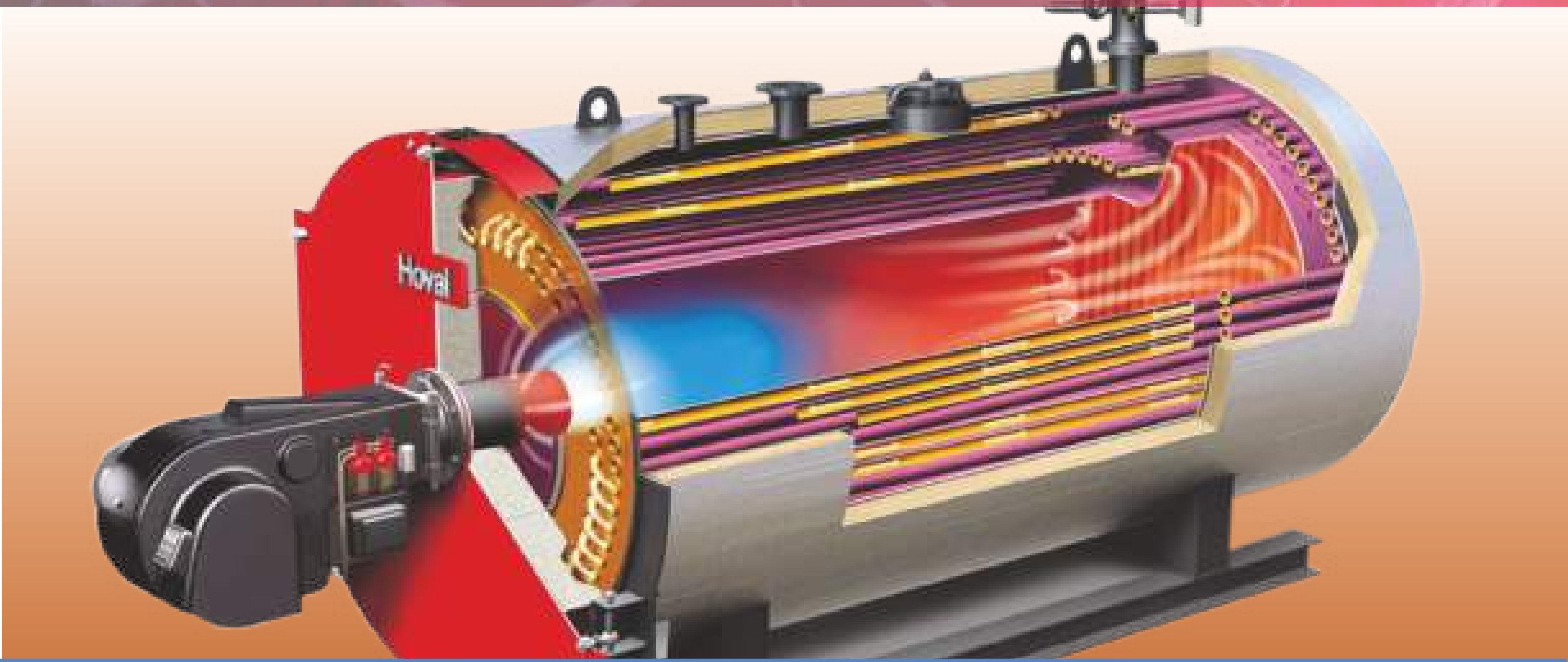
Achievements:

After completion of my Graduation from Pune University I was selected in Forbes Marshall which happened to be the best thing in my professional career. I worked for 25 Years at Forbes Marshallhandling various functions and roles in the Company. For 12 years, I was the Factory Head for the Steam Systems division, where my focus areas included quality improvement, bringing quality to international standards, and setting up advanced manufacturing facilities, which led to manyfold increase in productivity as well as achieving zero defect in several products. During my Tenure I was lucky to be a part and witness to the excellent growth of our company not only in numbers but also in terms of the way we did things, improved processes, level of quality improvement to international standards and being a highly commercially successful company.

I have fortunate to be trained in Steam Systems from Spirax Sarco, UK and have had the opportunity to visit many Steam Engineering Companies across the globe. I was associated with CII and ACMA as a member of the jury for various assignments and have conducted audits for reputed companies such as Bosch and Subros.

I have been associated as guest speakers for about such as IoT, Industry 4.0, Zero Defects and Manufacturing Excellence in various industrial conferences.

In my current role, my focus has been to develop products with unmatched features, which are maintainable and compatible with rugged Indian conditions and giving our customers services which speaks volume about our company. My biggest aim is to see how we can reduce fuel cost for the industry through improves processes and make our customers more competitive along with doing a bit of service for environment which ia paramount going forward.



EFFICENCY ENHANCEMENT THROUGH QUALITY OF STEAM

QUALITY OF STEAM

Steam is being used for all process Industries for doing their process in the most effective and economical manner. Steam is now being used for ages and still happens to be the first and foremost choice across process industries, different industry segments and across the globe.

STEAM A PREFERED CHOICE

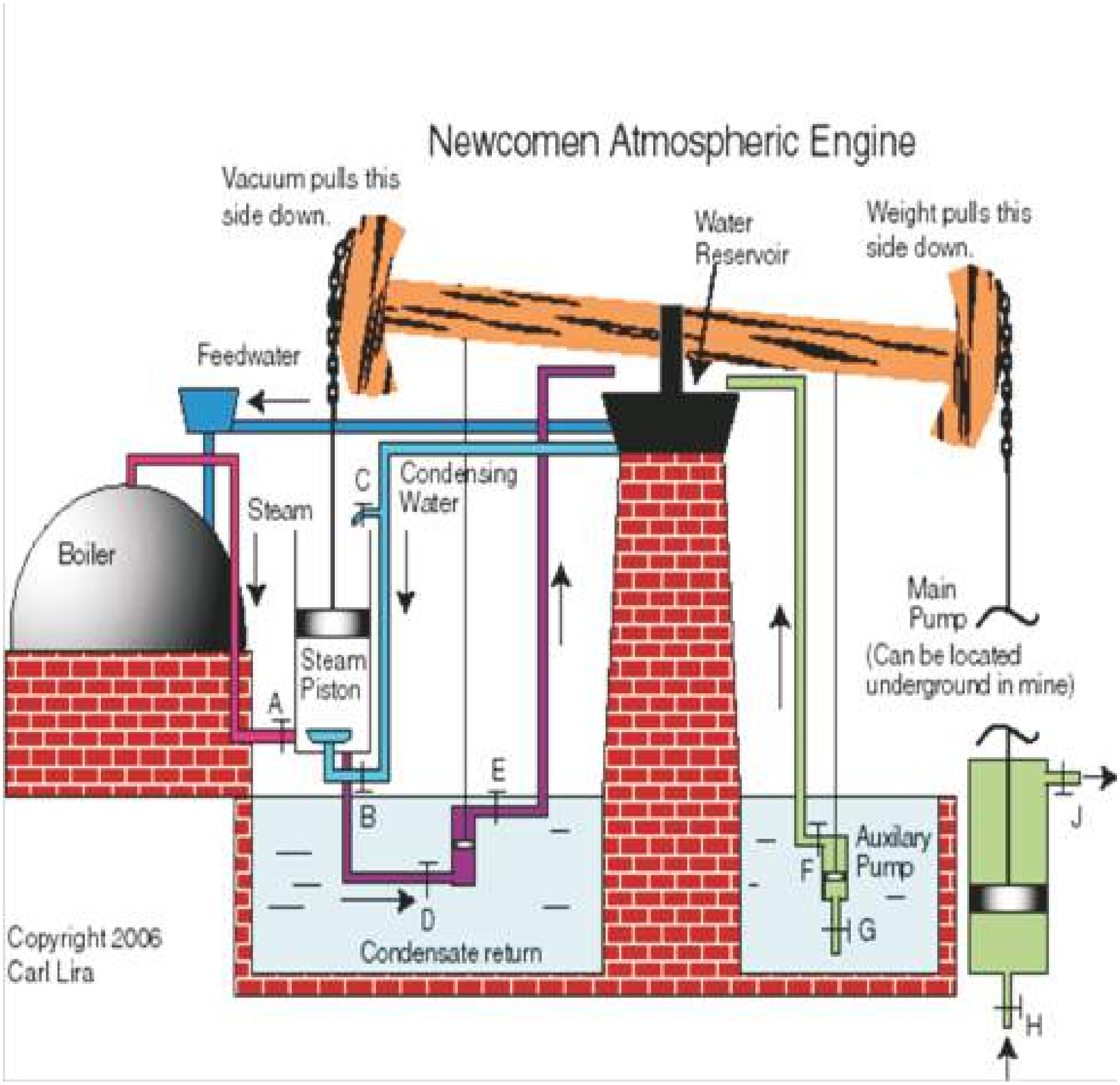
Steam is the first and foremost preferred choice for all process Industries because of the following:

- Water is easily available in abundant.
- Steam is efficient and economical to generate.
- Steam can carry large amount of heat energy in a very small pipeline.
- Pressure and temperature in steam follow a unique curve which makes process control very easy through steam.
- Steam can be easily transferred from one place to another in a plant.
- Steam can be used for all Industry segment with equal ease and safety.

STEAM FIRST USAGE IN INDUSTRIES:

The industrial use of steam power started with Thomas Savery in 1698. He constructed and patented in London the first engine, which he called the "Miner's Friend" since he intended it to pump water from mines. Early versions used a soldered copper boiler which used to burst easily at low steam pressures.

Later versions with iron boiler were capable of raising water about 46 meters (150 feet). The Savery engine had no moving parts other than hand-operated valves. The steam once admitted into the cylinder was first condensed by an external cold-water spray, thus creating a partial vacuum which drew water up through a pipe from a lower level; then valves were opened and closed and a fresh charge of steam applied directly on to the surface of the water now in the cylinder, forcing it up an outlet pipe discharging at higher level. The engine was used as a low-lift water pump in a few mines and numerous water works, but it was not a success since it was limited in pumping height and prone to boiler explosions. Shown below with a small pic of how steam was used for taking out water from deep mines.



STEAM IN INDUSTRY TODAY:

Steam system is a part of all major industrial process today. All major industrial energy users devote significant proportions of their fossil fuel consumption to steam production ie food processing (57 %), paper & pulp (81%), chemicals (42%), petroleum refining (23%).
Since steam is used for one and all process industries ie Food & Beverages, Chemicals, Pharma, Paper, Textile, Power, Oil & Gas, sugar, Cement, Rubber etc. So, it becomes very important to have very efficient and economical steam systems as this will directly determine the cost of living for people across the globe.Quality of steam plays a very important role in making steam system efficient and effective as an improved quality of steam is directly impacting all above industry economics.

QUALITY OF STEAM?

The quality of steam refers to the percentage of vapor present in the steam mixture. Steam quality is a measure of how pure or dry the steam is, and it is typically expressed as a percentage.

Pure, dry steam has a quality of 100%, meaning it contains 100% vapor and no liquid water. As steam leaves a boiler, it often contains some amount of liquid water droplets mixed in with the vapor. The percentage of vapor compared to the total mass of the steam-water mixture is the steam quality.

For example, if the steam contains 95% vapor and 5% liquid water, the steam quality would be 95%. Lower steam quality indicates a higher proportion of liquid water, which can reduce the efficiency and performance of steam-powered systems.

GRADES OF STEAM:

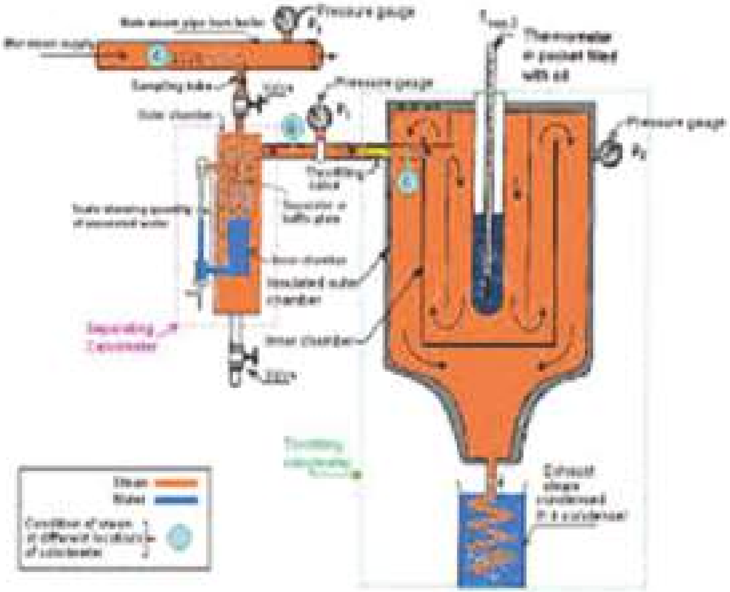
- **Plant Steam** ie Oil & Gas, Chemicals, Cement, Power, Tyres etc
- **Filtered Steam** ie Food & Beverages
- **Clean steam**ie Life Science, Hospitals & Food & Beverages
- **Pure Steam**ie Pharmaceuticals& Biotechnology

MEASUREMENT OF STEAM QUALITY:

Throttling Calorimeter

Material: Refer Fig. 26.1. The Throttling Calorimeter consists of inner chamber and outer chamber. The pressure gauge attached to the outer casing and thermometer in inner chamber gives the pressure and temperature of steam after throttling, respectively. In order to prevent any heat transfer from and to the system, the outer chamber is insulated.

Procedure: A sample of wet steam at pressure 'p_1' is taken from the main steam pipe of boiler into the inner chamber of the throttling calorimeter through a sampling tube and orifice throttling valve. This wet steam sample is throttled in orifice throttling valve before it enters into the calorimeter. Normally, pressure desired after throttled is few mm of Hg slightly above atmospheric pressure. The steam of the inner chamber is first allowed to flow down wards then flows upwards and finally turns downwards in the annular space between the inner and outer chamber. This is done so that the steam should flow long enough to ensure constant temperature of throttled steam.



FACTORS AFFECTING QUALITY OF STEAM:

BOILER HOUSE:

- Feed water quality
- Feed water management system
- Boiler level control ie on off & Modulating
- Blowdown Manual and Auto Mode: Bottom & Side.

Problem associated with above& its Resolution:

FEED WATER RELATED ISSUES:

Feed water impurities contain, calcium carbonate, Calcium sulphate, Calcium chloride, calcium bicarbonate, magnesium carbonate, magnesium sulphate, magnesium chloride etc.

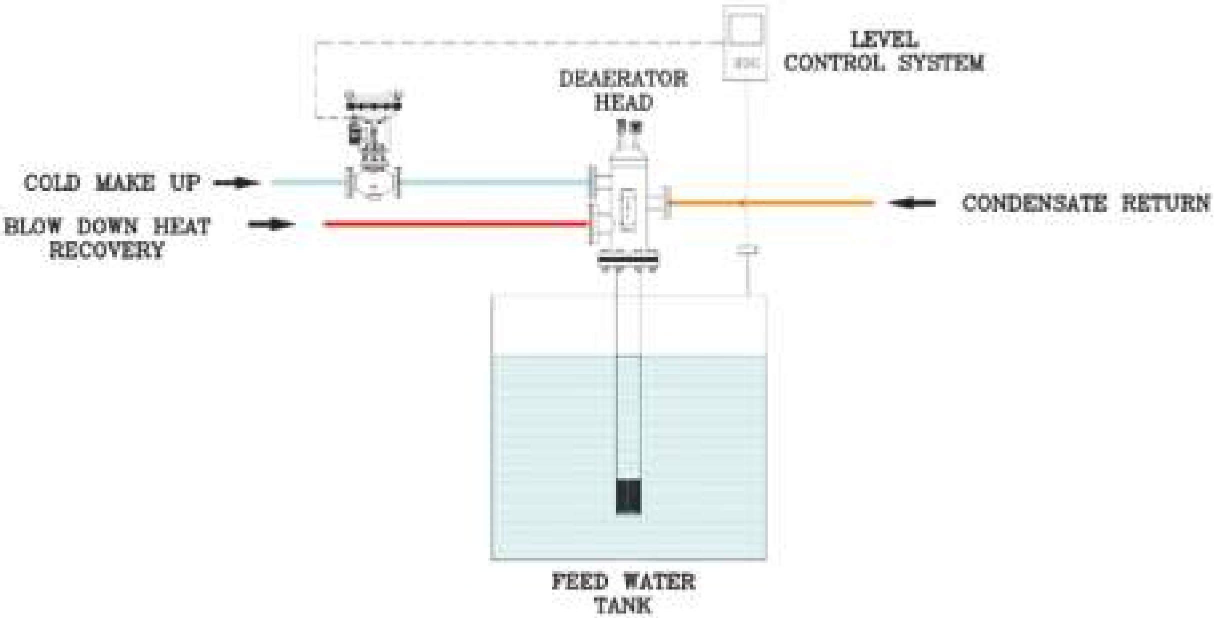
Feed water impuritiesmust be treated properly otherwise these will create problems associated with corrosion in the Boiler tubes and throughout the steam system.

PROPER TREATMENT OF MAKE UP WATER IS ABSOLUTELY MUST FOR IMPROVEMENT IN QUALITY OS STEAM

FEED WATER MANAGEMENT:

Feed water management system if not installed properly will pose many problems to the system. Oxygen and non-condensable gases which are released when cold water is heated if not removed will travel to the plant process and corrode equipments, lines and the entire network. It also ensures proper mixing of cold water; condensate return water and flash steam if recovered ensures higher efficiency of the Boiler house.

Pic of Feed water management system

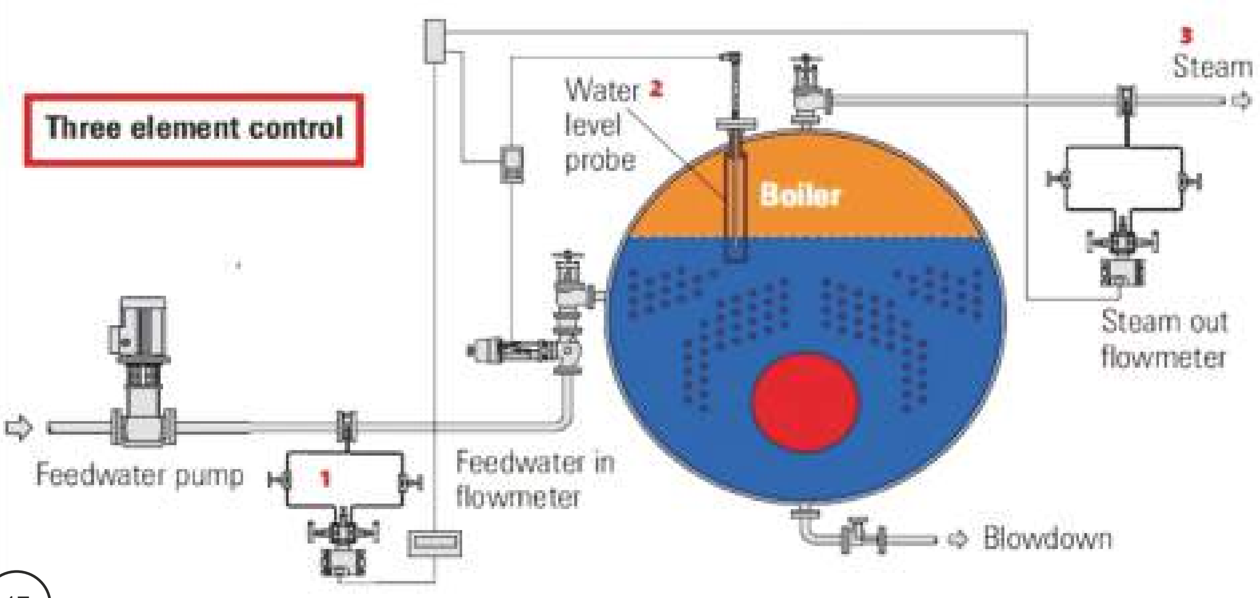


BOILER LEVEL CONTROL:

Boiler level need to be properly controlled to keep carry over at the minimum. If we have sudden fluctuation of demand of steam, sudden inflow of cold make up water we see sudden increase in carry over from the Boiler.

THREE ELEMENT CONTROL SYSTEM TAKE CARE OF BOILER LEVEL

Instead of On Off control of feed water we integrate modulating feed water pump with steam demand which ensures it provides only the correct quantity of feed water at the correct time with zero lapse in time to the Boiler. This ensures good quality of steam with very low carry over from the Boiler.

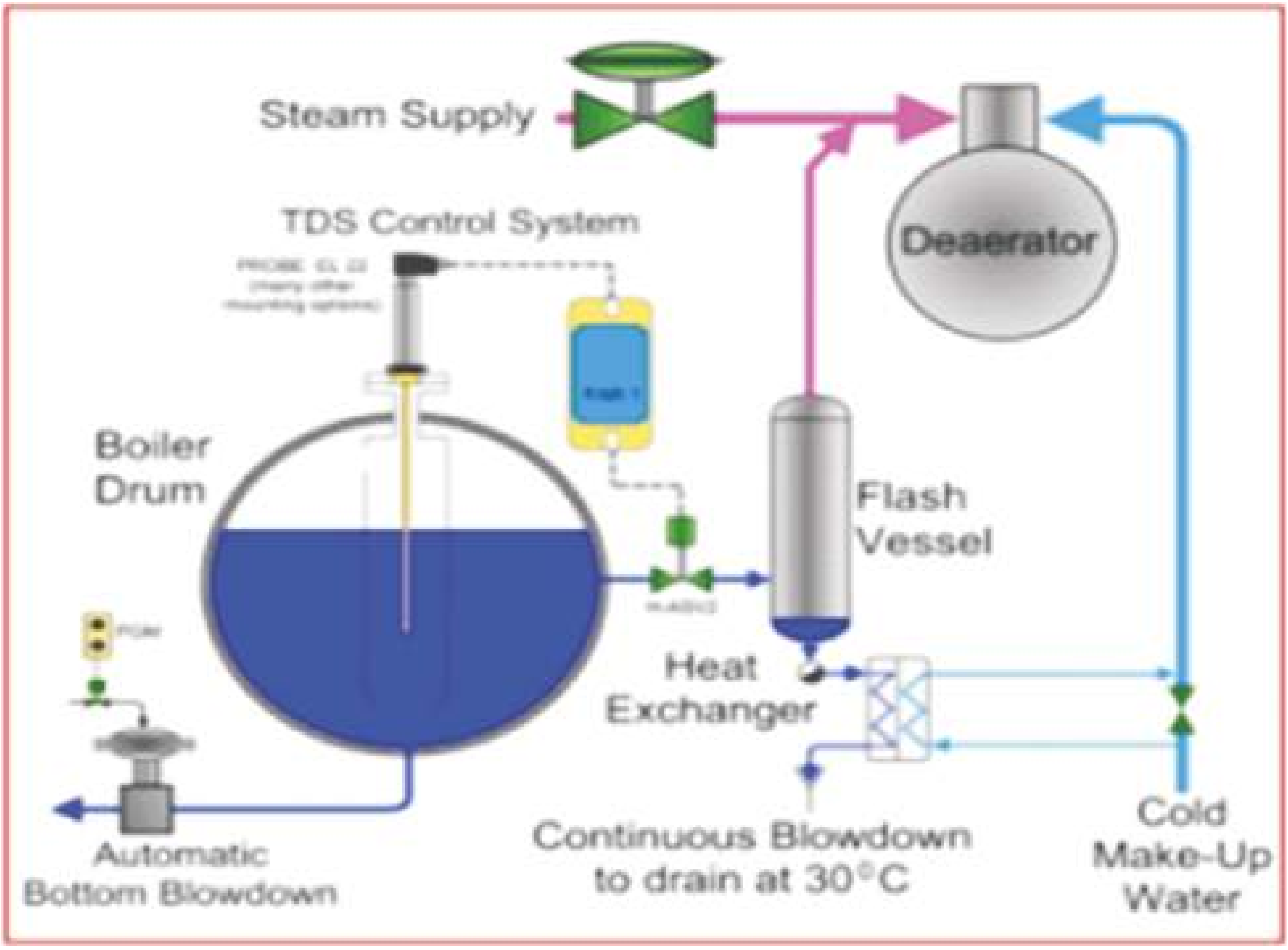


BLOWDOWN CONTROL SYSTEM:

Improper Blowdown often leads to deuterating Quality of steam. Higher the Blow down higher the carry over and poor quality of steam.

TDS BASED BOILER BLOWDOWN IE BOTTOM AND SIDE:

TDS based blowdown we can ensure that we blowdown only what is required ie it will ensure that we don't loose extra heat due to blowdown and more importantly we wont have a condition where we are blowing down less and putting a risk to our boiler and in the process increasing our carry over from the boiler. Bottom blowdown and side blowdown in combination can make a very efficient and safe blowdown system which will ensure good quality of steam.



STEAM DISTRIBUTION NETWORK:

STEAM LINE SIZING AND VELOCITIES:

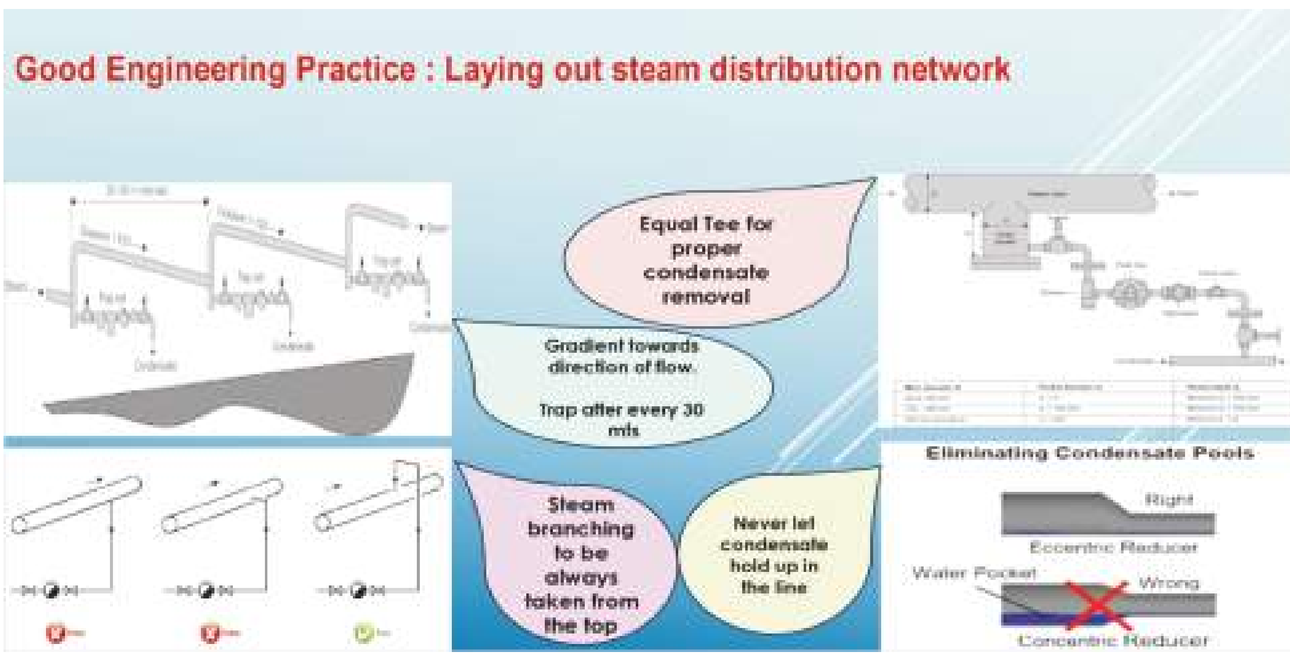
Steam distribution network need to be properly designed so that we receive designed temperature and steam pressure at the usage points. Line pressure drop need to be minimized. Steam has to reach the process at the desired pressure ie we have to design the system so that the pressure drop should be maintained at the minimum. We also need to ensure that correct quantity of steam reaches the process and there should be no steam starvation.

Key Point to consider while designing steam lines:

1. We should keep steam lines sizing at the optimum ie neither too big or too small.
2. We should consider steam velocity between 30 m/s to 50 m/s for saturated steam.
3. We should consider correct pressure drops over the line sizing.
4. We can consider higher steam velocity for dryer steam, ie dryer the steam higher the velocity we can keep as it will reduce the impact of water hammer ie closer to 40 m/s.
5. For poor quality steam we need to keep lesser steam velocity closer to 30 m/s.
6. For super-heated steam we can even keep velocities closer to 50 m/s

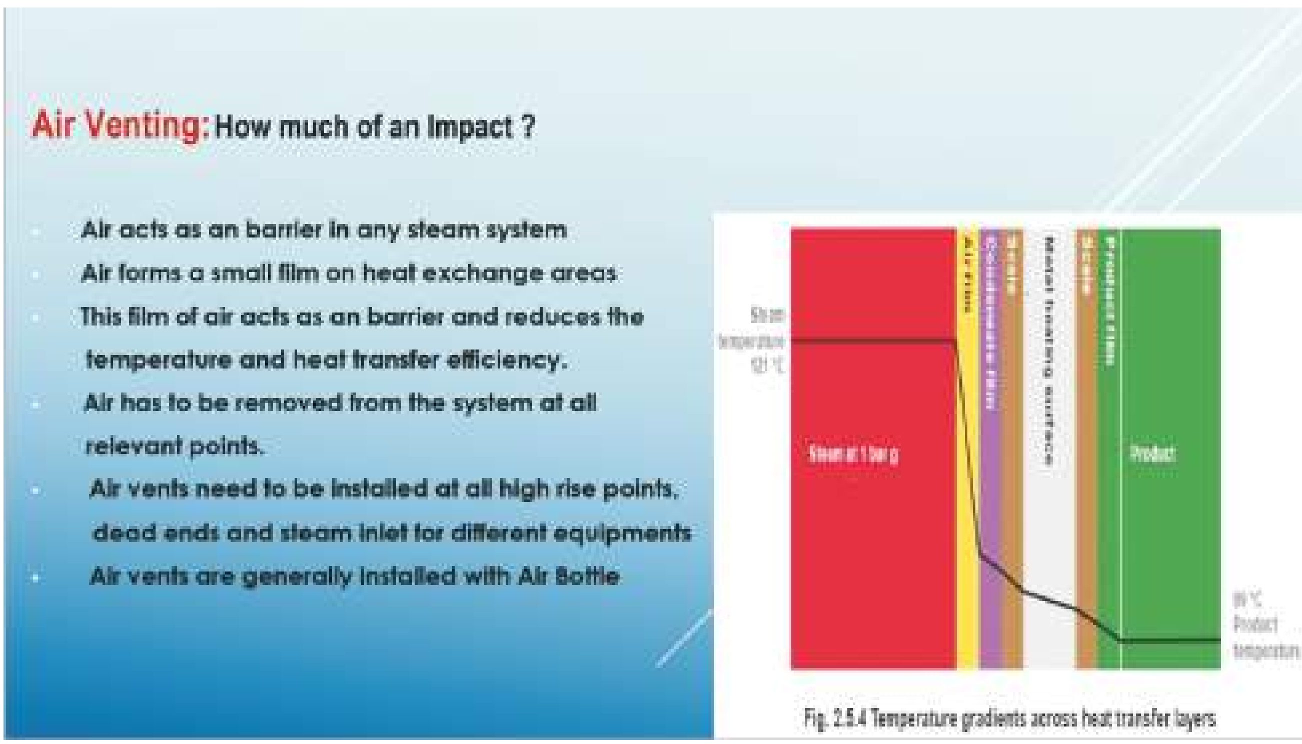
GOOD ENGINEERING PRACTICES FOR STEAM DISTRIBUTION NETWORK:

1. We need to install steam trap every 30 mt to 50 mt depending upon the condition of the line / plant.
2. We need to have a gradient of 1; 100 toward the flow direction.
3. Steam lines need to be branched always from the top.
4. We need properly designed drain points so that condensate evacuation is proper.
5. We need to keep other Piping installation guidelines for proper system operation.
6. Steam pipe line need to be properly insulated.



STEAM REACHING PROCESS HAS TO BE AIR FREE:

1. Air enters the steam lines during start up. Whenever a process is completed and as system is depressurized air is drawn into the system.
2. Boiler feed water has dissolved gasses ie Co2 and Oxygen mainly and some part of Nitrogen which is present in the air. As Boiler feed water is heated it releases these non-condensable gases and these mix up with the steam and travels along with the steam into the process.
3. Air needs to be removed from the steam system from all possible locations.
4. Air acts as a barrier to heat transfer and thereby reduces thermal efficiency of the process.
5. Air can be removed through installing Thermostatic air vents on the steam systems.



STEAM REACHING PROCESS AT CORRECT FLOW:

1. Steam must be supplied in required quantity at the process.
2. There must be no starvation even during startup when steam consumption is at its peak.
3. Steam lines must be correctly sized and we cannot have either undersized lines or oversized steam lines. One size higher steam line tends to have 40 % more Initial investment and 20 % more radiation losses. Smaller line sizes lead to steam starvation leading to product quality issues.
4. Heat load calculations for the heat exchangers need to be properly calculated.

STEAM REACHING PROCESS AT OPTIMIZED PRESSURE:

1. Steam to the process must be supplied at the least possible steam pressure so as to have the maximum latent heat transfer.
2. Increased steam pressure than required can lead to loss in thermal efficiency of the process.
3. Below table clearly shows that Latent heat increases as steam pressure reduces, so we use lowest possible steam pressure for our processes.

Gauge pressure (kPa)	Boiling point (°C)	Energy in water (kJ/kg) (sensible heat)	Heat of evaporation (kJ/kg) (latent heat)
100	120.4	505.6	2201.1
200	133.7	562.2	2163.3
300	143.7	605.3	2133.4
400	152.0	640.7	2108.1
500	158.9	670.9	2086.0
600	165.0	697.5	2066.0
700	170.5	721.4	2047.7
800	175.4	743.1	2030.9
900	180.0	763.0	2015.1
1000	184.1	781.6	2000.1

Pressure reducing station to be used for reducing Pressure reduction.

STEAM REACHING PROCESS BE DIRT & IMPURITY FREE:

1. Feed water quality and conditioning
2. Steam can have contamination from fabrication left over, welding slugs during the initial commissioning of the steam lines.
3. Steam can also have contamination from rusting and scaling of the steam lines over a period.
4. Impurities can enter steam lines by poor Boiler operations ie Drum level not maintained properly, Higher Blowdown TDS and even maintaining lower bed temperatures.
5. Improper water treatment also leads to impurities in the steam.

Installation of Strainers can ensure dirt and impurity free steam.

STEAM TRAPPING ROLE IN QUALITY OF STEAM:

1. Removes condensate with no loss of steam.
2. Improves steam quality by removing the condensate from the process thereby improving thermal efficiency of the process.
3. Reduces water hammering from the main line
4. Proper selection of steam trap helps in ideal start up times.
5. Steam traps help in Air venting there-by improving Steam quality.

How steam trapping helps in improving quality of steam:

New generation Thermodynamic steam trap can take care of Air venting along with weather prof design

New generation Thermodynamic steam trap can take care of Air venting along

Integrated Ball float trap module can take care of condensate evacuation for all process:

CONDENSATE RECOVERY SYSTEM

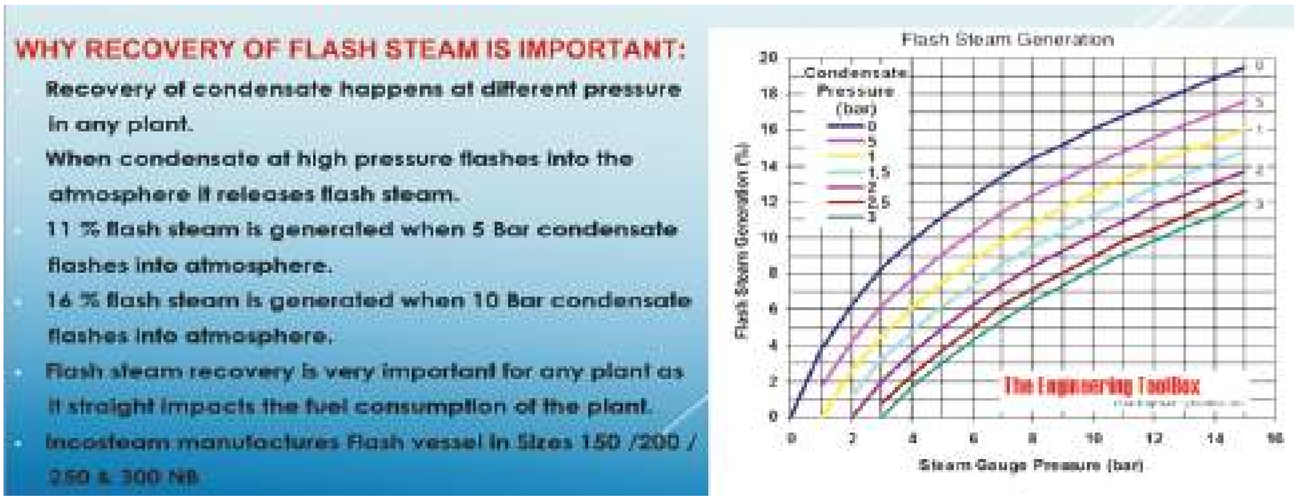
1. Condensate recovery plays very important role in improving quality of steam
2. More the condensate recovery the lesser will be fresh make up water induced into the system thereby improving steam quality.
3. Since condensate is at a higher temperature it will have to be less heated as compared to fresh water and has lesser holding of Air and non-condensable gases associated with it.

Condensate recovery pump ensures recovery of high temperature condensate

FLASH STEAM RECOVERY:

1. Recovery of flash steam is equally important to maintain and improve quality of steam.
2. Any loss of steam will require new water to be inducted into the system which brings along with its own set of problems and impurities in the system.

Flash steam generation chart:



SUMMARY ON HOW TO GET GOOD QUALITY OF STEAM:

- Boiler Selection & Design
- Quality of Water.
- Boiler level control linked with steam consumption from the plant
- Auto Blowdown
- Feed water management system
- Correct steam line sizing
- Good engineering practices followed during steam distribution network
- Proper air venting of steam lines
- Steam should reach process in correct quantity and pressure
- Proper care to be taken for ensuring removal of dirt and impurities from steam lines.
- Trapping plays very important role both on main lines and process equipments for ensuring Quality of steam.
- Ensuring proper condensate removal
- Finally ensuring flash steam recovery system.

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Company Name: Thermax Ltd.

Designation: DGM- Technology & Innovation

Educational Qualification: (a) B.Tech. (Mechanical Engg.)
(b) M.Tech (Energy system)
(c) PhD on Predictive modelling and dynamic simulation of a hybrid boiler in fluctuating load conditions.

Education Institute Details: IIT- BHU, IIT- Powai

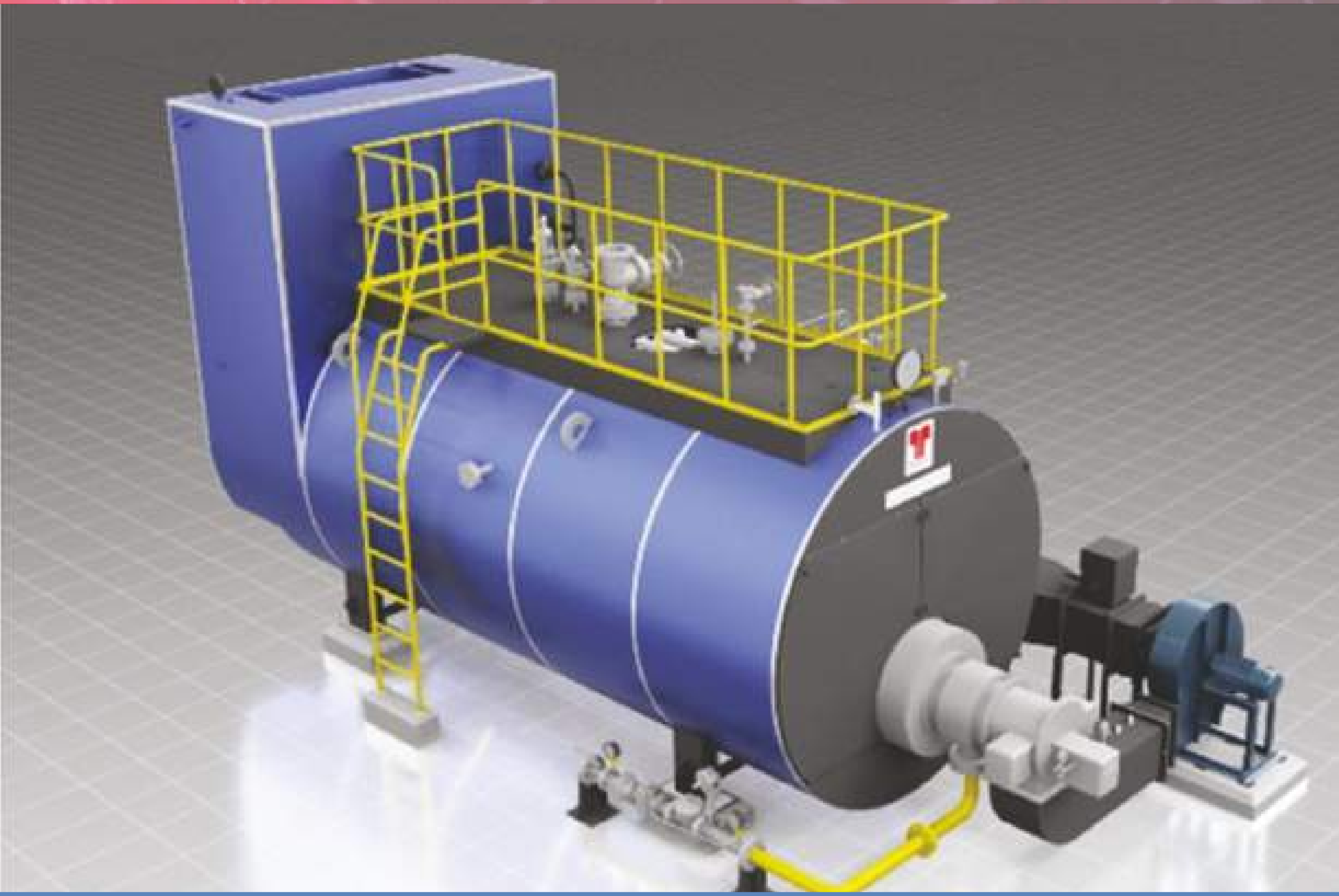
Current Job Profile: Heading global innovation & technology for heating business of Thermax Ltd.

Experience: 26 Years in development of new product & technology

Area of interests- Mathematical modeling & simulation, Combustion, heat transfer, Flow network analysis. Heat exchanger network analysis, Transient heat transfer, Furnace modeling

Achievements:

(a) 17 patents granted and 10 patent application
(b) 14 papers in different international journals
(c) New correlation for flow between two helical coils (Published in international journal of Therma science)



SUSTAINABILITY AND ENERGY TRANSITION: ADVANCEMENT IN BOILER TECHNOLOGY

Dr R. S. Jha, Global Head- Technology and Innovation, Heating, Thermax Ltd

Energy sustainability refers to the ability to meet present and future energy needs without compromising the ability of future generations to meet their own need. The energy sector in the global scenario faces a major challenge of providing energy at an affordable cost and simultaneously protecting the environment. The energy mix globally is primarily dominated by fossil fuels, coal being the major contributor. Increasing concerns about the adverse effect of the emissions arising from coal conversion technologies on the environment, the gradual depletion of fossil fuel reserves, and concerns about energy security have led to global initiatives like resource optimisation and energy transitionto meet future energy demands sustainably.

1.Energy efficiency

Energy efficiency is a critical lever to attain energy sustainability as it helps to reduce energy consumption and subsequent fossil fuel depletion. Both generation and utilisation are important for energy efficiency.

1.1.Flue gas heat recovery

The boiler efficiency depends on the combustor design, fuel type, boiler & HRU design. The major loss in the boiler is stack loss, which depends on the stack temperature. The efficiency of the boiler is increased by reducing the stack temperature with the application of a suitable heat recovery system. The design and selection of the heat recovery system have the following challenges.

- Selection of heat sink- Feed water and combustion air provide the required heat sink for the flue gas heat recovery.
- Poor heat transfer performance- HRU requires a higher heat transfer area due to poor heat transfer performance. The poor heat transfer performance of HRU can be attributed to the lower temperature difference.
- Low-end corrosion- Low-end corrosion is the result of condensation of acids like sulfuric acid, and sulfurous acid. The dew point temperature of sulfuric acid provides a limiting condition on the design of the heat recovery system. The heat recovery system is designed in such a manner that the metal temperature should never be less than the desired metal temperature to avoid sulfuric acid condensation.

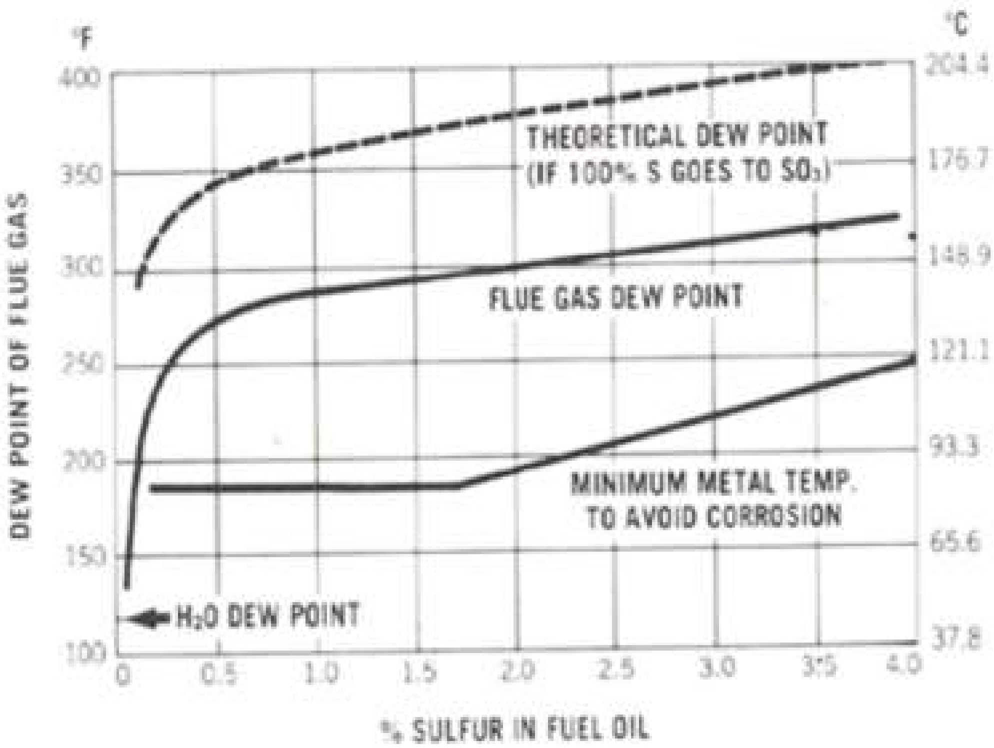


Fig.1. Dew point temperature as a function of sulphur content

Low-end corrosion problems can be solved by increasing the metal temperature above the required metal temperature to eliminate the possibility of corrosion. This problem of dew point condensation can be resolved as follows.

- Preheating of feed water- The problem of dew point condensation in the economiser can be resolved by increasing the feed water temperature above the dew point temperature.

- Secondary medium- In conventional economiser, feed water directly receives heat from flue gas and the metal temperature is mainly governed by the feed water temperature. The problem can be also resolved by introducing a secondary medium, where circulating water or organic fluid receives heat from the flue gas in a flue gas cooler and transfers it to feed water or combustion air in the secondary heat exchanger. As the temperature of secondary fluid is higher than feed water and combustion air, metal temperature can be easily maintained above dew point temperature. Metal temperature is controlled by controlling the temperature of the secondary fluid. It also employs a bypass line to control the circulating fluid temperature.

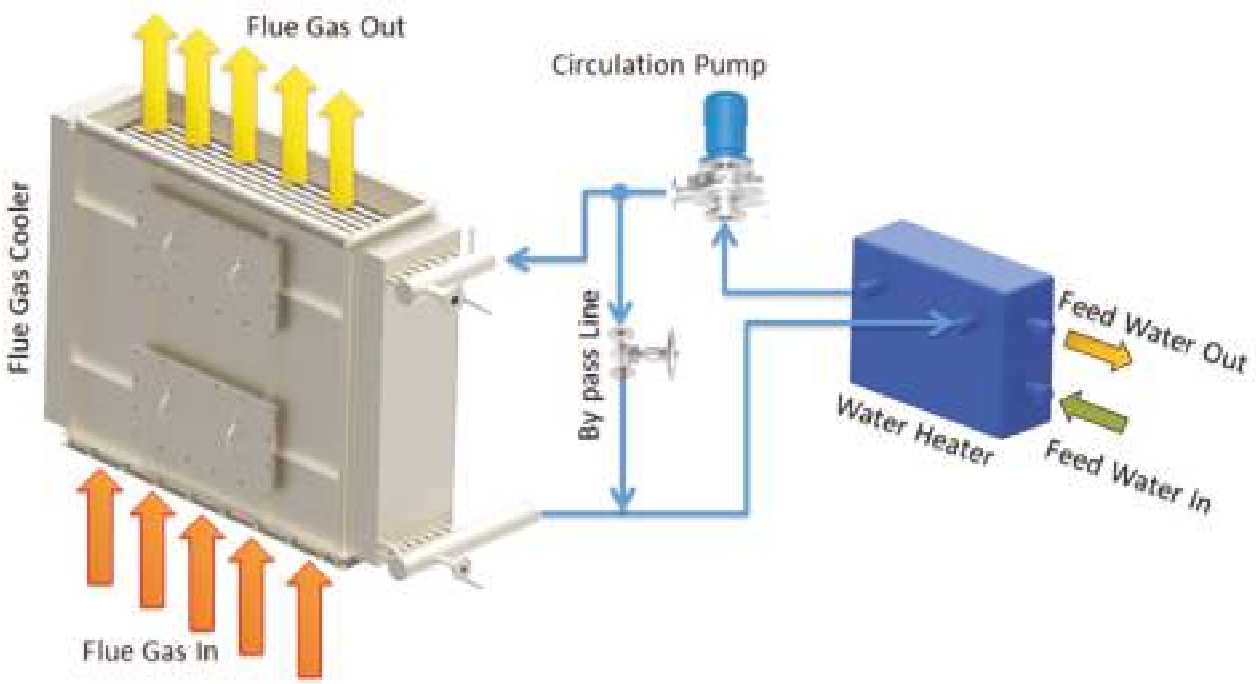


Fig. 2. Secondary medium for heat recovery

- Thermosyphon- The heat pipe works on a thermosyphon loop, where the phase change of the transfer fluid takes place after receivingheat from the flue gas and condenses back after rejecting heat to the cold combustion air. The selection of transfer fluids and vacuum levels is quite important for the elimination of low-end corrosion as it controls the fluid and metal temperature.

1.2. Condensing heat exchanger

Any gas stream which contains a condensable liquid in vapour form contains both sensible and latent heat. Sensible heat can be simply recovered by cooling the gas and transferring the heat to some other medium. Latent heat, however, requires condensation of the liquid and subsequent recovery of that heat into some other medium. The opportunity for latent heat recovery increases with the increase in hydrogen concentration of the fuel. To recover the latent heat, the metal temperature of the heat transfer should be reduced below the dew point temperature. This causes condensation of water vapour and subsequent heat recovery.

Condensing heat exchanger offers the following benefits

- It is designed to increase the efficiency by reducing the flue-gas temperature below the dew point temperature (sulfuric acid, Sulfurous acid, Water) & increasing the rate of condensation.
- It maximizes sensible heat recovery in addition to the latent heat, which increases boiler efficiency beyond 100% (On NCV basis).
- It can partially reduce SOX emissions.

Fig.3. Condensing economizer

It also has several limitations

- There should be sufficient heat sink below the dew point temperature.
- Material selection is extremely critical due to the possibility of low-end corrosion.
- It requires a higher heat transfer area due to lower temperature differences.
- It has a higher initial cost due to special metallurgy and a higher heat transfer area.

Most of the gaseous fuels like Natural gas and LPG contain a higher percentage of hydrogen, which leads to higher water vapour in the flue gas and a higher opportunity for heat recovery. In the case of natural gas boiler efficiency can be increased to 105 % on the NCV basis. Simultaneously, it contains less or no sulfur, which provides higher freedom in material selection. Due to these two characteristics, latent heat recovery is very economical with condensing economizer.

1.3. Focus on system efficiency

The operating cost and energy usage are not just governed by the efficiency of the steam generation system, but the utilization also plays a significant role. Focus on the system efficiency covering generation, transportation and utilization is very important for the effective utilization of the fuel. In a steam-based system design of condensate recovery and flash steam recovery is very important for the effective utilization of steam. Process integration also plays a very important role in the energy optimization. It is possible to integrate heat sources and sinks available in the boiler, heater and process for the best utilization of waste heat in the system. Integration with closed-loop systems like hot water can also play an important role in the energy optimization of a plant.

2. Biomass as an alternative fuel

Biomass is a non-fossil fuel and is derived from wood, wood waste, and agriculture residue like bagasse, rice husk, coconut shell, groundnut shell, coffee husk etc. Biomass is a carbon-neutral fuel, as the CO2 generation during the combustion process is balanced by the CO2 absorption during plant growth.

The lower cost and higher availability of biomass fuels make them a viable alternative to fossil fuel even though it has several commercial and technological challenges. The availability of biomass is quite inconsistent, and the characteristics of these fuels keep on changing. These fuels have higher moisture, slagging and fouling problems, higher emission issues and may have difficulty in handling and transportation. These constraints impose a major challenge in the design of biomass boilers. These boilers should be designed to handle wide varieties of fuel to counter the problem like supply and quality inconsistency. These boilers should be able to burn high moisture fuel and should have reduced levels of slagging and fouling problems. Due to the inconsistent supply and seasonal variation in the fuel, fuel flexibility plays a very important role in the boiler design.

Due to their lower calorific value and lower bulk density, these fuels are voluminous in transportation and call for large equipment for handling and storage. These fuels are fibrous, non-homogeneous and not free flowing, which creates a significant problem in metering and feeding. Some of these fuels could have higher moisture and lower calorific value, which may have difficulty in sustaining flame and calls for support fuel. Higher moisture in fuel also leads to the lower efficiency of the boiler. Biomass may contain nitrogen and sulphur primarily responsible for NOx and SOx emissions. Generally, biomass contains less amount of sulphur in comparison with fossil fuel and generates less SOx emission.

Other constituents of biomass fuel responsible for emission are chlorine and ash. The presence of sodium and potassium salt reduces ash softening temperature. If the flue gas temperature reaches beyond ash softening temperature, it can deposit over the heat transfer surface like the furnace water wall and convective tube bank. This reduces the effectiveness of the heat transfer area and has a significant effect on the performance and the life of the boiler.

The following can be summarised as challenges in the utilisation of biomass.

- Difficulty in handling due to lower density and lower calorific value
- Inconsistency in fuel supply
- Seasonal variation in fuel properties
- Higher level of emission
- Slagging and fouling characteristics of the ash

These problems can be resolved by the selection of suitable combustor and boiler design.

A reciprocating grate is the most appropriate combustion technology for the effective utilisation of biomass with the desired fuel flexibility to meet the seasonal variation of fuel. The reciprocating grate utilizes the successive oscillation of the grate linkage for the continuous movement of the fuel. In this type of grate, fuel is fed at one end of the stoker and ash is removed from the other after the complete combustion of the fuel. These are generally inclined with alternate rows of stationary and moving grate blocks. These movable grate blocks are generally hydraulically driven. Alternate movement of grate blocks pushes the fuel into the distinct combustion zones of the grate. These zones are drying, pyrolysis, combustion and burnout. The movement of fuel over the grate is like walking over the inclined plane. The fuel passes through these combustion zones and ash is automatically discharged due to the reciprocating action of grate blocks over the ash conveying system after the complete combustion of the fuel.

Thermax grate has been designed to deal with extremely poor fuel with lower density, lower calorific value, higher moisture level and ash with higher fouling and slagging characteristics. This grate has been designed for higher fuel flexibility to deal with inconsistent supply of fuel and seasonal variations of fuel. Reciprocating grate is designed for longer life with higher availability and reliability.

Fig.4. Reciprocating grate for biomass combustion

Some of the special features of this grate can be listed as follows:

- Biomass combustion follows various steps like drying, volatile generation, volatile combustion, char combustion & ash removal in a progressive manner over the reciprocating grate. This divides the complete combustion chamber into various combustion zones and all of these zones require different quantities of air depending on their fuel properties. Drying and ash removal zones may require less air in comparison with volatile and char combustion zones. Thermax grate design provides the physical division of the grate in the various combustion zones.
- All of these divisions are driven by separate hydraulic cylinders so they can be independently controlled based on the fuel characteristics.
- These zones are separated from each other by separating walls and each zone have its own independent primary air connection with a controllable damper to ensure optimal air distribution over the grate.

- Zone-wise air distribution is useful to optimize the air distribution over the grate but air distribution in each zone also needs to be optimized. Thermax reciprocating grate employs a very special design of the grate layout using a combination of multiple grate castings with different air perforations to achieve optimal air distribution over the grate. The multiple grate design with different perforations helps to achieve desirable air distribution over the grate.
- Only a small quantity of fuel reaches the side of the grate but this zone also receives higher air in comparison with the central part of the grate. Due to its proximity to the hot refractory wall and higher air quantity, the rate of combustion in this zone is very high. The central portion receives more fuel, but the rate of combustion is relatively low. This causes a tongue-like combustion effect at the end of the grate, where only fuel remains at the central portion of the grate. This problem is solved by using a very special grate layout with a combination of different grate designs with full, partial or no perforation. As the central portion of the grate requires more air, grate casting with full perforation is used in this zone. Near the side wall of the grate, no perforation casting is provided. In the intermediate zone, grate casting with partial perforation is used.
- As the grate near the side wall receives very little quantity fuel, the air utilization in this zone is relatively poor. The airflow in this zone is restricted by providing no perforation casting near the side wall in the entire grate length.
- The entire grate is protected by a unique side wall made up of special casting with a very high percentage of chromium.

Thermax has developed the host of the solution using reciprocating grate technology like boiler, heater, and multiutility solution.

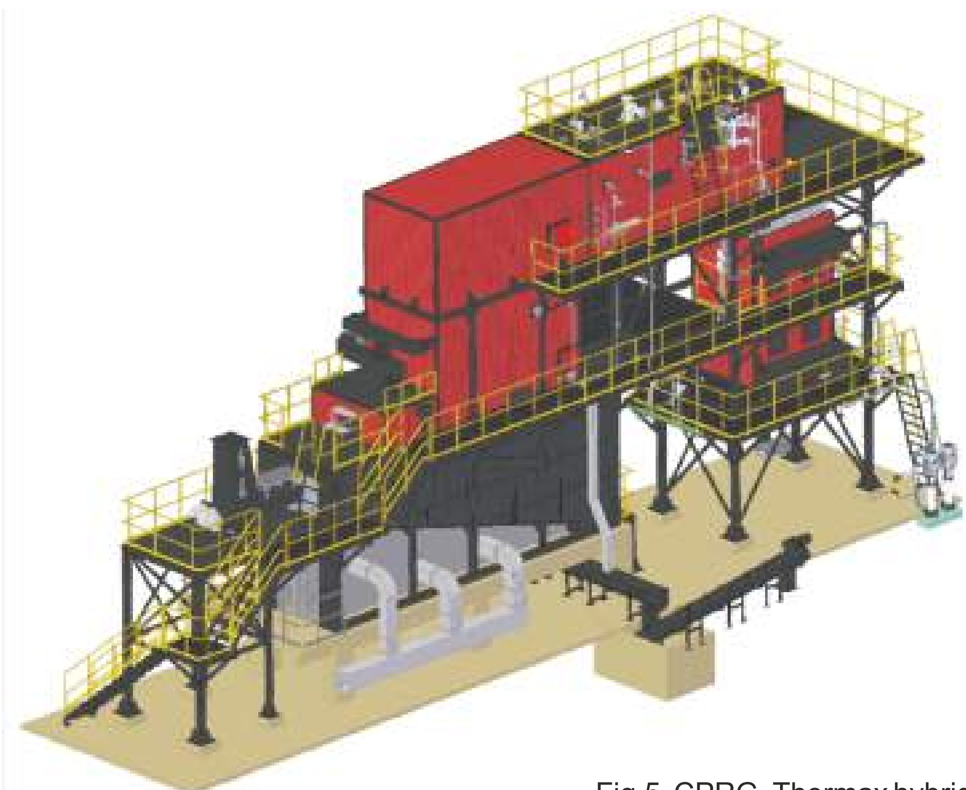


Fig.5. CPRG- Thermax hybrid biomass boiler

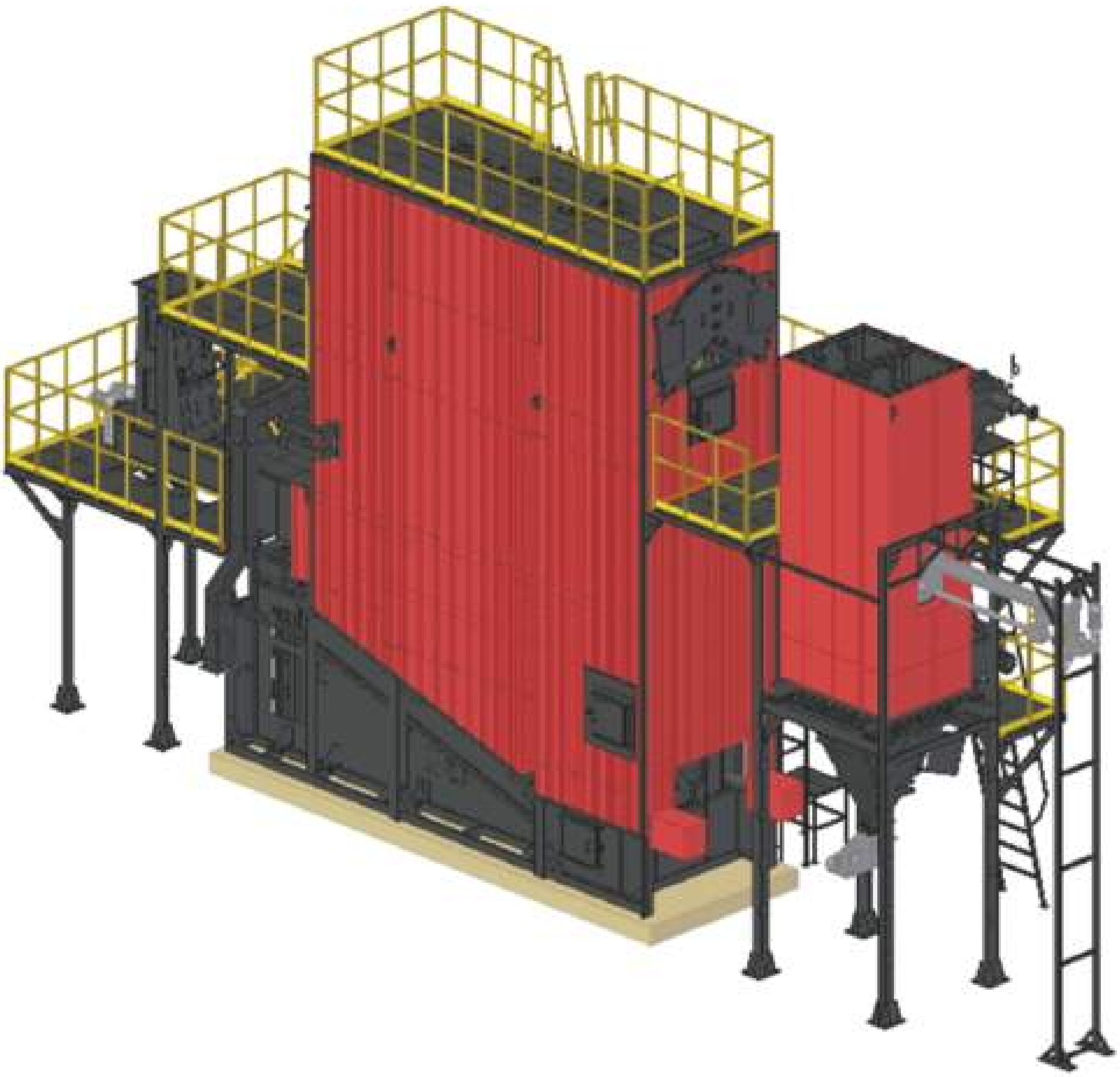


Fig.6. UPRG – Thermax Packaged biomass boiler

One of the major challenges in the design of small and medium-capacity boilers is the slagging and fouling characteristics of the fuel. For high-fouling fuels, the furnace is designed to reduce the furnace temperature sufficiently below the ash fusion temperature to reduce the slagging of the furnace and the fouling of convection tubes. Biomass combustion also requires a minimum residence time for the complete combustion of volatile. To meet these requirements, the furnace is divided into multiple passes to provide the required residence time and cooling of flue gas. Thermax has developed CPRG and UPRG boilers with reciprocating grates, which utilised hybrid design a combination of water tube furnace and firetube convective pass. UPRG is a packaged compact boiler, where the requirement of higher residence time and furnace exit temperature problems are solved by a special baffle design and multiple convective passes. These boilers also exploit a special soot-blowing technique based on the sonic principle. Thermax offers water tube boilers for medium and large capacity. These boilers offer higher uptime in comparison with hybrid design.

Fig.7. HTRG- Biomass thermal oil heater

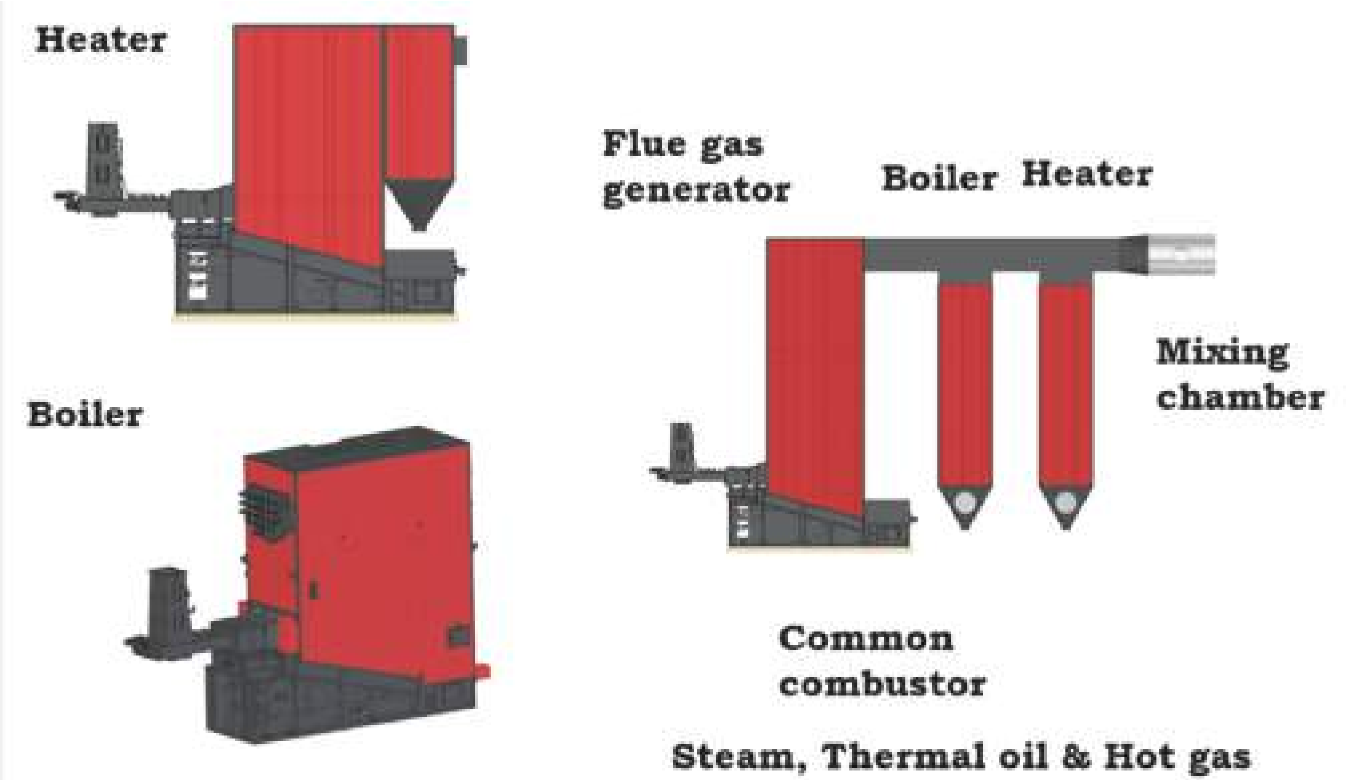


Fig.8. Schematic diagram of Energy

Thermax also offers thermal oil heaters using biomass design. This utilises a furnace surrounded by a membrane panel and a serpentine tube bank as a convective pass. Thermax offers an energy plant, which integrates multiple utilities like steam, thermal oil and hot gas. This increases the energy efficiency of the plant.

3. Electricity as a source of energy

Electricity is a clean source of energy, which can significantly change the future of steam generation and utilisation. The use of heat pumps is quite common for low-temperature hot water applications, as it helps to reduce substantial energy costs in low-temperature applications. The global surplus electricity production from solar and wind energy offers financial benefits when supplementing the heating supply with electric boilers in process heating applications. The cost of electricity is decreasing due to growth in renewables. With the lower cost of electricity, the use of electricity for steam generation is growing as a clean and affordable option.

Two types of electric boilers are used.

- Low voltage boiler
- High voltage boiler

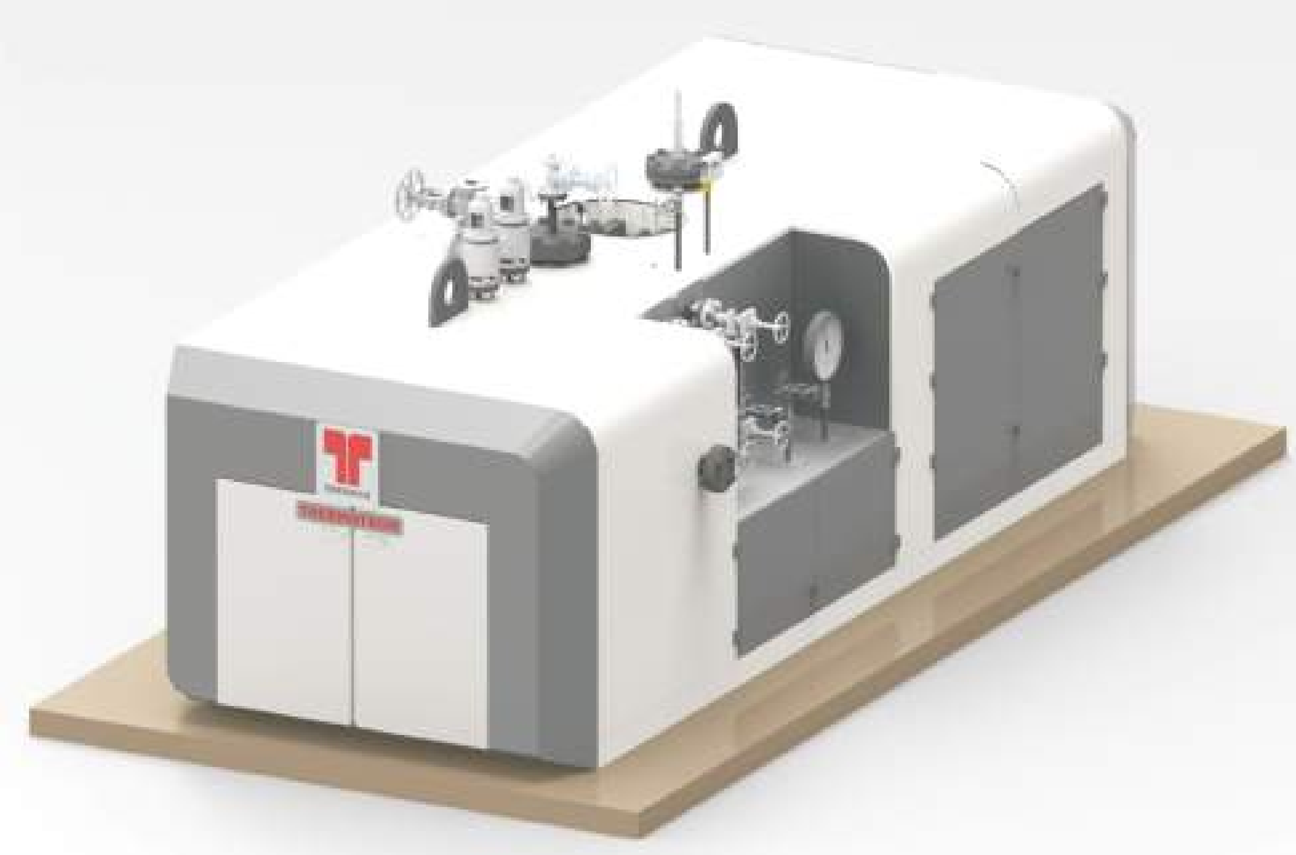


Fig.9. Thermotron- Thermax Electric

3.1. Low voltage boiler

The small-capacity electric boiler uses an immersion-type electric heating element for heat generation. Immersion-type heating element uses low voltage electricity source and resistance heating coil to generate heat and steam. An electric boiler is a non-tubular boiler, and it does not have a tube to support the boiler tube plate. Boiler tube plates need to be supported by using stay bars. This is only possible with the modularisation of the heating element, as these heating elements are placed on a boiler tube plate. The higher capacity of the heating element requires more area for supporting the heating element and increases the unsupported area of the tube plate leading to higher tube plate thickness. This problem is resolved by the optimisation of the heating element.

It provides the following benefits to users.

- A simplified design of boiler with electricity as a heating source
- Low voltage input
- Fail-safe design due to the absence of combustion and high-temperature flame
- Compact design
- Simplified operation as it does not require fuel sourcing and storage
- Does not require a chimney
- Low cost of installation
- Low heat flux design- no fear of high-temperature exposure.

3.2. High voltage boiler

High voltage electric boiler generates heat by passing an electrical current through the boiler water and using the water as the resistor. The boiler never operates in dry condition, because the electric power is cut off automatically, if the electrodes are not surrounded by water. Two types of design are employed for high-voltage heat generation: Two-vessel design and Jet flow design.

In a two-vessel design, electrodes are directly placed in the water and a high voltage current is passed through the water to generate heat. Steam generation is controlled by controlling the water level. Alternatively, current is passed through the jet of water to generate heat in the jet flow design of the boiler. These boilers use multiple jets and a moving sleeve is used to regulate the jet flow and steam generation.

These boilers do not require transformers, as they can utilize electricity at a higher voltage. It helps to meet the requirements of electric grid regulation. This is normally used as a backup boiler, which is used for steam production during the lower price of the electricity during the night.

4. Gasification

Gasification is a promising and important means of biomass conversion. A major driver of gasification is the conversion of waste or low-value fuels to high-value gas and liquid fuels. Gasification is a partial oxidation process, which converts coal or biomass into a mixture of combustible gases. Steam, air, or oxygen are used as gasification agents. The various technologies employed for the gasification are downdraft, updraft, fluidised bed, and entrained flow gasifiers. Appropriate technology is selected based on fuel availability and the relative benefits and limitations of the various gasification technologies. The performance of gasifiers depends on the fuel, type of gasifiers, gasification temperature and oxidising agent.

While combustion is the easiest process for the utilisation of fossil or biomass fuel for the production of energy, it has several limitations like emissions and fuel flexibility.

- **Clean technology-** Gasification is a cleaner method for utilisation of biomass, as it results in lower dust, CO, NOx and greenhouse gas emissions.
- **Wider application-** Gasification also helps to increase the efficiency of the power plant cycle. It provides wide applications like gas engines, gas turbines, combined cycle, process heating, hydrogen production and fuel cells.
- **Fuel flexibility-** Gasification is getting popular for the utilisation of a wide range of biomass, as it offers higher flexibility in using different feedstock materials.

Due to concerns of global warming and climate change, emission norms are slowly becoming more stringent. This may lead to a shift in the technology of biomass from direct combustion to gasification.

5. Hydrogen energy

Hydrogen is a clean fuel with zero carbon emissions and provides a huge opportunity for the fuel shift. In future, many industries can adopt hydrogen combustion as a part of decarbonisation. Hydrogen technologies enable energy efficiency improvements and system integration by providing flexibility in energy production, storage, and utilization.Major challenges associated with hydrogen combustion are higher flame propagation velocity and a wide range of flammability limits. Due to the wider flammability range, it can burn in a very lean mixture and any leakage can be extremely dangerous. This makes fuel storage, transportation and combustion extremely critical. Gas train design is very critical and quick shutoff valves, flame arresters and high velocity in the pipeline are used to avoid the possibility of flashback.

6. Hybridisation of energy source

The energy scenario is highly complex, and dynamic influenced by changing norms, fuel price dynamics and the evolution of technology. Hybridisation of energy sources like biomass, electricity and renewables can play a significant role in cost optimisation and demand side management. It will provide flexibility and reduce dependability on one energy source simultaneously providing the opportunity for cost optimisation. A hybridisation with a heat pump and geothermal energy can also play a good role in energy cost optimisation and decarbonisation.

7. Digitalisation

Digitalisation can play an important role in the design and utilisation of the future boiler. This can help to maximise the efficiency and uptime of the boiler. IIoT-enabled boilers with data analytics, artificial intelligence and machine learning tools can compute the online performance of the boiler and generate incites and recommendations for the improvement in the efficiency and uptime. This is especially important due to variations in fuel, boiler health and ambient conditions.

7.1.EDGE Live solution

Thermax has developed EdgeLive solution to maximise the efficiency and uptime of the boiler. EDGE Live has three major components: Energy management system and uptime management and incident management.

- **Energy management system**

The energy management system of EDGE Live solution analyses efficiency, fuel consumption, various losses, power consumption etc. It consists of diagnostic, variation analysis and advance analytics. It identifies the gap between design and actual efficiency, Identifies the causes of the gap, conducts consistency analysis and provides recommendations. It tracks the change in the lookup table based on recommendations and analyses the impact of modification. It continuously guides the customer for optimum operation. The energy management system also helps to identify changes in fuel by observing oxygen level changes and conducting consistency analysis across all the load brackets.

- **Uptime management system**

The uptime management system continuously monitors the critical parameters related to the health of the boiler like currents, hydraulic oil temperature, bearing temperature, vibration of moving equipment etc. It identifies the abnormality of the operation and sends a critical alarm to the user. It also observes the operation time and on/off frequency of each equipment. These data are used to recommend maintenance planning, repair requirements, and spare change requirements etc. It also generates and analyses data like grate speed to identify the possibility of jamming or mechanical damage. It analyses data on fouling like changing patterns of boiler exit temperature, pressure drop across the various equipment. ID fan frequency to analyse and predict the fouling of the boiler, the effect of fouling on efficiency and the plan for boiler cleaning.

It also has an incident management system integrated with fault tree analysis to identify the reason for the anomaly and a solution to rectify it.

7.2. Model-based control

Due to the variability in fuel and ambient conditions, boilers are normally operated in the sub-optimal condition. The problem can be resolved by the model-based control. A dynamic model-based control can use dynamic characterisation of the fuel and equipment to control the optimum parameter and maximise boiler efficiency. The concept can significantly change the operating efficiency and uptime of the boiler.

8. Conclusion

Energy efficiency upgradation, biomass conversion, and conversion towards clean energy sources like hydrogen and electricity will play a significant role in the future boiler technology development, operation and decarbonisation. Process integration, low-temperature heat recovery, and heat pump technology will be the key to efficiency improvement. Digitalisation and hybridisation can play a significant role in energy optimisation and decarbonisation through effective demand-side management and energy integration.

Title:	**Dr**
Full Name:	**Pritesh M.**
Last Name	**Shah**
Company Name:	**PRIMA EQUIPMENT, INDIA.**
Email Address:	pritesh@primaequipment.com
Telephone:	**9825007609**
Country:	**INDIA**

Presenter Bio:

“Only with Clean Environment & Intensions, Rises a Clean Great Nation...!”

Very Purposefully said by Dr. Pritesh M Shah, Chairman of PRIMA. Pritesh is a dynamic & Very Optimistic personality born in Jamnagar, a small town in Gujarat, INDIA

With a meagre cash amount of INR 140, PRIMA EQUIPMENT was established on October 11, 1992. While designing Gas Detectors, and Analysers for Safety, Pollution, and Environment Monitoring products, the priority was the ruggedness and sustainability of equipment.

In 1998, got an opportunity to develop continuous stack gas emission monitoring equipment and that sparked off a new journey in terms of design, development, and innovation.

PRIMA could now provide solutions as per customers' needs of pollution and environment monitoring applications to various industries.

Dr.Pritesh has developed an in-house Testing & Calibration facility as per EN Standards for CEM System, CAAQM System, Gas Detectors, Gas Analyzer testing & calibration, accredited according to ISO/IEC 17025 IAS, U.S.A., the only facility in Asia.

Being a technocrat and leader in the field Dr. Pritesh M. Shah has been invited to speak at various business and technical meets and conferences. His speeches and presentation are very highly regarded at national as well as international platforms.

He is a kind-hearted person and runs charitable foundation named “Kalabharti Charitable Foundation”, with the goal to cater Education, Entrepreneurship & Environment & Build Our Dream Nation.

Dr. Pritesh visualize PRIMA as a proud Indian manufacturer supplying equipment internationally. He would like to serve an increasing number of industries with the most affordable solutions while creating more awareness for environment conservation.

His mantra is 'if you can visualize it, you can actualize it.'

Precision Emission Monitoring: Reliability to Sustainability

Brief description of the presentation

A practice of performance testing & developing a **Reliability of measurement data to achieve a sustainable quality of Continuous Flue Gas & Dust Emission Monitoring System** for the operator.

In the current scenario, with the increase in Industries, pollution is also increasing. To reduce pollution various corrective measures have been taken by national & international regulations

Corrective action such as Standards for Quality Assurance Levels, Limit of Detections, Defining % of Emission limit value @95% confidence intervals, and many more.

For accurate measurement of source emission components, an Online Continuous Emission Monitoring System (CEMS) is used.

This presentation will discuss the Quality and reliability of CEM System performance, in regard to standards such as EN 14181 (QAL-1, QAL-2, AST), EN 15267-3, EN 15259, EN 13284-1, EN 13284-2. Performance test with the acceptance criteria is defined in these standards.

EN 15267-3 contains Performance criteria and test procedures (laboratory test & field test) for CEM systems for monitoring emissions from stationary sources.

The Thought:

- Deterioration of quality of air now a days due to dependency on industries.
- Industry & environmental quality levels are vice versa.
- Decrease in quality of the environment can lead to increase in disease related to heart & lungs.
- Reliable tested measuring equipment is a tool for accurate & credible Pollution Monitoring & reporting.
- Do AMS/CEMS have Accurate & Credibility Assurance?
- Can we rely on the Quality & Sustainability of AMS/CEMS installed at field?
- Is the AMS/CEMS & Sampling probe of AMS/CEMS Correctly Installed at the site location?
- Do AMS/CEMS operates properly at Field Location?
- Is calibration function & maintenance of AMS/CEMS done regularly by Operators & Manufacturers as per the defined method?

Do You Install AMS/CEMS, for only Regulatory Compliance Purpose?
Wish to UTILISE CEMS for PROCESS OPTIMISATION, SAFETY ASSURANCE & SAVE MONEY??

Will also be discussing Various standards adopted to ensure the Quality performance of the CEM System

Overview of Quality Assurance Level As per EN 15267-3, EN14181

Definition: QAL is a systematic approach to ensure the quality and reliability of industrial emission pollutants measurements from stationary sources.

Components: The QAL includes a set of quality control measures, such as the use of standardized testing equipment, drift & linearity check, maintenance of the equipment, calibration checks, and more.

Process: The QAL process involves the systematic assessment and verification of the performance of environmental measurement systems in three levels.

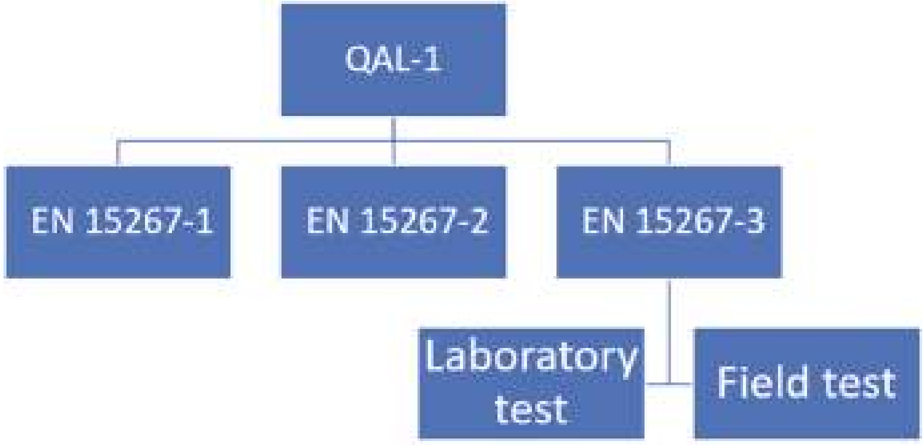
Types of QAL

Types of QAL

QAL-1	QAL-2	QAL-3	AST
Before Installation of CEMS	Post installation with calibration	During Operation	After one year of QAL_1
Once	At least every 5 year	Continuously	Annually
Operator/ Manufacturer from Accredited Laboratory	Accredited Laboratory	Operator	Accredited Laboratory
EN 14181 , EN 15267-3, EN 14956	EN 14181, EN 15259	EN 14181	EN 14181, EN 15259
EN 14181 : Cl. No 6, 8, 12 EN 15267-3 : Cl. No 10.9 ,.10,.11,.12,.13,.14,.16,.17,.19	EN 14181 : Cl. No 6 EN 15259: Cl. No. 8.3	EN 14181 : Cl. No. 7	EN 14181 : Cl. No 8 EN 15259: Cl. No. 8.3

Importance of Performance tests for manufacturers & Operators

QAL-1 is a Quality Assurance Level for Continuous Emission Monitoring Systems AMS/CEMS that focuses on ensuring reliable and accurate measurement of pollutants. It requires stringent testing procedures and performance evaluations.



SCOPE OF TESTING AS PER QAL-1

GENERAL REQUIREMENT PRIOR TO TESTING OF CEMS AS PER EN 15267-3 OF QAL-1

- Two identical AMS/CEMS Shall be provided to Testing Laboratory.
- Testing Laboratory will record all environmental and test conditions during the test.
  Various following VISUAL TESTS should meet for System under test prior to performing laboratory test:
- Cl. No. 10.1 AMS for testing
- Cl. No. 10.2 CE labelling
- Cl. No. 10.3 Security
- Cl. No. 10.4 Output ranges and zero point
- Cl. No. 10.5 Additional data outputs
- Cl. No. 10.6 Display of operational status signals
- Cl. No. 10.7 Prevention or compensation for optical contamination
- Cl. NO. 10.8 Degrees of protection provided by enclosures

1) **<u>Laboratory Test as per EN 15267-3</u>**

A) Clause No. 10.9 Response time

B) Clause No. 10.10 Repeatability standard deviation at zero point

C) Clause No. 10.11 Repeatability standard deviation at span point

D) Clause No. 10.12 Lack of fit

E) Clause No. 10.13 Zero and span drift

F) Clause No. 10.14 Influence of ambient temperature

G) Clause No. 10.16 Influence of the sample gas flow for extractive AMS

H) Clause No. 10.17 Influence of voltage variations

I) Clause No. 10.19 Cross-sensitivity

2) **Field Performance test as per EN 15267-3**

GENERAL REQUIREMENT FOR FIELD TEST AS PER EN 15267-3 OF QAL-1

- Source Emission Mass concentration in the range of 30 % to about 100 % of the daily emission limit value being monitored.
- The measurement site shall be selected in accordance with EN 15259.
- The field test duration shall be at least 3 to 4 months and shall not be interrupted
- During the field test, the performance criteria shall be determined under near-practice and realistic conditions.

A) Clause no 12.1 Calibration function
B) Clause no 12.2 Response time
C) Clause no 12.3 Lack of fit
D) Clause no 12.4 Maintenance interval
E) Clause no 12.5 Zero and span drift
F) Clause no 12.6 Availability
G) Clause no 12.7 Reproducibility
H) Cl. No. 8.3 Determination of Homogeneity of EN 15259:2007
I) Testing for QAL-2 asper EN 14181:2014- Clause No.6. Calibration Function & Functional Test

KEY BENEFITS OF QAL-1

Improved Accuracy: Through the verification and calibration of test results, QAL can help ensure that the data is reliable and accurate, providing insight into process efficiency.

Increased Efficiency: The assurance provided by QAL can have a positive impact on the efficiency of the process, reducing the production costs and minimizing waste.

Legal Compliance: Testing compliance Reports and certification provides legal compliance for emission testing; this is an essential requirement for facilities to obtain an operating permit for their pollution systems.

AVAILABLE FACILITIES FOR PERFORMANCE TESTING COMPLIANCE FOR EN 15267-3, EN14181, EN 15269, QAL-1, QAL-2, AST.

UK	NPL, London
GERMANY	TUV Rheinland
INDIA	TCQA LABS PVT. LTD.

Keywords: Automated Measuring system, Continuous Emission Monitoring System, Quality Assurance Level, Sustainability, Emission Limit Value, EN 14181, EN 15267-3, TCQA LABS, Performance testing, Quality, standard.

Abbreviation: Automated Measuring system (AMS); Continuous Emission Monitoring System (CEMS); Quality Assurance Level (QAL).

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Bill Gurski

Director, Global Power Sales and Applications Engineering

Bill Gurski brings over 33 years of combined industry experience in the utility, industrial, combined cycle and large commercial markets to his position as Director of Global Power Sales within the Zeeco Power Group. Zeeco Power incorporates Ultra Low NOx and Low NOx firing system technology for all the above markets including products, services and turnkey projects.

His industry experience includes executive management, business owner, global business and product development engineering for boiler and burner companies, including Combustion Engineering / Alstom Power / GE, Todd Combustion, John Zink Company and Hamworthy Peabody Combustion.

Bill has also authored numerous technical articles and published papers for Power Engineering, AIChe, ASME, AFRC, CIBO and ABMA Today's Boiler.

Bill Gurski

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Web: www.zeeco.com

William H. Gurski Zeeco Inc. - Power Division

OVERVIEW:

30+ years of Boiler and Combustion systems experience for Utility, Industrial, Fluid Bed, Stoker, HRSG and Package Boilers. Partial experience includes +30,000 MW's of utility boiler / firing systems experience (design / installation / commissioning / start up), several hundred industrial boilers (new and retrofits) and package boiler combustion systems (new and retrofits) – equating to several thousand burner systems supplied. Experience includes process applications (pressurized air heaters, kilns, etc.)

CURRENT WORK EXPERIENCE:

May 2011- June 2016 Director, Global Power Sales and Applications Engineering Oct 2021-Present: Zeeco Inc. – Power Division - Plainville, CT - USA

- Market / Sales responsibility and management for Zeeco – Power Division
- Division Business Management of Sales and Applications including commercial
- Business development, risk analysis / profit analysis and engineering for all Power Contracts - Utility, Industrial and Turnkey Contracts.
- Continued expertise in solid fuels (coal, wood, renewables), gaseous and liquid fuels
- Assistance for Market / Product development and engineering

PAST WORK EXPERIENCE INCLUDES:

The Boiler Expert, LLC

Owner / Principal, Shelton CT – USA

- Consultant to the Power industry for various clients – utility, industrial, universities, colleges, and large residential co-ops.
- Performed a variety of engineering evaluations including energy studies for the clients, boiler and combustion system review and optimization.
- Owner’s Engineer for several clients to assist with retrofit and new power plant additions.
- Service and start up work for said clients.

Analytical and Combustion Systems Vice President of Sales, New Milford, CT

- Development of Principals for new products and services
- Sales development for new boilers, projects, and combustion systems
- Marketing integration for new and existing products and services.
- Market expansion for new principals and products

National Sales Manager – Americas

Hamworthy Peabody Combustion, Division of Hamworthy Combustion - Shelton, CT - USA

- Market / Sales responsibility and Management for Hamworthy Combustion Power Division for the Americas
- Business Unit Management and Direction
- Business Development for Utility, Industrial (Power and Process Boilers) and Large Commercial contracts. (all boiler designs and firing systems)
- Expertise in Solid Fuels (Coal, wood, renewable / opportunity fuels), gaseous and liquid fuels.
- Presentations and Papers Published with several trade / industry associations.

Manager, Utility and Industrial Boiler Business Development

ALSTOM Power Inc. – Utility Boilers - Performance Projects Group - Windsor, CT - USA

- Market responsibility and Management for Industrial, Utility and Fluid Bed Business Development (All boiler designs and firing systems)
- Development of Market & Business Development strategies, marketing tools & product development.
- Responsibility for Business Unit integration for customer and business development for the Performance Projects Business Unit.
- Recent development and strategic training of in-house staff as front-line sales support for Performance Projects Business Unit.
- Six Sigma Black Belt training and execution of two Six Sigma Projects.
- Also served in capacities of project management and engineering, plus design and service engineering duties as needed.
- Presentations and Papers Published with several trade / industry associations.

Project Engineering – Product Design Engineering KOCH Industries - John Zink LLC- TODD COMBUSTION Group - SHELTON, CT - USA

- Project Engineering & Management on various projects; Utility & Industrial Turnkey Low NOx Burner Projects.
- Low NOx Burner Engineering and Design, ancillary systems engineering and design (pressure piping, structural, windboxes, fans, BMS/ CC's, etc).
- New and retrofit installation, unit performance and operational evaluations for new Low NOx Burner installation projects, including burner design & installation on ALSTOM, FW, B&W, Riley, etc.
- Design, engineering, fabrication, and implementation of new R&D and "Burner Kit" projects for emissions reduction.
- Also performed Service Engineering duties, client training, and new staff training.
- Presentations and Papers Published with several trade / industry associations.

Project Engineering - Project Management

PEABODY ENGINEERING CORPORATION. - SHELTON, CT - USA

- Project Engineering and Project Management on varied products; Utility and Industrial Low NOx Burner Projects, Air Heaters, CFB Duct Burners, Kiln Burners and Packaged Burners. Experience includes domestic and international clients.
- Various Types of Burner Engineering and Design; ancillary systems engineering
- New and retrofit installation projects, unit performance and operational evaluations for various Burner installation projects.
- Full working knowledge and experience with CSA/CGA, FM, IRI, NFPA, ANSI/ASME Power Piping / Pressure Vessel code and many foreign codes.

Project Engineering - Project Management TODD COMBUSTION, INC. - SHELTON, CT - USA

- Project Engineering and Project Management on various projects; Utility and Industrial Turnkey Low NOx Burner Projects and Packaged Burner Projects.
- Low NOx Burner Engineering and Design, ancillary systems engineering and design (fuel/steam/ air piping, structural, windboxes, fans, BMS/ CC's, vendor components) on all boiler OEM's and types.
- New & retrofit installation, unit performance & operational evaluations for new Low NOx Burner installation projects.
- Also performed Service Engineering duties, client training, and new staff training.

Technical Services Department - Service Engineer

ABB C-E SERVICES, INC. (Now ALSTOM Power), PITTSBURGH, PA / WOODBRIDGE, VA (USA)

- Responsibilities included on-site management, engineering, and installation of ABB C-E Low NOx Burner Systems (clients include Reliant, PP&L, Dominion and many other utility and industrial sites).
- Experience includes various pressure part retrofits, new and existing windbox retrofits, all structural modifications, pulverizers and start up and test for all BMS and control systems.
- Other experience also includes boiler inspections operational tuning and performance for all pre / post retrofit installations, troubleshooting and tuning of new Low NOx and ancillary systems, and full unit performance and emissions guarantee tuning.
- Boiler condition assessments / life extension studies / uprating / fuel conversions engineering and installation.

BOILER FUEL CONVERSION FROM COAL / HEAVY OIL TO CLEANER FUELS LIKE NATURAL GAS & H2.

Decarbonization is the reduction or elimination of CO2 emissions into the atmosphere primarily from processes such as manufacturing or the production of energy. The reason for focus world over on decarbonization is the need of the hour to avoid climate damages (global warming) as well as health damages which have become a huge cause of concern world over.

Rapid decarbonization and reduction of all harmful pollutants emissions is a critical strategy for the current Indian government's climate goals of reducing greenhouse gases by 45% below 2005 levels in 2030, with the goal to net-zero greenhouse gas emissions by 2070.

One of the major pillars of Decarbonization is Energy Efficiency and switching over to **Low Carbon Fuels, Feedstocks and Energy Sources.** Developing fuel flexible processes, Integration of cleaner fuels like Natural gas & hydrogen, use of biofuels into industrial and utility applications is going to be the main topic of discussion for our today's seminar on Fuel Conversion.

Zeeco is a world leader in Low NOx & Ultra Low NOx burners for all boilers – new and retrofit kits up to 400 MMBtu/hr single burner heat release. It has tons of experience **of Fuel Conversions / Additions (Oil/Gas) on any boiler design (Utility, industrial, stoker, wall, CFB, etc.)** as well as done such retrofits of literally every major Boiler OEM globally.

With the **ZEECO experience in Fuels Conversions Studies for Boilers as well as Physical air flow and CFD modelling,** discover the seamless way of converting your boiler to the cleanest fuel possible without compromising on efficiency, safety and reliability.

To understand the technology and expertise for such Fuel conversions, please do attend the seminar on 25th Sept 2024 (Day 1 of the Expo) @ 15.45 hours for an engaging discussion to be delivered by Mr. Bill Gurski, Director – Boiler burners Sales and Applications at ZEECO USA. The venue for the same is the Auditorium and Multipurpose Hall at the Cidco Exhibition Centre Vashi.

General Company Information

- #1 combustion company in the world
- 26 global offices
- 8 manufacturing facilities
  - Oklahoma, USA (HQ)
  - Kansas, USA
  - Mexico
  - United Kingdom
  - Saudi Arabia
  - India
  - China
- 3 combustion test facilities
- Oklahoma (HQ), United Kingdom, South Korea ▪ South Korea
- 2 airflow modeling laboratories (USA and China)
- Over 60,000 installations in over 100 countries
- 3,000+ employees (2,000+ engineers and technical professionals)

Product Line and Capabilities

Ultra-Low-NOx and Next Generation Ultra-Low-NOx Burners

Thermal Oxidation, Sulfur Recovery Units (SRU), Waste Heat Recovery Equipment, and Flue Gas Treatment Systems

Gas and Liquid Flares and
Flare Systems

Vapor Recovery Units (VRU), Vapor Combustor Units (VCU), and Flare Gas Recovery (FGR)

Product Line and Capabilities

Rental Flares, Combustors, and Thermal Oxidation Systems

Global Field Services and Support – 24/7, 365

Direct Replacement Parts and Engineered Solutions for All Combustion Equipment

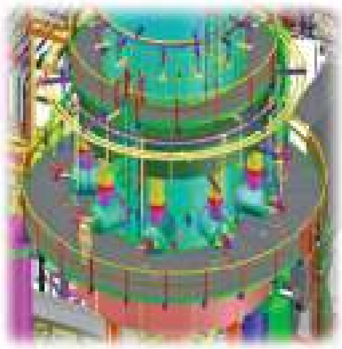
Flame Scanners and Flare System/Pilot Monitoring

Broken Arrow Test Facility:

- 22 total test rigs
- 16 Test furnaces
- 1 Furnace under construction
- 170,000 pph Packaged boiler
- Boiler and Duct Burner Rigs 6 test flares
- Full Data acquisition for all emissions

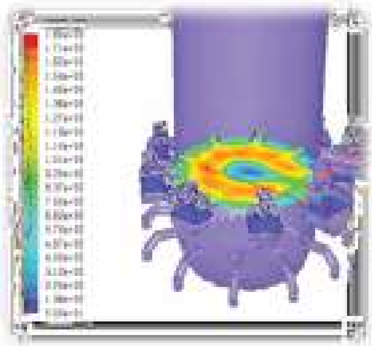
Test Facility / Testing Capabilities

Advanced Engineering Capabilities



3-Dimensional Modeling

Computational Fluid Dynamics (CFD)

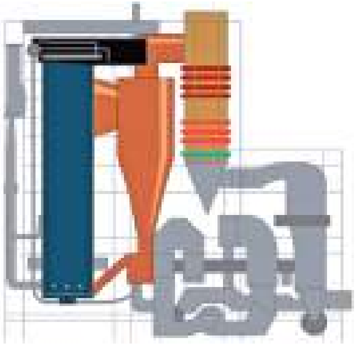


Finite Element Analysis (FEA)

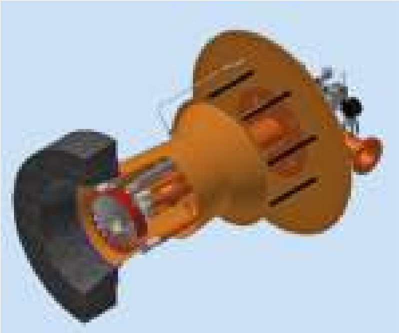
Product Development & Testing

Fuel Conversions

Zeeco Power Product Overview



- Ultra Low NOx FreeJet / GB burners for all boilers – new and retrofit kits up to 400 mmbtu/hr single burner heat release
- Fuel Conversions / Additions (Oil/Gas) – any boiler design (Utility, industrial, stoker, wall, CFB, etc.)
- Low NOx Duct burners rated +700 mmbtu/hr and ancillaries
- All classes of ignitors / gas / oil guns, up to +80 mmbtu/hr
- Fuels Conversions Studies
- Physical air flow and CFD models

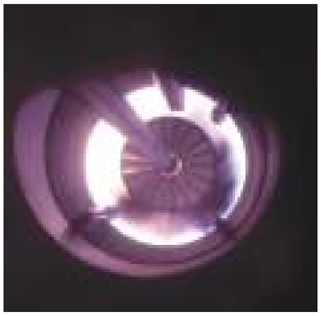


Zeeco Power – Combustion & Boiler Expertise

- 25 years average technical experience
- >500 years combined experience
- >2000 burners installed worldwide
- Zeeco Power engineers have:
  - Worked for the most prominent combustion companies in the industry
  - Authored the well-known combustion handbooks in circulation today
  - Designed/engineered many of the low/ultra- low NOx burners used throughout the industry
- Zeeco personnel have been in most of the steam/power plants across the globe

Zeeco Expertise to Serve Your Customers:

- 11000+ venturi / parallel flow style burners designed and installed.
- Several hundred material / turnkey contracts for industrial, CFB, stoker, OTSG, package and utility boilers.
- Several hundred airheaters, kilns, elbow duct burners engineered / designed, commissioning and installation
- 112,000+ MW of utility projects.
- 500+ duct burner systems for power and industrial installations.
- 75+ turnkey / material stoker start up burner contracts.
- Several dozen single / multi burner projects in Canada:
- TSSA, BCSA, ABSA, etc – NG, HFO, LFG, BFG, COG, RFG, etc
- Material and Turnkey projects
- Hundreds of multi-solution projects in worldwide refineries – burners, flares, thermal oxidizers, process burners, aftermarket



Zeeco Expertise to Serve Your customers:

- +350 years Boiler OEM Expertise on Staff - Alstom, C-E, Mitsui Babcock, Riley Power, Foster Wheeler, Kvaerner / Metso
- +250 Boiler Studies for analysis on performance and conversions
- 1700 TEG / air system CFD and Physical models utility, industrial, stoker, HRSG, SCR & package boiler systems.
- 400+ BMS and Control systems designed and engineered for all market sectors / boilers types, along with coal / oil / gas firing systems
- 600+ Burner and Firing Systems designed and supplied contracts
- 75+ contracts for oil and gas ignition systems, ranging to 80 mmbtu/hr (dual purpose igniters and warm up guns).
- All Gaseous and Liquid fuels (NG, Hydrogen RFG, LRG, #2/#6, Bitumen, Pitch, NCG's, etc.
- 60+ Fluid Bed Start up and Support Firing Systems with ancillary equipment.

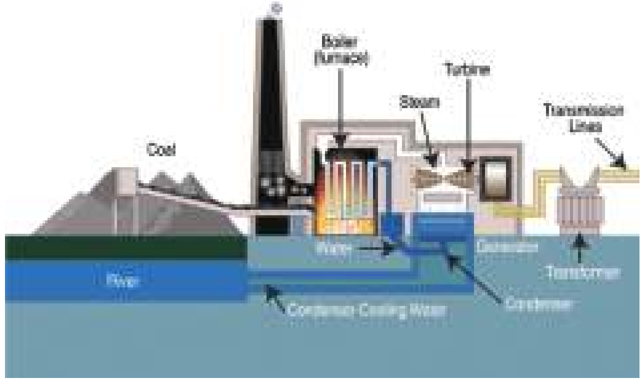
Partial list of New / Retrofit boilers with Zeeco Power Burners

➤ B&W multi burner boiler	➤ Rentech HRSG	➤ Erie City	➤ HRS
➤ FW package boiler	➤ Vogt HRSG Boiler	➤ Lentjes	➤ Ecoenergia
➤ Riley stoker boiler	➤ Lamont (Indeck) HTHW Gen's	➤ Nooter Eriksen	➤ Harbin
➤ B&W utility boiler	➤ Zurn package boiler	➤ BHI Utility boilers	➤ MHI
➤ FHI (Alstom / CE) CFB boiler	➤ ABCO	➤ NEM HRSG	➤ Hangzhou
➤ Alstom (CE) Tangential fired	➤ Bryan boiler	➤ NEM Field Erected	➤ Shuanliang
➤ boiler	➤ ESI stoker boiler	➤ Valmet (Metso)	➤ EIT
➤ Alstom (CE) Package Boiler	➤ English Boiler	➤ Thermax	➤ Murray Iron Works
➤ Alstom Wall Fired	➤ Nebraska Boiler	➤ ISGEC	➤ Cochran
➤ Macchi Boiler	➤ Jianglian	➤ Sifang	➤ CMI
➤ Pensotti boiler	➤ Shangdong	➤ BHI	➤ Simoneau
➤ Victory Package Boiler	➤ Hailu	➤ DKME	➤
➤ Victory HRSG			

Plant Re-Powering Retrofit and Fuel Conversions

General Fuel Conversion Information

- What are the primary reasons for fuel conversions:
  - Main – emissions, boiler performance, condition assessment
  - Can be done on utility, industrial, HRSG, package style boilers
  - Environmental pressures / Lower emissions
  - Low CO2 initiatives
  - Conversion incentives
  - Operating costs including maintenance and manpower, fuels
  - Electrical / Steam generation changes
  - Fuel availability / logistics
  - Cost of new / replacement generation assets
  - Local impact (manpower, community)
  - Equipment upgrades / Reliability improvements

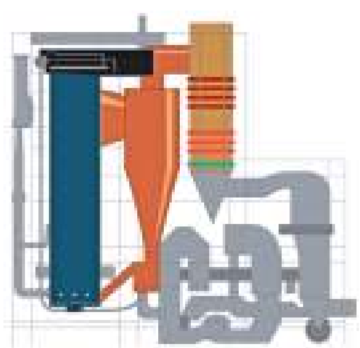


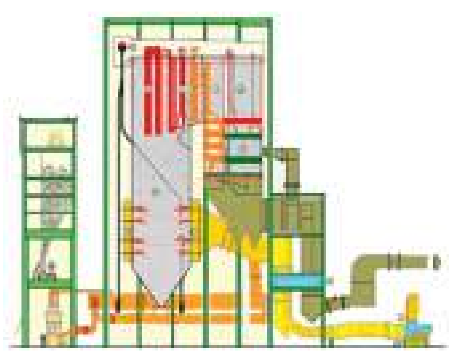
General Fuel Conversion Information

- Where can fuel conversions apply:
  - Electric Utility Plants
  - Industrial sites (chemical, refinery, steel, textiles etc).
  - Universities, Colleges
  - Health Care, Hospitals
  - Large housing complexes
  - Co-ops
  - Regional power facilities

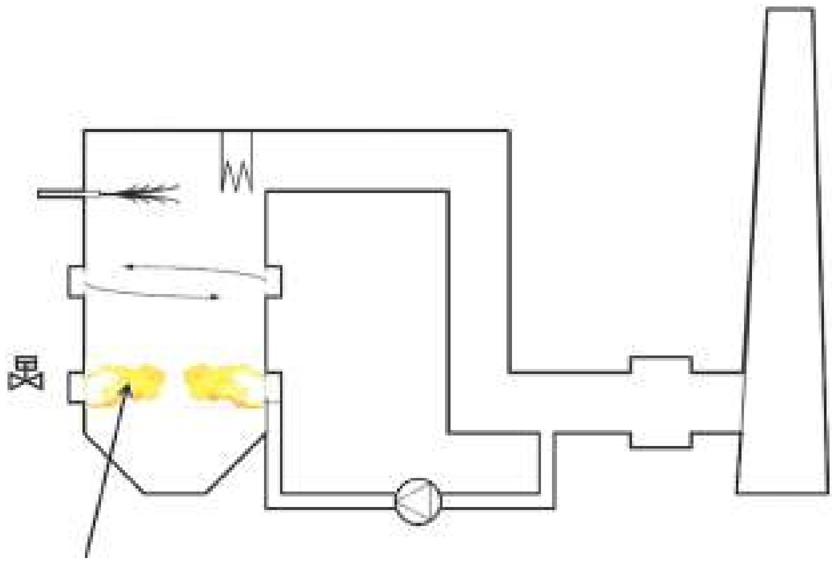
Boiler Analysis – Basics and what is needed:

- Integral part of the co-firing / conversion for “new fuel”
- Maximize steam temperature and integration of the new fuel(s).
- Determine the feasibility of operation with full steam temperature and steam flow.
  1. Steam and gas side temperature profiles, superheater metal temperature profiles, boiler efficiency, air and flue gas flows, fuel flow requirements, and pressure drop.
- Evaluate all practical ways to maximize boiler rating, efficiency - operate at the normal operating range
  1. Field data, including operational data for each unit, will be required to “harmonize” the boiler performance program to existing operation to ensure proper engineering and design to the actual data from the boilers.
- The Boiler Impact Study is based upon the following specific tasks that will be performed:
  1. Review baseline boiler performance, of the boilers at full load utilizing file reference operating data
  2. Perform an analysis of the existing superheater / reheater, header and link piping for compliance with ASME Section 1 compliance requirements.
  3. Based on file and test information, assess the air (primary, secondary, FD and ID fan systems for adequacy when firing the new burners, mixed fuel and “new fuel” at the MCR load point.
  4. Assess the potential for boiler vibration when firing “new fuel” and mix.
  5. Review existing firing systems and controls / DCS to verify compliance with “new fuel” firing.
  6. Prepare a report addressing the findings, conclusions and recommendations associated with this Scope of Work.
  7. Pricing and scope estimates as required



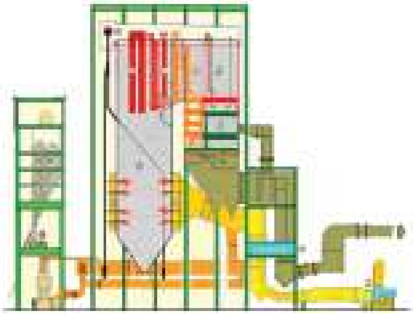


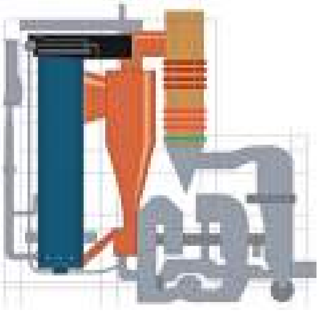
Emissions analysis - What are the Techniques Available Today to Reduce NOx Emissions?



How do Manufacturers Evaluate NOx Emissions?

- Major Factors that influence NOx and other emissions:
  - Combustion air temperature
  - Combustion air balance
  - Fuel composition (mixed fuels)
  - Furnace geometry and design
  - Refractory (CFB / BFB)
  - BZHR - Burner Zone Heat Release
  - Flame temperature / Burner geometry – Our Focus!
  - Zone heat release analysis of the radiant section to determine heating surface



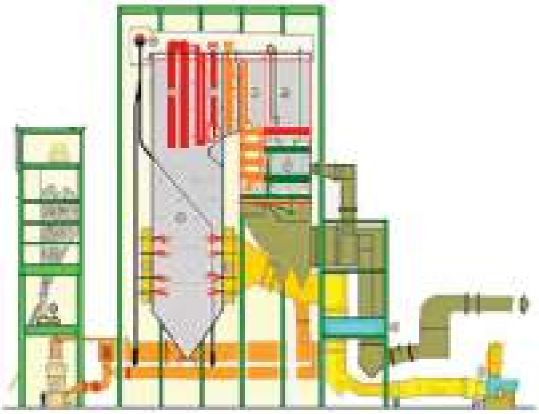


Emissions Considerations – part of boiler study:

- What factors determine achievable emissions – need to be addressed in thermal analysis:
  - NOx
    - O2, Excess Air
    - Furnace Construction / Refractory Detail
    - Combustion Temperature
    - Reaction with Nitrogen
    - Lowering CO
  - CO
    - O2, Excess Air
    - Combustion Efficiency
    - Low NOx and FGR
    - Combustion Temperature

General Fuel Conversion Information:

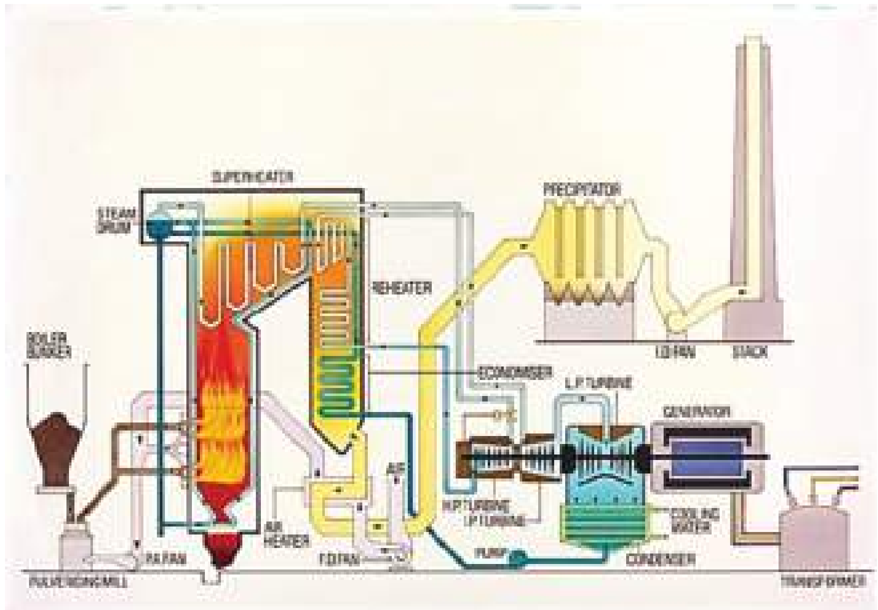
- What is to be considered and reviewed for candidates for conversion:
  - Power Plant and Boiler design, construction and vintage
    - Age of the equipment / asset
    - Operating / maintenance costs
    - Current capacity of operation (electric generation or steam production)
    - Current Performance (does it meet the original or updated design requirements)
    - Any significant upgrades, modifications, etc.
    - Knowledge transfer from plant staff and interviews for plant assessment



  - Location of the plant:
    - Fuel(s) availability – space for new fuel production
    - Consistency of generation, i.e. capacity factor for electric generation or steam production (revenue)
    - Community viewpoint / importance (employment for local trades, support businesses, etc.)
    - Schedule / Timeline for conversion

General information needed for review:

- Boiler drawings and details
- Field Data to conform boiler analysis
- Design boiler conditions including heat input (MMBtu/hr.)
- Combustion air/FGR temp and duct losses
- FD / ID fan information, manufacturer, ratings, curves, available windbox / furnace dP (RDL)
- O2 (excess air) control range Windbox / duct dimensions
- OFA ports (if applicable) with elevation, separation, size, quantity, location and waterwall openings



General information needed for review:

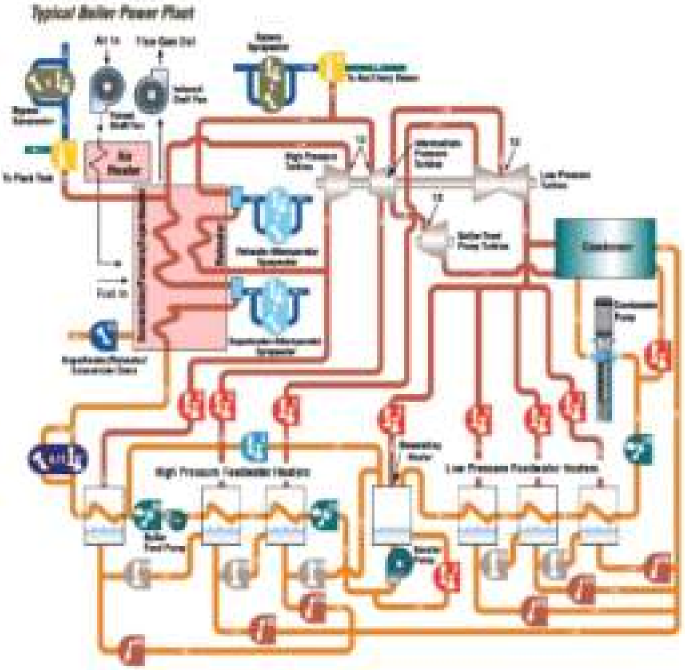
- Recent fuel analysis (ultimate analysis)
- Available fuel pressure
- Common Fuels:
    - Hydrogen, Natural Gas, Refinery Gas, #2 / #6 oil, Low-BTU, waste, etc.
- Existing control system details - BMS, CCS, DCS, O2 Trim Existing igniters (NFPA Class and Fuel)
- Existing flame scanners

GENERAL RETROFIT INFORMATION

- Where do you find this information?
- Boiler manufacturers data sheets in owners manual Plant filing systems / archives
- General arrangement drawings (front, side, refractory, tube)
- Burner drawings Windbox / duct drawings Fan curves
- Operating data (PI data) Outage inspection reports

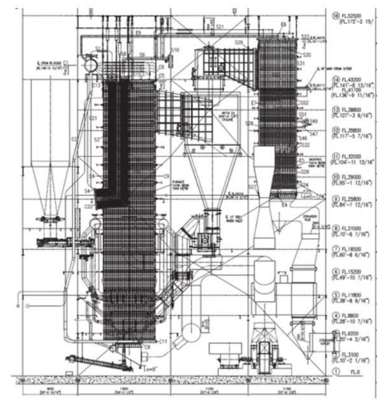
Plant / Generation / Boiler Audits

- Considerations:
  - Fuel Costs
  - Personnel costs (staff reductions if solid fuel conversion
  - Equipment “layup” and storage
  - Maintenance costs
  - Condition assessments
  - Water costs for steam generator
  - Plant Pro Forma



Case Study - Project Overview

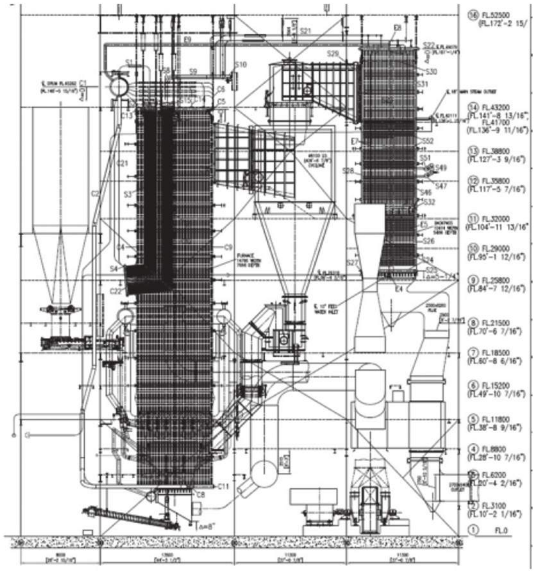
- CFB conversion from solid fuel to Natural gas
    - For economic reason due to solid fuel costs and NOx emissions
- 1200 kpph utility design CFB
- Assisted end-user and boiler OEM with full conversion for boiler modifications and firing system modifications
- Zeeco has many years of Boiler OEM experience for CFB's and BFB technology (boiler and firing system design, varying radiant / cyclone, loop seal, FBHE, convective section designs).



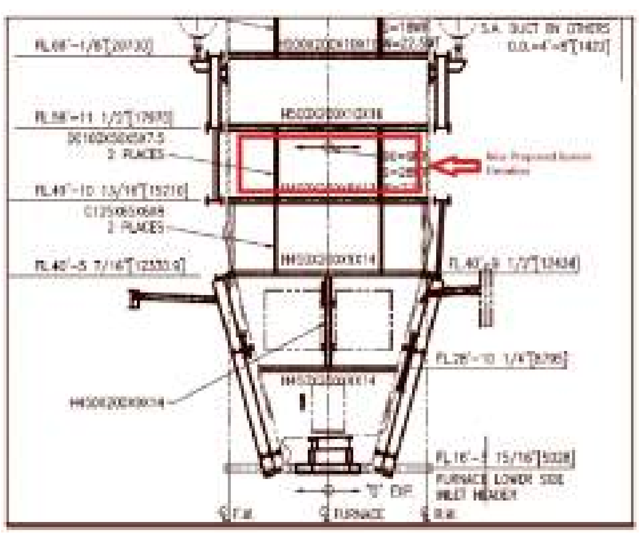
Topics:

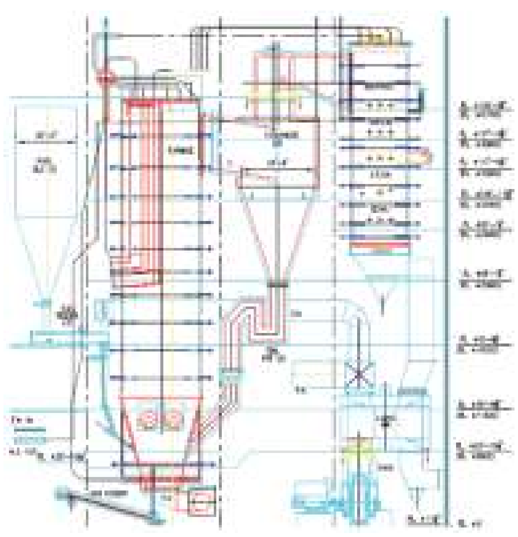
- The CFB
    - Designed for Solid fuel – solids recirculation
    - Heat transfer (water and steam circuits) for solid fuel firing
    - CFB plant in service for under 1.5 years in total before decision (economic)
        - After initial engineering, Plant wanted to keep potential for returning to solid fuel..
    - One key point – if a CFB can be converted, so can your boiler (whether solid, liquid, gas.)
- Challenges to overcome:
    - Meet current permit NOx limits – 0.07lbs/mmbtu
    - No E-FGR (convective impacts).
    - Ensure no degradation / derate on steam production.
    - Solids return systems – cyclone
    - Ancillary equipment
    - Fluidization system

- Solutions:
  - Thermal performance analysis (boiler) cases run with varying firing systems solutions
  - Very important to water and steam circuits
  - Firing system cases – chosen one was dual elevation (run with thermal boiler performance)
  - Performance runs are critical for waterwall protection system (circulation ratio) and reliable steam production post-retrofit.



Firing System Selection:



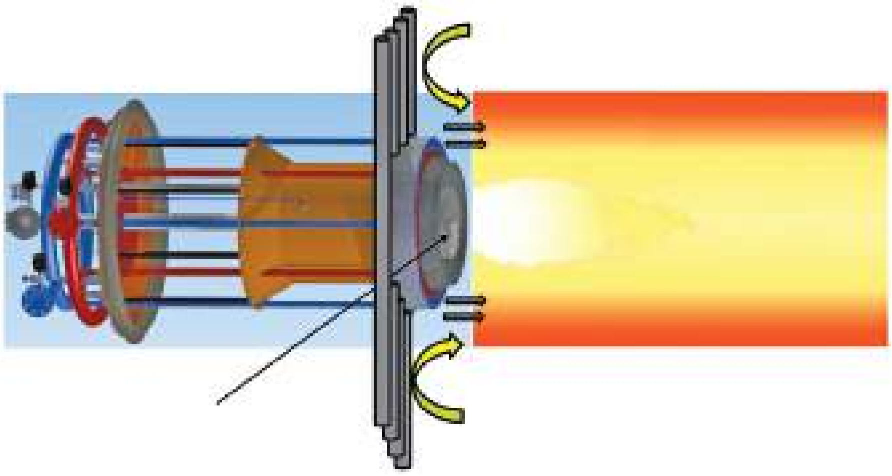


Fluid Bed Bottom – refractory to be removed:

Project Overview, Continued

- Zeeco's scope:
- New Low NOx Gas fired burners – eight per boilers
- 177 mmbtu/hr capacity
- Complete header and local valve trains
- Redundant BMS
- Controls Logic and Boolean
- Installation assistance
- Fixed Price Start up
- Complete new combustion air system
- KEY GOAL – maintain 80% of original solid fuel firing equipment for future potential for conversion back to solid fuel

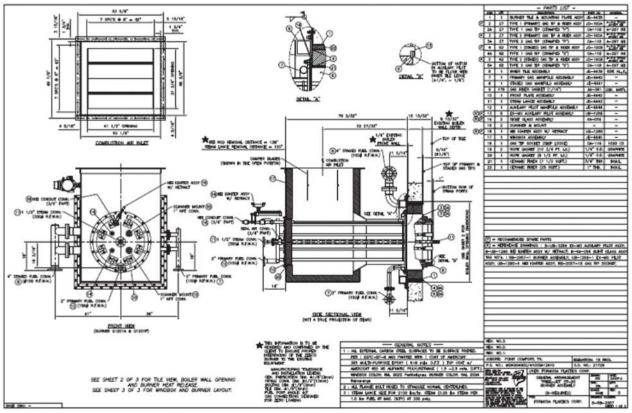
Zeeco Free Jet - Fuel Reconditioning for Lower Thermal NOx:

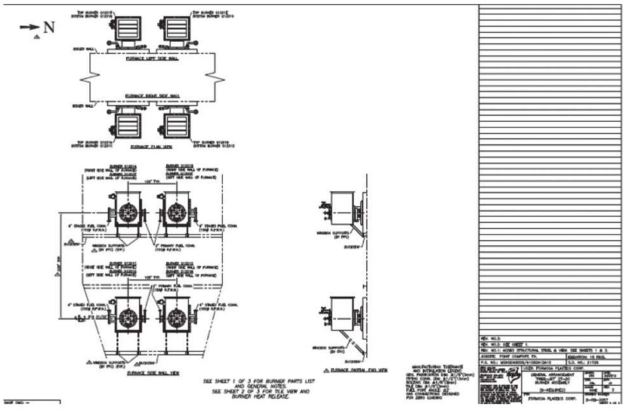


- Simple design for a complex problem.
- The fuel gas is mixed with inert products of combustion before combustion occurs, thus “reconditioning the fuel gas”.
- Mitigates / eliminates need for external FGR fan / ducting / insulation / hangers etc.

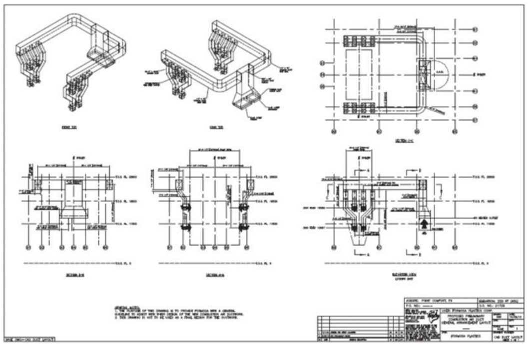
Recent contract for CFB gas conversion –

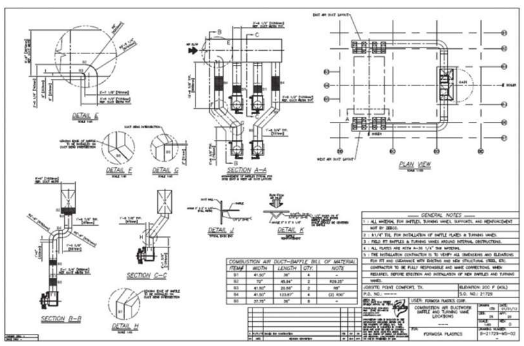
burner general arrangement:





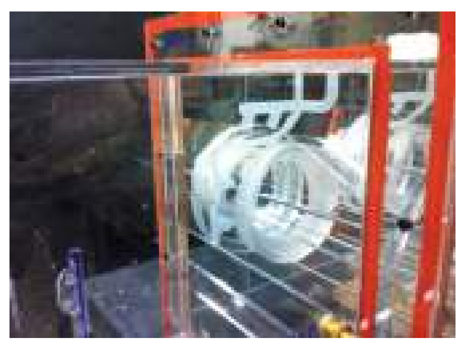
Complete redesign of Air system and airpreheater:



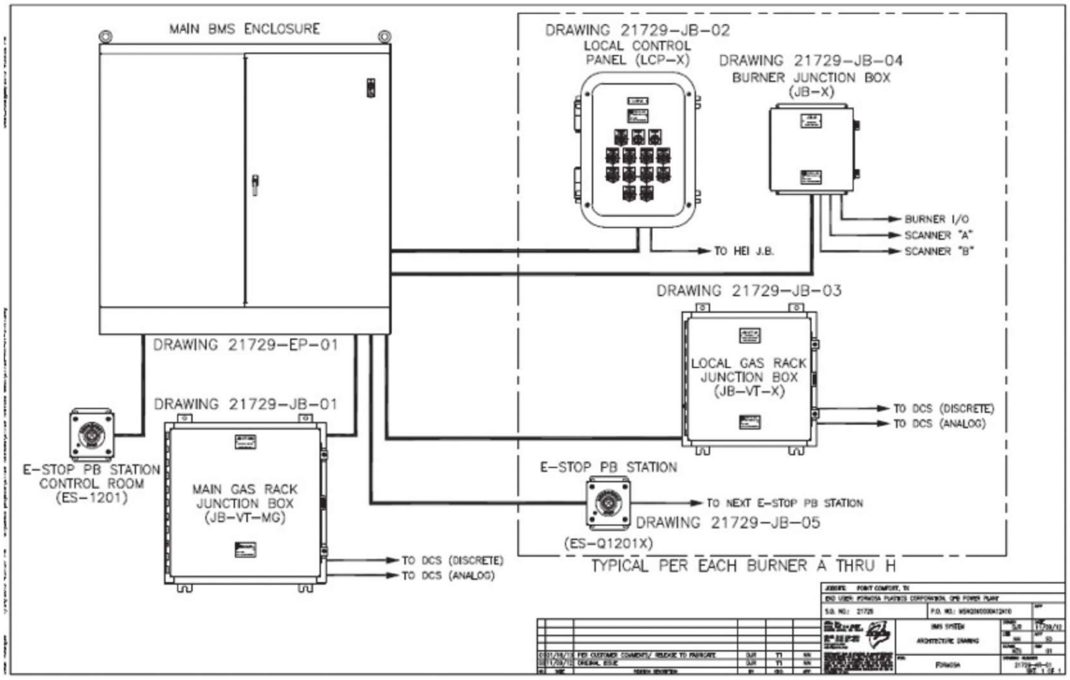


Physical / CFD Modeling

- 95% mass thru burner is air
- Requires balance
- Lowers excess air
- Lowers CO2 footprint
- Burners / OFA / FGR systems
- Low pressure fuel systems
- Coal units…

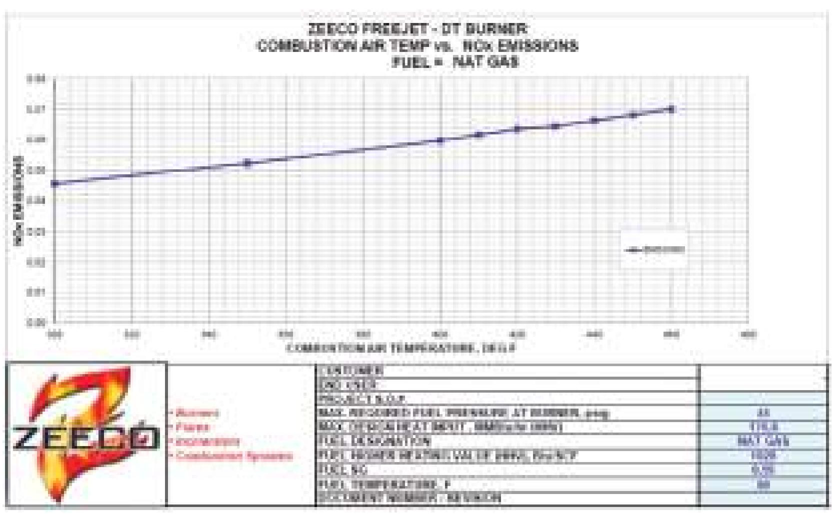


System Architecture:



Data / Validation / Conclusion:

- Physical flow modeling:
    - All burners within ~1% airflow distribution
- NOx – 0.07 lbs/mmbtu (25-100%boiler load)

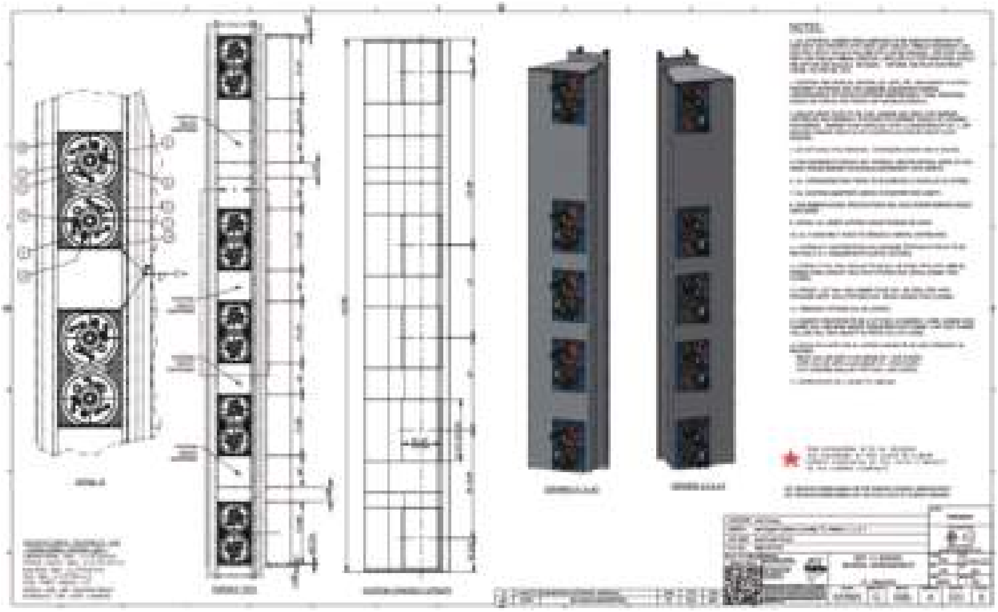


- CO – less than 50 ppm
- Steam production as designed and modeled (and required for steam turbine performance).
- Temperature duties in the water and steam cycle as modeled.
- Lastly – full conversion from a solid fuel fluid bed process to a natural gas fired boiler – all within 12 months
- Second boiler awarded / now completed as well
- Zeeco is currently studying numerous CFB's for conversion.

Case Study – Xcel Energy Harrington Station

Harrington Station:

- Three (3) C-E controlled circulation T-Fired units
- 2,680 mlbs/hr SH; 2,180 mlbs/hr RH
- Coal to Gas conversion and boiler study
- 3,600 kbtu/hr gas input
- 5 elevations, 40 burners per unit / 3 level SOFA
- 0.15 lbs/mmbtu NOx
- 3D model, Low NOx burners, all fuel piping from metering yard, installation drawings



1. **Full Name:** Nagamanickam P
2. **Company Name:** Retd ED from BHEL
3. **Designation:** Executive Director/ Spares & Services Business Group (SSBG) – Retd.,
4. **Education Qualification and Education Institute details:**
   - B.E. (Mechanical) - CIT Coimbatore, Madras University
   - M.E. (Design & Production of Thermal Power Equipment) – {formerly REC} NIT Tiruchirappalli.
5. **Job Profile:**

   Mr. Nagamanickam joined BHEL as an Engineer Trainee in 1984 at Tiruchirappalli Boiler Plant. With over 37 years of experience, he held various positions of esponsibilities within the organisation in areas of Field Engineering Services (FES), Renovation & Modernisation (R&M) and Spares & Services Business up to General Manager. In 2018, he was transferred to BHEL HQ and took charge as Head of SSBG and HERP. He became Executive Director of SSBG and continued till his retirement in 2021. In his journey at SSBG, he directed a steady growth in order booking, project management, execution of R&M orders.
6. **Experience:**

   For major part of his career till middle management, Mr. Nagamanickam focused on customer service through Field Engineering Services, trouble-shooting of boiler issues in the areas of boiler pressure parts, boiler fuel systems and combustion, performance optimization of high-pressure boilers and industrial boilers, supporting customers during their emergencies and providing diagnostic services for safe, reliable and optimised operation.

   At senior management level, he spearheaded the Spares and Services support to all major power plants to ensure their trouble-free operation and maintenance of boiler and auxiliaries. As Executive Director he ensured the timely supply and availability of spares and services for the whole power plant {BTG} for the PAN INDIAN customers of BHEL. He also handled the effective execution of R&M projects of various types and capacities and ensured their successful completion.

In addition, Mr. Nagamanickam also trained young engineers in the field of boilers and interacted with boiler board officials on a regular basis for equipment design aspects and to meet the Indian Boiler Regulation and standards for the life assessment of critical components.

7. **Achievements:**

- Solved many issues related to boiler and its auxiliaries to the satisfaction of the customers, both in domestic and overseas power plants.
- Had contributed in the field of residual assessment studies and condition assessment studies and had close association with central Boiler board and Boiler boards of various states.
- Solved many pressure parts, combustion optimisation(COAL, OIL & GAS} and tube failure issues for many customers.
- Worked as a dedicated Task Force member for the Boiler Tube failure Reduction with Mahagenco and GSECL .
- Some of the notable international assignments successfully carried out by him are below,
- Boiler retrofit at 50 MW Sidhirganj Station (Bangladesh)
- Resolution of major problem in Boiler left right temperature difference at 120 MW Pasir Gudang Station (TNB, Malaysia)
- Burner issue resolution paving way for completion of PG testing at TJPS Malaysia
- Resolution of a major noise problem for the Boilers supplied to Al-Arish Power Station (Egypt) which upheld the reputation of BHEL with the overseas customer.
- Business generation in Non-BHEL overseas arena by providing expert service to Batu Hijau plant of Amman Mineral in Indonesia.
- Rich experience of conducting many customer training programmes, customer meets and conferences for the knowledge sharing.
- Worked for World Energy council as a Technical Member for Efficient operation of Aged coal fired power plants in south East Asia for 2 years along with members from Japan, Indonesia, Thailand, etc. Visited power stations in in India and Indonesia and shared the experience in the world energy conferences at Bangkok (Thailand } and Daegu (South Korea),
- Served as Chairman Institute of Engineers at Tiruchirappalli Local Chapter in the years 2012-2013 and during his period the institution grown from strength to strength and Seminar on super critical Technology was conducted at National Level
- Best Engineer Award was conferred on him by IEI in the Year 2015.
- He is a Life member of Indian Institute of Metals
- Presented more than 25 Technical papers in National, International Seminars and in journals mainly in the area of Combustion, Boiler pressure parts failures and remedies, Residual life assessment of boilers, Renovation and Modernisation of boilers, corrosion problems in boilers etc.,

CONDITION ASSESSMENTS AND CONDITION MONITORING OF BOILER PRESSURE PARTS AND COMPONENTS AS PER IBR 391 A REGULATION

Abstract

There is a growing need of power in our country and huge power addition programme is at the forefront owing to the National Electricity Plan 2022-2032, through Renewable Energy Sources and fossil fuel-based power plants by means of super critical units. These projects are expected to get commissioned and meet the increasing demand of power in the years to come. However, even with this fast addition of power plants, it is expected that the supply may not commensurate with the demand and a gap may exist in the power requirement. Fossil fuel-based units still play a huge role in ensuring the supply of power meets the demand through their continuous availability and uninterrupted power supply. However, when these units cross 15 to 25 years of service, the equipment's gets deteriorated through wear and tear and various damage mechanisms.

To alleviate this problem, ensuring the highest availability of power plants by bringing down the forced outages with predictive maintenance-based approach in upkeeping the health of the units is key. The Condition Assessments/RLA as a predictive maintenance tool along with Renovation & Modernisation can quickly yield this result, since the gestation period of the project and the cost of execution of R&M is less when compared to green field projects. Currently there are large numbers of power plants in operation with a life of 25 years or more. By doing RLA and R&M appropriately, this life can be further extended to another 15 – 20 years easily.

Fossil utility boilers, life assessment and life extension programs help to identify and implement strategies so as to ensure continued operation of the unit in a cost-economical way. A team effort is needed between the utility and designer to ensure safe and reliable operation of steam generators, with minimal unscheduled outages. A coordinated analysis combining the unit's operational data with design expertise and problem-solving knowledge is a basic requirement for the success of the exercise.

The economic life assumed for a fossil fired generating station is normally 20 to 25 years. Under the present conditions of escalating construction cost and environmental regulations, the option to extend the service life of the steam generating equipment is important to electric utilities. Boiler pressure parts like super heater, re-heater tubes, steam pipes and headers operating in the creep range are designed for certain minimum lifetime. As units age, critical components may distress through mechanisms such as oxidation, corrosion, creep, fatigue and interaction of the above mechanisms. These components deteriorate continuously during service as a result of the above time dependent material degradation processes. In actual practice, material damage results from interaction of two or more of these mechanisms, causing unanticipated failures. Sometimes such failures may be catastrophic resulting in huge losses.

Condition of critical components and the remaining time before replacement or major repair are the main considerations in extending life of a unit. Units, originally designed for base load, for operation on cycling duty, require improvements to equipment and controls. Additionally, modifications to operating philosophy are also to be covered in life assessment program.

The useful life of components in service may well exceed or fall significantly short of the design life. The reasons of such behaviour are related to design, operational, maintenance and metallurgical conditions.

This paper deals with the basic approach to Condition Assessments and Condition Monitoring of Boiler Pressure parts and components as per IBR 391 A Regulation and the advanced tools and methodology adopted in carrying out the studies.

INTRODUCTION

Boilers, normally designed for a specific life, are capable to deliver an extended useful life because of the conservatism built-in during design stage itself. Pressure part components operating at high pressure and temperature are prone for service damages like creep, fatigue or a combination of creep and fatigue. Hence Condition Assessments and Condition Monitoring of Boiler Pressure parts and components as per IBR 391 A Regulation is carried out more specifically for the Boiler pressure parts.

The assessment calls for certain special techniques over and above the routine requirements like laboratory analysis by doing destructive testing through sampling and non-destructive examination. Special techniques like detection of hydrogen damage in water walls by attenuation method as well as corrosion damage of pressure part components are employed on a need-based requirement, depending upon the operational history of specific unit.

IBR Act 391 A / Requirement of Condition Assessment study

Water Tube Boilers: -

(i) The boilers which are operating at a temperature of 400°C and above including utility or industrial boilers and all boiler parts operating in the creep range of the boiler shall be non-destructively tested as per the table 1 in IBR document after they are in operation for 1,00,000 hours for assessment of the remnant life of the parts;

(ii) The parts of a boiler when it completes a life of twenty-five years are to be tested as per table 2 in IBR document for assessment of the remnant life of such parts. If results are acceptable as per the standards laid down by the Central Boilers Board, a certificate shall be issued by the Chief Inspector of Boilers for extending the life of the boiler for a further period of ten years or such less period as recommended by the Remnant Life Assessment organisation. This assessment of remnant life shall be carried out thereafter every five years by the organisations working in the field of boilers and remnant life and extension thereof after such organisation is approved by the Central Boilers Board. Such organisation shall work in close coordination with the office of the Chief Inspector of Boilers in the field of remnant life assessment and extension. The working pressure of such boilers may be reduced on the recommendations of such approved organisation.

Notwithstanding anything contained in this regulation, for boilers working at a pressure less than 50 kg/cm2, such elaborate remnant life assessment is not mandatory. However, in such cases, drums and headers of such boilers shall be inspected by Ultrasonic testing, Magnetic particle testing and Dye penetrant test.

The study can be carried out in three phases. The first phase involves the study of boiler operational history, failure history, details of replacements / modifications carried out during service. The second phase is the actual field study carried out using advanced non – destructive testing methodology as well as collection of samples for destructive testing and other laboratory analysis. The third phase is the post–field study at laboratories involving destructive testing / deposit analysis, root cause analysis of problems and this phase involves evaluation of the remaining life of the unit based on the analysis carried out in all the three phases. Emphasis is given to the collection of relevant data during field study and critical evaluation of the data collected and marrying the results in an appropriate manner for deciding on run / repair and replacement.

I Phase:

* Review of operational history of equipment
* Analysis of data, records and maintenance/overhaul reports.
* Analysis of failure records and reports.

II Phase:

* Visual examination
* Non-destructive examination – LPI, MPI, UT.
* Hydrogen embrittlement survey in water walls using special NDT.
* Sampling for laboratory analysis and uniaxial creep rupture test.
* Header internal inspection through Videoscopic/Fibroscopy technique.
* In-situ Metallography replica technique.
* In-situ oxide scale thickness measurement
* Critical piping stress analysis and hangers and supports assessment.

III Phase :

* Laboratory analysis of tube/deposit samples.
* Accelerated creep rupture testing
* Critical piping Stress analysis
* Root cause analysis and Remaining life calculation
* Formulation of recommendations and reports

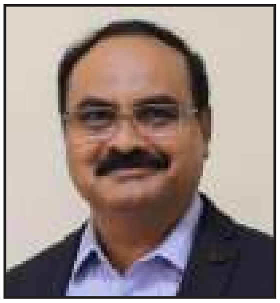
A brief on damage Mechanisms:

The boiler components in a thermal power station, could face a wide variety of hostilities, with a potential to face many possible service damage mechanisms. In the initial part of the bath tub curve of the service, the boiler tube failures could be due to mechanisms such as weld leakages, parent metal leakages, overheating damages due to inadvertent choking inside etc. The efforts of all the manufacturers is to contain such failures through careful control of incoming raw materials, use of well-established welding processes, mainly automated processes, and use of good practices of control of inadvertent choking. Any undue restraints in the design or due to non-removal of any temporary supports could possibly result in ductile overload failures in the initial service. Once the Units stabilize after the initial run, there are no worries on this count.

The other boiler tube service damage mechanisms that take over after some years in service are more of time bound mechanisms such as diffusion, corrosion, wear, fatigue and creep or a combination of these. Dissimilar weld failures in tubular weld joints between ferritic to stainless steels is an example of diffusion-based degradation, with carbon migration from the ferritic side into the weldment (uphill diffusion accentuated by higher Cr). The service stress also adds to the issue. This mechanism is well researched today and in the last five decades, it has been contained by various measures like the use of nickel base consumables, shifting of the joints from furnace to pent house regions, stocking of pre-fabricated DMW spools welded by automated welding process at defined intervals (say after 1 lakh hours) and so on. Corrosion mechanisms could show up on the fire-side or water side of tubes and has a lot to do with the type of fuels used and the water chemistry regimes maintained in the boiler and these can be contained to an extent by taking proper care. Wear or erosion is a mechanism that eats away the materials in relatively short time periods. The care that is needed is in design, use of erosion shields, coatings etc. but still in many cases, the inevitable is only prolonged, unless the sacrificial shields are not replaced at planned intervals. Creep and fatigue are mechanisms that show up after some service. In boiler tubes, the various reasons from short term creep failures may range from inadequate flow inside tubes, incorrect material, high restraint stresses or bending loads etc. Incompatible fillers could also be an issue. Fatigue failure in boiler tubes usually is accentuated by creep or corrosion or alternate wetting & drying conditions etc. Inadequate flexibility in design and inflexible restraints caused by certain attachment welds add to the woe.

CONCLUSION:

Following the guidelines stipulated as per IBR A in determining the correct mechanism for any failure is important for the prevention of failures of boiler components. Proper corrective measures can be undertaken to alleviate the root cause or causes for a failure once the correct mechanism is known. Determination of the correct failure mechanism is a complex process, which can involve many individuals and organizations. Technical specialists in metallurgy, chemistry, combustion, and boiler design are often called in to assist in a failure investigation. The plant's personnel must provide the initial information on the failure and boiler conditions prior to the failure. The plant's operating records and failure histories must be in order so that pertinent data may be extracted. The plant's management and technical staff must follow up on the failure investigation and implement the corrective actions required to solve the problem.



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Organisation:	Directorate of Steam Boilers, Govt. of Maharashtra
Designation:	Joint Director
Education:	B.E. (Mechanical), DIT (CEDTI) (Visvesvaraya National Institute of Technology, Nagpur) MBA (Operations)
Experience:	**12 years** at Chandrapur Super Thermal Power Station. **18 years** at Directorate of Steam Boilers, Govt. of Maharashtra. **2016 to 2022**- Secretary, Board of Examiners, Maharashtra State. **2021** to till date, Member, Gasket & Packing

Amendments With Regards to RLA.
Eligibility, Periodicity & Validity of Certificate.

Mr. G.D. Wankhede, Joint Director, Steam Boilers, Maharashtra State, Mumbai

How many more years will I be able to use my boiler?

This question, I am sure troubles many boiler users. The answer to the question is in Regulation 391A, which defines ageing of Boiler. In this regulation it is very well defined and illustrated with the help of tables. It becomes simple to understand and determine Remnant Life of a Boiler.

In view of consideration of the ageing effect on Boilers, following guidelines are provided in the Indian Boiler Regulations, 1950.

This regulation provides guidelines for assessment of ageing effect on boilers according to the classification of boilers into mainly two categories.

1) Shell Type Boilers

2) Water Tube Boilers

Regulation No. 391A - Ageing of Boilers

a) Shell Type Boilers

i) In order to take the aging effect on boilers, the working pressure as calculated from the formulae in these regulations shall be reduced as per the table given below.

TABLE

Age of Boiler Exceeding (in Years)	**25**	**35**	**45**	**50**	**60**	**70**	**80**	**90**	**100**
Maximum permitted working pressure in percent	95	90	85	80	70	60	50	40	30

ii) for those boilers, the plates of which have already been cut and tested shall be given a further lease of life of fifty years from the date of test of the boilers. The working pressure that shall be allowed after the testing shall be reduced as per the table given below:

TABLE

Period after date of test (in Years)	10	20	30	40	50
Maximum working pressure allowed (percentage)	90	80	70	50	30

iii) Shell Type Waste Heat Boilers(un-fired):

(As per amendment vide Govt of India, Gazette Notification dt 11/09/2020)

a) Shell type waste heat boilers (unfired), on completion of a life of twenty-five years, shall be non-destructively tested by a Remnant Life Assessment Organisation approved by Central Boilers Board.

b) Pressure parts, including shell, endplates, stand pipes, of such boilers, shall be inspected by ultrasonic testing, magnetic particle testing and dye penetrant testing.

c) If results are acceptable as per the standards laid down by the Central Boilers Board, a certificate shall be issued by the Chief Inspector or Director of Boilers, as the case may be, for extending the life of the boiler for a further period of twelve years or such less period as recommended by the Remnant Life Assessment Organisation.

d) The working pressure of such boilers may be reduced on the recommendation of the Remnant Life Assessment Organisation.

e) The assessment of remnant life by non-destructive testing shall be carried out thereafter every twelve years by a Remnant Life Assessment Organisation approved by the Central Boilers Board and the agency shall work in close coordination with the office of the Chief inspector or Director of Boilers, as the case may be.

Note:

1. It shall at the option of the owner to opt for the provisions of Para (i) or Para (ii) above or opt for the Remnant Life Assessment of boiler as per para (iii).
2. Wherever, it is not possible to carry out non-destructive testing of boiler for Remnant Life Assessment, provisions of para (i) or para (ii) shall be applicable.

b) Water Tube Boilers:

i) The boilers which are operating at a temperature of 400°C (main steam outlet temperature) and above shall be tested by Remnant Life Assessment Organisation for the components as per Table 1 given below after they are in operation for 100,000 hours for assessment of the remnant life of the components.

If results are acceptable as per the standards laid down by the Central Boilers Board, a certificate shall be issued by the Chief Inspector/Director of Boilers as the case may be, for extending the life of the boiler for a further period of six years or such less period as recommended by the Remnant Life Assessment Organisation. This assessment of remnant life shall be carried out thereafter every six years by a Remnant Life Assessment Organisation approved by the Central Boilers Board. The Remnant Life Assessment Organisation shall work in close coordination with the office of the Chief Inspector/Director of Boilers as the case may be, in the field of remnant life assessment and extension. The working pressure of such boilers may be reduced on the recommendations of the Remnant Life Assessment Organisation;

TABLE- 1

Component	Visual	Ultrasonic Testing	Magnetic Particle Inspection	Liquid/ Dye Penetrant Inspection	Replication	Sampling	Deposit Analysis	Outside Diameter and Thickness	Fibre Optic Inspection	Hardness	Others
1	2	3	4	5	6	7	8	9	10	11	12
Steam Drum	Yes	Yes	Yes	Yes	Yes	No	Yes@	Yes*	No	Yes	-----
Water Drum	Yes	Yes	Yes	Yes	Yes	No	Yes@	Yes*	No	Yes	-----
Bottom Headers	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	-----
Low Temperature Header (Less Than 4000C)	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	-----
Attemperator Header	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Swell Measurement
Economizer Tubes	Yes	No	No	No	No	Yes	No	Yes	No	Yes#	-----
Convection Superheater	Yes	No	No	No	No	Yes	No	Yes	No	Yes#	Non-Destructive Oxide Thickness Inspection
Primary Superheater Coils	Yes	No	No	No	No	Yes	No	Yes	No	Yes#	
Prefinal Superheater Coils	Yes	No	No	No	No	Yes					
$$	No	Yes	No	Yes#							
Final Superheater Coils	Yes	No	No	No	No	Yes $$	No	Yes	No	Yes#	
Reheater Coils	Yes	No	No	No	No	Yes $$	No	Yes	No	Yes#	
High Temperature Headers (400°C and above)	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Swell measurement
Main Steam Piping	Yes	No	No	No	Yes	No	No	Yes	No	Yes	-----
Cold Reheat Piping	Yes	No	No	No	No	No	No	Yes	No	Yes	-----
Hot Reheat Piping	Yes	No	No	No	Yes	No	No	Yes	No	Yes	-----

SH/RH Links	Yes	Yes	No	Yes	Yes	No	No	Yes	No	Yes	-----
Bank Tubes	Yes	No	No	No	No	No	No	Yes	No	No	-----
Furnace Water walls	Yes	No	No	No	No	Yes	Yes				
@	Yes	No	No	-----							

Note: - *Other Components shall be checked/examined visually.*

**OD or ID measurement to be taken for steam Drum and water drum/bottom headers.*

 # Hardness of Tube samples (both inside and outside) to be checked at laboratory.

@ Deposit analysis to be done;

$$ Sample shall be subjected to accelerated creep rupture test.

ii) The boilers which are operating at a temperature of less than 400°C (main steam outlet temperature) on completion of a life of twenty-five years are to be tested by the Remnant Life Assessment Organisation for the components as per Table 2 given below for assessment of remnant life of the components.

If results are acceptable as per the standards laid down by the Central Boilers Board, a certificate shall be issued by the Chief Inspector/Director of Boilers as the case may be, for extending the life of boiler for a further period of twelve years or such less period as recommended by the Remnant Life Assessment Organisation. This assessment of remnant life shall be carried out thereafter every twelve years by a Remnant Life Assessment Organisation approved by the Central Boilers Board. The Remnant Life Assessment Organisation shall work in close coordination with the office of the Chief Inspector/Director of Boilers as the case may be, in the field of remnant life assessment and extension. The working pressure of such boilers may be reduced on the recommendations of the Remnant Life Assessment Organisation.

Notwithstanding anything contained in this regulation, for boilers working at a pressure less than 50 kg/cm2 and temperature less than 400oC(main steam outlet temperature) , such elaborate remnant life assessment is not mandatory. However, in such cases, drums and headers of such boilers, shall be inspected by Ultrasonic testing, Magnetic particle testing and Dye Penetrant test.

TABLE- 2

Component	Visual	Ultrasonic Testing	Magnetic Particle Inspection	Liquid/ Dye Penetrant Inspection	Replication	Sampling	Deposit Analysis	Outside Diameter and Thickness	Fibre Optic Inspection	Hardness	Others
1	2	3	4	5	6	7	8	9	10	11	12
Steam Drum	Yes	Yes	Yes	Yes	Yes	No	Yes@	Yes*	No	No	-----
Water Drum	Yes	Yes	Yes	Yes	Yes	No	Yes@	Yes*	No	No	-----
Economizer Tubes	Yes	No	No	No	No	Yes	No	Yes	No	No	-----
Convection Superheater Coils	Yes	No	No	No	No	Yes	No	Yes	No	No	-----

Primary Super-heater Coils	Yes	No	No	No	No	Yes	No	Yes	No	No	-----
Final Superheater Coils	Yes	No	No	No	No	Yes	No	Yes	No	No	-----
Water Headers	Yes	Yes	No	Yes	No	No	No	Yes	Yes	No	-----
Steam Headers	Yes	Yes	No	Yes	No	No	No	Yes	Yes	No	-----
Bank Tubes	Yes	No	No	No	No	No	No	Yes	No	No	-----
Furnace WaterWall	Yes	No	No	No	No	Yes	Yes@	Yes	No	No	-----
Main Steam Piping	Yes	No	No	YES	No	No	No	Yes	No	No	-----

Note: - Other components shall be checked / examined visually

*OD or ID measurement to be taken for steam drum and water drum /bottom headers

@ Deposit analysis shall be undertaken at laboratory.

Heat Recovery Steam Generators (HRSGs):

Heat Recovery Steam Generators (HRSGs) which are operating at a temperature of 400°C (main steam outlet temperature) and above shall be non-destructively tested by the Remnant Life Assessment Organisation for the components as per Table 3 given below after they are in operation for 100,000 hours for assessment of remnant life of the components.

TABLE- 3

Component	Visual	Ultrason-ic Testing	Magnetic Particle Inspec-tion	Liquid/ Dye Penetrant Inspec-tion	Replica-tion	Samp-ling	Deposit Analysis	Outside Diame-ter(OD) and Thick-ness	Fibre Optic Inspec-tion	Hardness	Others
1	2	3	4	5	6	7	8	9	10	11	12
SH/RH tubes	No	No	No	No	No	Yes					
*	No	No	No	Yes							
*	-----										
SH/RH Inlet & Outlet Header	Yes	No	No	No	Yes						
#	No	No	Yes	No	Yes	-----					
DESH Header	Yes	No	No	No	Yes						
#	No	No	Yes	No	Yes	-----					
DESH inlet & outlet link	Yes	No	No	No	Yes						
#	No	No	Yes	No	Yes	-----					
Drum	Yes	Yes	Yes	Yes	Yes	No	Yes	ID & thickness	No	Yes	-----
Down Comers	Yes	No	No	No	No	No	No	Yes	No	Yes	-----
Evaporator Outlet Links	Yes	No	No	No	No	No	No	Yes	No	Yes	-----
Evaporator Tubes	No	No	No	No	No	Yes					
*	Yes										
*	No	No	Yes								
*	-----										
Economizer Tubes	No	No	No	No	No	Yes					

*	Yes										
*	No	No	Yes								
*	-----										
Economizer Inlet & Outlet Header	Yes	No	No	No	No	No	No	No	No	Yes	-----
Economizer to Drum Link	Yes	No	No	No	No	No	No	Yes	No	Yes	-----

* To be decided based on history of failure

\# for SH/RH headers above 400 deg C."

Regulation No. - 376(ff) & 376(fff)

Many Boiler Users and BOE are unaware of many changes in the regulations, hence today we shall be discussing the same here in detailed manner. The regulations for boilers used exclusively for electric power generation and waste heat boilers used exclusively in continuous process plant are somewhat different than other regular boilers. The regulations are amended from time to time to ease the use of these boilers taking into consideration the requirements of industry and the difficulties faced by them. The State Inspecting Authority and boiler users give feedback and recommendations on various aspects of boilers to the Central Boilers Boards, New Delhi which if accepted are amended into new regulations. Amendments to regulations are done from time to time to fine tune them and make them more user-compliant without compromising on Boiler safety.

Regulation No. - 376(ff)

For boilers used exclusively for electric power generation, the inspection shall be carried out in accordance with provisions of Appendix JA.

APPENDIX JA {see regulation 376(ff)}

A. Power boilers working at a pressure above 100 kg/cm2 and up to 100,000 hours of operations.

(1) The boilers working at a pressure above 100 kg/cm2 and up to 100,000 hours of operations, generating steam for power generation shall be inspected as detailed below after the expiry of twelve months from the date of inspection carried out in accordance with the procedure provided in regulation 390 and certification of fitness shall be issued by the concerned Competent Person in the State, through inspection of the following records which shall be made available along with application in Form – XIX duly filled in, to the concerned Competent Person at least thirty days before the expiry of the operating certificate , provided he is satisfied that the boiler can be allowed to be operated for a further period of twelve months.

a) Operation data for superheater and reheater temperature excursions from the output of Data Acquisition System (DAS).

b) History of shutdowns during the previous year with their causes and actions taken.

c) Records of any Non-Destructive test carried out on the boiler pressure parts during the year.

d) Water quality to the boiler is maintained up to the requirement of such boilers and online data of the quality be provided.

e) Boiler tube failure record (location, number of tubes repaired/replaced).

(2) Inspection shall be carried out by the concerned Competent Person at the expiry of twenty-four months as provided in regulation 390. However, in case of shutdown of fifteen days or more any time before expiry of the certification period and after six months of the certification, the Competent Person shall be duly informed so that inspection can be scheduled during the said shut down period.

B. Power boilers working at a pressure up to 100 kg/cm² and up to 100,000 hours of operations or 25 years of operations as applicable.

(1) The boilers working at a pressure up to 100 kg/cm² and up to 100,000 hours of operations for boiler operating above 400°C and 25 years of operation for boilers operating less than 400°C generating steam for power generation shall at the expiry of twelve months from the date of inspection carried out in accordance with the procedure provided in regulation 390 and certification of fitness by the concerned Competent Person in the State, and having satisfied with the operation records at the paragraph A, shall be allowed for running for another period of twelve months.

(2) Inspection shall be carried out by the concerned Competent Person at the expiry of twenty-four months as provided in regulation 390. However, in case of shutdown of fifteen days or more any time before expiry of the certification period and after six months of the certification, Competent Person shall be duly informed so that inspection can be scheduled during the said shut down period.

C. Power boilers working at pressure above 100 kg/cm² and more than 100,000 hours of operations.

(1) Boilers working at a pressure above 100 kg/cm² and more than 100,000 hours of operations, generating steam for power generation shall continue to be subject to inspection as provided in regulation 390 every year to the satisfaction of concerned Competent Person in States. However, if Remnant Life Assessment (RLA), as per provisions in these regulations is carried out on the boiler and if found satisfactory, then procedure as per paragraph "A" above shall be applicable.

(2) Inspection shall be carried out by the concerned Competent Person at the expiry of twenty-four months as provided in regulation 390. However, in case of shutdown of fifteen days or more any time before expiry of the certification period and after six months of the certification, Competent Person shall be duly informed so that inspection can be scheduled during the said shut down period.

D. Power boilers working at a pressure up to 100 kg/cm² and more than 100,000 hours of operations or twenty-five years of operations as applicable

(1) Boilers working at a pressure up to 100 kg/cm² and more than 100,000 hours of operations for boiler operating above 400°C and twenty-five years of operation for boilers operating less than 400°C, shall continue to be subjected to inspection every year as provided in regulation 390. However, if Remnant Life Assessment (RLA) as per provisions in these regulations is carried out on the boiler and if found satisfactory, then procedure as per paragraph "B" above shall be applicable.

(2) Inspection shall be carried out by the concerned Competent Person at the expiry of twenty-four months as provided in regulation 390. However, in case of shutdown of fifteen days or more any time before expiry of the certification period and after six months of the certification, Competent Person shall be duly informed so that inspection can be scheduled during the said shut down period.

Note: Whenever High Pressure (HP) and Low Pressure (LP) boilers operate from the same enclosure, the procedure for inspection as applicable to High Pressure (HP) boiler shall also be applicable to Low Pressure (LP) boiler.

Regulation No. - 376(fff)

For Captive Boilers and Waste Heat Boilers (Fired and Unfired) used exclusively in continuous process plants, the inspection shall be carried out in accordance with the provisions of Appendix JB. The boilers used in corrosive environments such as Sulphuric acid plants shall not be covered under provisions of Appendix JB.

APPENDIX JB

(As per latest amendment in IBR, 1950 dt. 11/09/2020)

A. Waste Heat Boilers (Fired) upto twenty years of age used exclusively in continuous process plant.

1) For Waste Heat Boilers (Fired) up to twenty years of age used exclusively in continuous process plant, at the expiry of twelve months and at twenty four months from the date of inspection carried out in accordance with the procedure provided in regulation 390 and certification of fitness issued by the concerned Competent Person in the State, and having satisfied with the operation records as given below received along with application in Form XIX duly filled in shall be allowed for running for another period of twelve months:—

   a) Operation data for superheater and reheater temperature excursions from the output of Data Acquisition System (DAS) or operation data for superheater temperature excursions maintained in the log sheet temperature record;

   b) History of shut downs during the previous year with their causes and actions taken;

   c) Records of any Non-Destructive test carried out on the boiler pressure parts during the year;

   d) Water quality to the boiler is maintained as per the requirement of such boilers and on line data of the quality be provided through Data Acquisition System (DAS) or through water quality record logbook maintained at plant or at source of water;

   (e) Boiler tube failure record (location, number of tubes repaired/replaced).

2) Inspection shall be carried out by the concerned Competent Person at the expiry of thirty-six months as provided in regulation 390.

3) In case of shutdown of fifteen days or more any time before the expiry of certification period and after six months of the certification, Competent Person shall be duly informed so that inspection can be scheduled during the said shutdown period.

B. Waste Heat Boilers (Unfired) up to twenty years of age used exclusively in continuous process plant.

1) For Waste Heat Boilers (Unfired) up to twenty years of age used exclusively in continuous process plant, at the expiry of twenty four months from the date of inspection carried out in accordance with the procedure provided in regulation 390 and certification of fitness by the concerned Competent Person in the State, and having satisfied with the operation records at paragraph "A", shall be allowed for running for another period of twenty-four months.

2) Inspection shall be carried out by the concerned Competent Person at the expiry of forty-eight months as provided in regulation 390.

3) In case of shutdown of fifteen days or more any time before the expiry of certification period and after six months of the certification, Competent Person shall be duly informed so that inspection can be scheduled during the said shutdown period.

C) Waste Heat Boilers (Fired) more than twenty years of age used exclusively in continuous process plant.

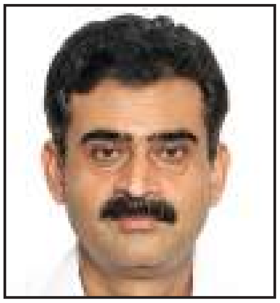
1) Boiler more than twenty years of age shall continue to be subjected to inspection as provided in regulation 390 every year to the satisfaction of the concerned Competent Person in the State.

2) If Remnant Life Assessment is carried out on the boiler as per the provisions of these regulations and is found satisfactory, then procedure as given under paragraph 'A' shall be applicable.

D) Waste Heat Boilers (Unfired) more than twenty years of age used exclusively in continuous process plant.

1) Boiler more than twenty years of age shall continue to be subjected to inspection as provided in regulation 390 every year to the satisfaction of the concerned Competent Person in State.

2) If Remnant Life Assessment is carried out on the boiler as per the provisions of these regulations and is found satisfactory, then procedure as given under paragraph 'B' shall be applicable."



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CREDENTIALS

M. Tech (Operations Research in Business and Industry), NIT Durgapur-Mathematics

PG Diploma (Business Management), MDI, Gurgaon-Finance & Strategy

B.S. (Mechanical Engineering), BIT, Ranchi University

Mr. Anjan Sinha is a power plant specialist with 35 years of industry experience-30 years at NTPC. Post NTPC he worked at Deloitte and Vedanta (as COO). He is currently working as Technical Director, Intertek. Mr. Sinha has experience with operation, maintenance, commissioning, and R&M of large thermal power plants. He has prepared concept papers on power sector reforms and evaluated studies of international consultants on policy and regulatory options. Among his publications, the “recipe book on flexible operation” is one of the most cited works on the subject.

RECENT WORK/PROJECT EXPERIENCE

Recent work includes strategic planning and techno-commercial evaluation of power business, including investments. Played an expert role in providing technical-commercial support to government agencies, regulators, and policy makers on electricity sector expansion programs and renewables. Responsible for carrying out training programs for government agencies and policy makers as a member of special task force and national committees. Had been Senior Advisor to GTG-RISE under USAID.

SPECIALIZED PROFESSIONAL COMPETENCE

Member of Special Task Force on Flexibilization under the Indo Germany Energy Forum. Managed the complete power business operations of Vedanta Jharsuguda (3615 MW Thermal). Experienced in power business supply chain management, strategy development, and review.

Provided expert inputs to government, multilateral agencies like USAID and policy makers on power sector reforms. Performed collaborative research with organizations, consultancy firms, and OEMs.

PUBLICATIONS

- Recipe book for Flexibilization of coal-based power plants"- published in Oct 2020.
- Fleetwide strategy for flexibilization of thermal power plants of NTPC, July 2019
- Minimum load Test Procedures for coal-based stations, April,2019
- Regulatory concept paper for compensating thermal power plants for flexible operation, Feb 2019
- Flexible Operation- NTPC's Approach, Feb 2017
- Techno-economics of flexible operation, November 2018
- EPRI Documents- Benchmarking for Flexible Operation & Defence strategy for Flexible Operation.
- EPRI Document- SH & RH drains borehole cracking.
- EPRI- Operation Flexibility-Failure Mitigation Strategies Handbook, Published December, 2022.
- More than 60+ Conference papers

BOILER FUNCTIONAL SAFETY MANAGEMENT: ADHERENCE TO STANDARD OPERATING PROCEDURES (SOP) DURING SHUTDOWN AND CHEMICAL CLEANING

Boiler Process Optimization for Flexibility during cyclic Operation

Anjan Kumar Sinha

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Abstract

India has made a remarkable achievement by achieving the target of 175 GW of RE (committed in COP 21 and further raised the target of achieving 500 GW of RE deployment by 2030. The deployment of large scale RE has set a trend that will lead to a fundamental change of electricity markets, with renewable prices as a key driver of this change. Several utilities have already started to face difficulties in coping up with this trend with a hit in the bottom line. In India, a largely coal-based generation, with limited storage hydro and gas supplied, most of the cost- effective balancing resources must be provided by coal generators. Amidst a rapid growth in demand as seen in the recent years, flexibility requirements will be an important factor for ensuring the reliability of the grid with 24X7 uninterrupted supplies.

Flexibilization of coal-based plants with the low grades Indian coal will need investments in retrofits procedural changes in practices besides capacity building of the entire generating staff.

This paper comprehensively outlines the issues and solutions of coal power plant flexibility with a

focus on boiler process optimization. It is based on a wealth of literature survey, case studies, pilot studies and data, which provides a reference source for the technical capabilities of power plants and the costs of providing actual flexibility. It discusses the technical options and of operational procedural modifications and boiler retrofits and control optimization to existing power plants for enhancing system flexibility.

Keywords — Flexibilization, Coal generation, Retrofits, Boiler, combustion optimization, Life consumption

Introduction

With increased use of smart grids, low-carbon energy, and other cutting-edge technologies, 21st-century power systems will prioritize resources with low marginal costs and system flexibility— such as the capacity to turn on and off in response to variations in the output of variable renewable energy plants. There are still unanswered concerns regarding what will happen to coal plants in this situation and if they can sustainably run if they cycle on a regular basis1.

The future of coal plants and how their operations might alter in systems with rising penetration levels of variable renewable energy, including wind and solar, are yet to be addressed as power systems go through this paradigm shift. More adaptable generation resources might be required for power systems in the future. To supplement changes in production from high penetration levels of renewable energy, these resources can be characterized by their capacity to run at low minimum loads and cycle on and off. Though some coal plants, (included in our case study, have been cycling for decades, coal plants are generally thought to be incapable of sustaining prolonged cycling. During peak morning and afternoon hours, CGS has occasionally cycled on and off up to four times a day.

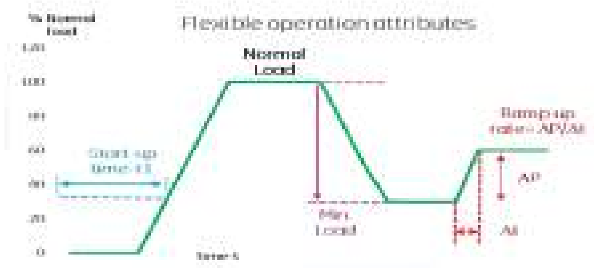
Flexible operation/cycling is a difficult mode of operation and even the most conservative approach will increase plant life consumption, O&M costs along with per MW variable costs, faster equipment degradation, damages accumulation, performance degradation, and loss of availability & reliability. At the extreme end, there can be cases of severe damage or accidents, rendering the unit unavailable for long periods. However, those plants that can operate flexibly to meet market conditions while minimizing the financial impact of operating in this environment, will continue to be dispatched, at least for the near future. Proactive approach towards revisiting the operational procedures, awareness, training of O&M manpower and investments in retrofits can enhance flexibilization as well as largely reduce damages, enhance safety and reliability of the units. Although, flexibility affects all the plant components at different levels, this paper will focus on boiler process optimization for flexibility during cyclic Operation.

The paper includes, case studies, review of published international literature on the subject, reports of pilot studies, expert and Original Equipment Manufacturers (OEM) inputs, review of O&M manuals of multiple Utilities operating their plants on cycling mode, failure and maintenance records of utilities, site inspections, workshop discussions and the author's research works. The cycling date has been collected for an extended period (for about 10 years).

[1] [1] Cochran J, Lew D and Kumar N (2013) Flexible Coal Evolution from Baseload to Peaking Plant available at: https://www.nrel.gov/docs/fy14osti/60575.pdf (Dec 2013) Accessed on 15 August 2024

Definitions of Cycling[23]:

Figure 1: Attributes of Flexible Operation



Minimum Load: The minimum load is the lowest possible net load a generating unit can deliver under stable operating conditions. It is measured as a percentage of the nominal load.

Start-up: The start-up time is defined as the period from starting plant operation until reaching minimum load. The start-up time of different generation technologies varies greatly. The other factors influencing the start-up time are, down time (period when the power plant is out of operation) & the cooling rate.

Flexibility-related improvements to coal plant startup typically occur through reductions in four key areas: (1) startup time, (2) startup fuel cost, (3) startup emissions, and (4) startup variation.

Startup Time

A typical small or large subcritical coal unit can take several hours for a start up. With a time-based classification, the shutdown/ startup event is classified by the number of hours the unit has been off-load prior to the startup.

For medium sized units a commonly used time classification is:

- < 8 hours off-load = hot start
- 8 to 48 hours off-load = warm start
- 48 hours off load = cold start.

In most cases, for large units these time values will be higher. Traditionally, the turbine casing

[2] [2] IEA (2018) Status of Power System Transformation Advanced Power Plant Flexibility 2018. Available at: pp115 (May 2018)

[3] [3] CEA- Report on "Flexible Operation for Thermal Power Plant for RE Integration" – Jan. 2019

temperature drop from a hot to ambient condition is used to determine the start types. Unfortunately, these time-based and high- pressure steam turbine casing metal temperature-based start- up classifications do not adequately classify the start-up type with respect to the boiler's thick-section pressure parts or other boiler components, which generally cool down much faster than the high-pressure steam turbine casing. A hot or warm start on the turbine might be a cold start on the boiler. In general, a cold start is more damaging than a warm or hot start due to the excessive temperature differentials on the components.

It should also be noted that the cooling behaviour of the boiler and drum/other thick walled components can vary widely, depending on the shutdown procedure and how the procedure affects the preservation of drum pressure and furnace gas temperature, and the circulation of fluid into the drum either from the feedwater/economizer or throughout the waterwall circuits.

Ramp rate:

The ramp rate describes how fast a power plant can change its net power during operation.

Mathematically, it can be described as a change in net power, ΔP, per change in time, Δt. Normally the ramp rate is specified in MW per minute (MW/min), or in the percentage of nominal load per minute (% P/min). In general, ramp rates greatly depend on the generation technology.

There are several different aspects which are important to consider when characterizing ramp rates. Coal units can have ramp rates of 1%/min to 3%/min depending on size and control technology at the operator's disposal.

Several factors impact ramp rates on steam units, including the fuel quality variation, which can have a significant impact on ramping capability. The typical Indian coal quality variation directly corresponds to temperature variations, thus making load (MW) change more difficult. The control of boiler parameters is more challenging with ramping, often resulting in increasing variability of waterwall outlet temperatures. Further, the ramping can elevate combustion dynamics which induces hardware damaging pressure pulses. All of this needs to be managed properly to ensure reliable operation. The rapid increase/decrease of firing temperature can further add stress to the hardware during ramping events. Control systems allow operators to vary fuel to air ratio and control rate of change of energy, some hardware replacement with advanced controls can improve ramp rates.

Two-Shifting: Units which start and shut down daily and operate only during two shifts. Typically, there are three shifts in a day, each of eight hours.

Damage Mechanism during Flexible Operation[4]

The traditional, older coal-based fleet were designed to operate most of the time on creep conditions. The older design codes for power plant (ASME, DIN, BS) did not give specific requirement for consideration of fatigue as a failure mechanism. These earlier design codes were based on the assumption of base load operation which was adequate then. But, with the change of operating regime from base load to flexible regime, the damages due to the interaction of fatigue and creep is a significant concern.

Materials behave differently in a complex and synergic manner in the presence of both fatigue and creep, to cause early failure. The interaction between creep and fatigue is non-linear and very strong. For example, if the creep and fatigue damage fractions are equal, time-to-failure will be only one-eighth (versus one-half for a linear sum) the life predicted for either mechanism acting by itself.

The ASME (American Society of Mechanical Engineers) provides a guidance on this interaction of fatigue and creep and its effect on the life expectancies of the materials.

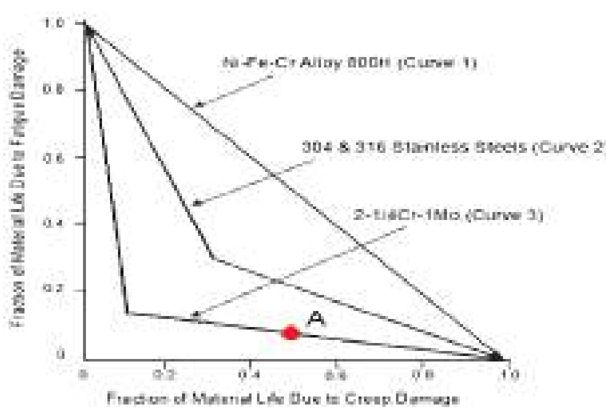


Figure 2: *ASME Creep-Fatigue Interaction Curves for Several Materials [Intertek-Cost of cycling Ramagundam]5*

THE RECIPE BOOK for FLEXIBILISATION OF COAL BASED POWER PLANTS

[4] Sinha A, K,2020: THE RECIPE BOOK for FLEXIBILISATION OF COAL BASED POWER

PLANTS. Available At: *https://sarepenergy.net/wp-content/uploads/2022/10/flexibilisation-of-Coal-Based-Power-Plants_A_K_Sinha.pdf,Accessed* on 15 August, 2024

[4] [5] N.Kumar & D.Hilleman - USAID GTG-RISE Report on "Cost of Cycling Studies" for NTPC's Ramagundam & Jhajjar stations

Equipment Failures due to Fatigue-creep Interactions[6]

Cracking of Thick Wall Components

Example: Boiler and Turbine stop valves cracking due to high wall temperature difference during start- up shutdown. Frequent failures of turbine valves have been seen at a few stations.

Superheater and Reheater Cracking

SH/RH headers have a finite life due to creep. Boiler cycling introduces the additional fatigue and creep- fatigue interaction damage mechanisms. During cold start-up of the boiler, the SH headers are subjected to humping as a result of top-to bottom temperature differences. For frequent on/off cycling, the cyclical bending stresses have caused cracking in the outlet leg tube stub-to-header welds.

Cracking of ligaments between header stubs and penetrations due to thermal fatigue is one of the main life consuming mechanisms on headers. The superheater outlet header, particularly the horizontal tube draining SH is at greater risk, including the intermediate headers operating at lower temperature during rapid start-up and shutdown.

Crack initiation and growth occurs due to the temperature transients during the following operation:

- High ramp rates: this may affect sudden changes in air flow and steam flow.
- Hot Start -when undrained condensed water formed during preceding shutdown quenches the hot headers.
- Cold start-up: when hot steam is introduced to cold headers
- Excessive water carry over and quenching of hot header surface due to excessive use of attemperator. Defective and passing attemperator nozzles can also cause the same problem.
- Boiler forced cooling -carry over of saturated steam from drum to final SH.

Figure-3(a)/3(b): Cracking of ligaments between header stubs [Intertek-Presentation at NTPC conference]7

[5] [6] EPRI (2013) Impact of Cycling on the Operation and Maintenance Cost of Conventional and Combined-Cycle Power Plants. Available at: https://www.epri.com/#/pages/product/3002000817/?lang=en-US)

[6] [7] N.Kumar & D.Hilleman - USAID GTG-RISE Report on "Cost of Cycling Studies" for NTPC's Ramagundam & Jhajjar stations

Figure 4 (a)SH Stub (normal)

Figure 4 (a) SH Stub joint crack

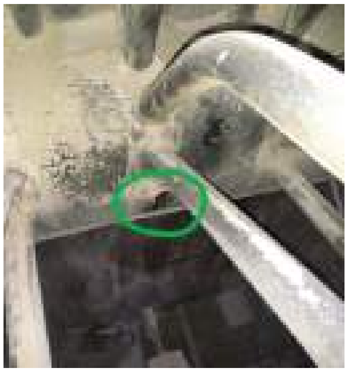


Figure 5: Hanger stub joint

Figure 6: Cracked Tube

Figure 7: Cracked Tube

Figure 8: SH tube longitudinal crack

Evaporator header Stub Cracking

During start-up, with incidents of non-uniform heating, the expansion of waterwall tubes expansion is not uniform. Some tubes are more exposed to firing and expand more rapidly than the others. The waterwall tubes are connected to top and bottom headers which can be comparatively rigid. The differential expansion of the tubes lead to high stress concentration in the stub to header connections. This leads to thermal fatigue cracking of the stub to header weld or stub to tube weld. The ununiform temperature can also exist during shutdown & unit tripping and during forced cooling. The effect will be manifested with increased BTL.

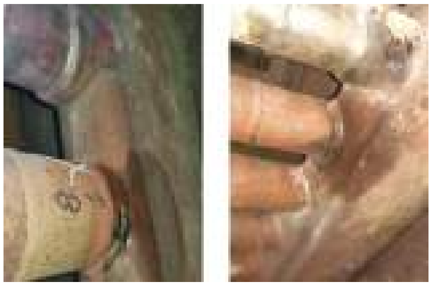


Figure 9: Stub Cracking

Mitigation:

- Replacement of long headers with shorter interconnected boxes
- Regular inspection

Economiser Inlet Headers cracking

During shutdown periods, the economizer retains the temperature at a relatively high level. To maintain drum level, colder water is periodically fed through the economizer to the drum.

Mitigation:

- Economiser recirculation
- Deaerator heating
- Arrangements of hot filling of boiler. Hot filling arrangements from another running unit can be made.

Condensate Management

Condensate Management can result in catastrophic damages in a cycling unit. Most of the plants have inadequate condensate monitoring systems and inadequate instrumentations. Regular checks of pipes, hangers, drain pots and connections and attemperator valve passing must be performed.

Drain line connections

On/off cycling can lead to severe localized damage to the header because of thermal shock. In plants where more than one boiler or header are tied to a common blowdown tank, it has been found that condensate can sometimes back up through drain lines and enter a hot header during start-up. The resulting thermal shock can cause fatigue damage to the header immediately adjacent to the drain connection.

Figure 10: Drain line connections

Improper Boiler Expansion

Boiler structures

A boiler should expand downward from its roof this expansion has to be contained in a support framework, permitting the relative expansion. Thus, the furnace wall buck stay, gas ducts, wind box attachments, and boiler support have to accommodate the thermal movement. This is usually achieved using a slip bracket assembly. The expansion cold and hot may be checked with the OEM.

Backstays are typically attached to the furnace walls with a link and sliding clip arrangement, which is almost static during baseload operation but during flexible operation there is a requirement for the mechanism to flex regularly and failure of the backstay attachment is a common problem in older plants running on severe cyclic mode.

During flexible operations, there can be issues like seizure of connections that accommodate relative thermal movement between hot pressure parts and cold structural support. In the extreme case this could lead to collapse in the boiler pressure parts. Another problem can be the redistribution of load, where the support load is transferred across the boiler.

Figure 11: Platen zone spacer failure

Figure 12: Attachment Weld failure

Mitigation:

- Periodic checks with reference readings
- Reference readings must be recorded and must be available with shift charge engineer
- Walkdown Checklists

Piping Support/Hangers

The piping in the boiler, from boiler to turbine has to accommodate its own expansion as well as the movement of the boiler and turbine. These piping are flexible but can generate extreme levels of system stresses under cyclic operations if the supporting structures are inadequate.

To facilitate smooth pipe movements, mostly the piping systems are based on constant load supports and typically have a load variation of less than +- 5% over the movement range. Wear and tear of the supports, hangers and springs boxes is typical for units that are changing the operating mode. The supports are susceptible to load changes and during thermal cycling or deterioration of support mechanism there can be issues like piping drop/lift or getting locked in position and will lead to increased resultant stresses towards the terminal connections of boiler or turbine causing creep and fatigue damage. Some springs and hangers' breaks are expected in the long term due to increased frequency of thermal movement and possible water hammer incidents.

Mitigation:

- Periodic extensive walk-downs to check A complete visual inspection of pipelines with both cold and hot position readings
- Movements of each support to be identified and compared with design.
- Detail analysis of readings with significant difference (around 25%)
- When abnormal conditions are observed, immediate action should be to avoid larger consequences.

Chemistry related Damages

Waterside corrosion

During frequent shutdowns followed by starts, there is an increased requirement for DM (demineralized) water. With to the increased intake of DM water, there is an increased level oxygen in the boiler water and difficulty in maintaining the boiler contaminants below the normal level.

There can be various sources of oxygen ingress into feed water – starting from the DM water storage tanks, condensate storage tanks, through the vacuum system (drains, turbine parting plane) and turbine seals. Typically, Hydrazine which is dosed in feed water, cannot remove dissolved oxygen (DO) during start-up with low water temperature.

High DO levels accelerate the corrosion fatigue in economisers, feed water heaters and evaporators.

Figure 13: Water side corrosion

Figure 14: FAC- Economizer inlet stab joint pipes thickness is reduced

Figure 15: WW Hydrogen damage

Fireside Corrosion-Furnace Wall, superheater and reheater

Cycling accelerates the furnace wall corrosion. During frequent starts, when the furnace wall temperature is low, proper burning of pulverised coal becomes difficult. This creates reducing conditions and triggers corrosion along with sulphidation. The furnace wall corrosion is mainly due to oxidation and sulphidation.

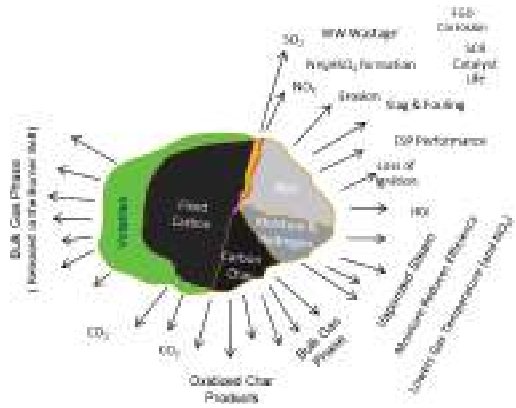
High chlorine levels in coal lowers the ash fusion temperature and thereby increases the fireside corrosion in the superheater zone (when ash softening temperature becomes lower than the floe gas temperature entering the superheater zone.

Mitigation of Chemistry related problems:

Maintain good water chemistry which assures clean steam enters the turbine, & ensure good shutdown, layup and maintenance procedures:

- Recharge condensate and makeup water demineralizers punctually and correctly to avoid sodium and chlorine contamination.
- Keep water chemistry monitoring instrumentation calibrated & functioning.
- Avoid caustic contamination of the turbine and follow OEM and others guidelines with steam purity.
- Use dehumidification or nitrogen blanketing during layup to reduce corrosion.
- Use non-contamination clean solutions on turbine components, piping, condenser and FW Heaters.
- Diligently monitor system chemistry during transients.
- During maintenance inspections pay attention to areas in the early moisture regions of the steam path where stress corrosion cracking (SCC) is most susceptible.
- Ensure that all water introduced into the boiler and turbine steam path is treated.
- Condensate water should be frequently used for attemperating sprays and exhaust hood water sprays.
- Condenser tube leaks into the hot well allow for untreated water into the condensate system. Needs diligent monitoring.

Coal Quality and flexible operation



Source: EPRI

Boilers in India often don't get the coal as per original design. Stations, especially the non-pit head get supplies from multiple sources and the fuel management must manage a complex logistic network. There is a large variation of quality amongst the different regions. At times, during scarcity, coal is procured through imports (high grade coal). Moreover, coal blending becomes very difficult with scarcity, when the stations are running with "hand to mouth" situations.

Change in coal from the design coal to a lower quality coal affects boiler operation and performance. The varying coal quality (due to multiple source) adds to the operator's woes of combustion optimisation.

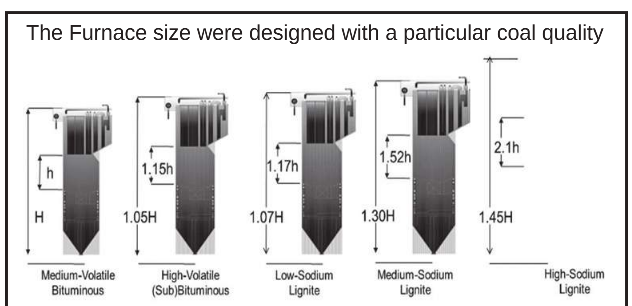
Problems due to changes in coal quality include:

- Boiler slagging and fouling
- Increased corrosion and erosion
- Boiler tube metal temperatures excursion
- Lower boiler efficiency
- Overloading ash handling system
- Overloading of dust removal system and increased emissions

It is important to understand, how the different constituents in coal influence the performance during flexible operation and what improvements can be made. Samples from eighteen different stations were collected and compiled below.

Combustion optimization with varying quality of coal is extremely difficult and even more when these boilers are operated on cycling mode. It requires a different approach from base load operation.

[illegible]	Moist (%)	VM (%)	Ash (%)	FC (%)	HGI	GCV
1	7.2	25.3	36.36	31.14	68.54	3795
2	6.05	25.25	29.92	38.78	59.22	4058
3	8.24	18.34	45.5	27.92	65.2	2869
4	11.45	26.06	38.92	23.57	62.5	3284
5	4.86	31.82	30.02	33.3	58.62	4623
6	6.99	27.79	35.21	30.01	76.09	3871
7	7.41	29.96	32.49	30.14	61.23	4821
8	13.28	20.54	34.46	31.72	48.69	4014
9	9.81	23.45	38.38	28.36	65.93	4268
10	12.96	22.74	46.51	17.79	57.49	2636
11	4.04	28.97	24.26	42.73	60.37	5003
12	6.08	24.01	43.85	26.06	76.65	3692
13	6.58	27.01	38.6	27.81	70.32	3962
14	2.66	22.75	53.22	21.37	57.28	3645
15	7.39	31.05	32.28	29.28	52.33	4538
16	13.6	18.71	46.97	20.72	59.22	2683
17	8.91	20.89	44.67	25.53	63.57	3066
18	4.79	22.11	41.77	31.33	62	3937



Coal Variation during a test run

Table 1: Coal Quality Variation

Retrofits, with modified burners, better controls and changes in O&M procedures can help to a large extent.

Recent Studies conducted on 4 Units (3 supercritical Units)[8]

Recently studies were carried out on 4 units (3 of which were super-critical Units). The life consumption and costs of cycling were also estimated on these units. The name of these units has been kept anonymous. Some of the observations of these units have been discussed as follows:

[8] Author's research

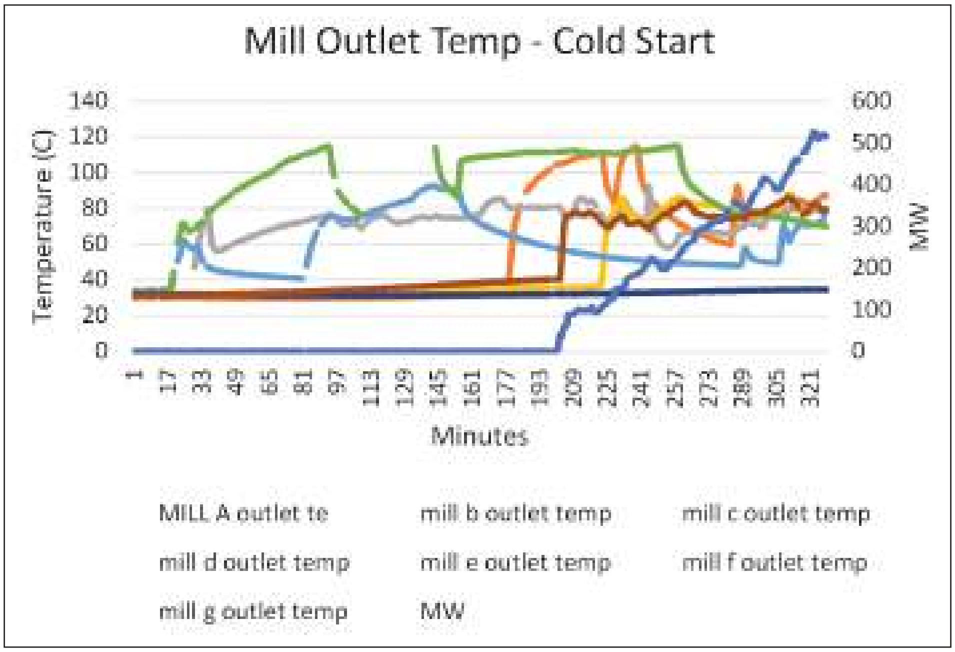


Figure 16: Mill Outlet temperature low

This leads to many combustion issues- like distorted temperature profiles in furnace, secondary combustion, improper distribution, coal pipe chocking.

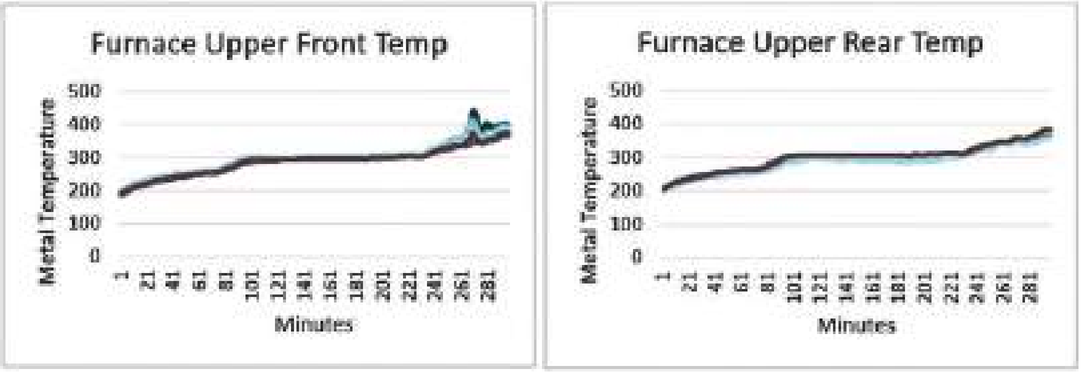


Figure 17: High Thermal Transients during start-up

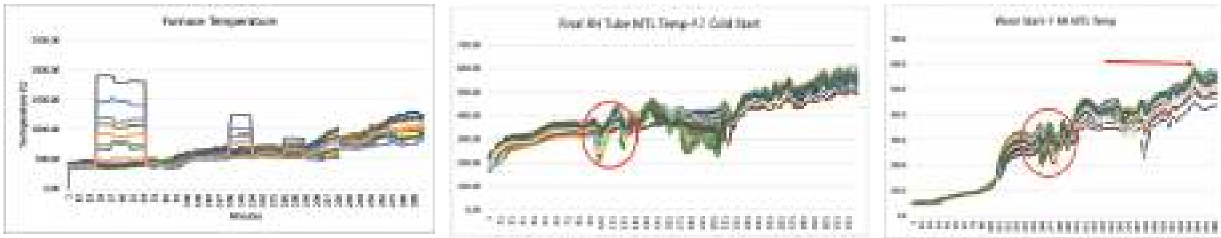


Figure 18: High metal temperatures during start-up

The operational parameters for a few years were analyses and it was seen that it had a good correlation with premature failures, accelerated damages and BTLs.

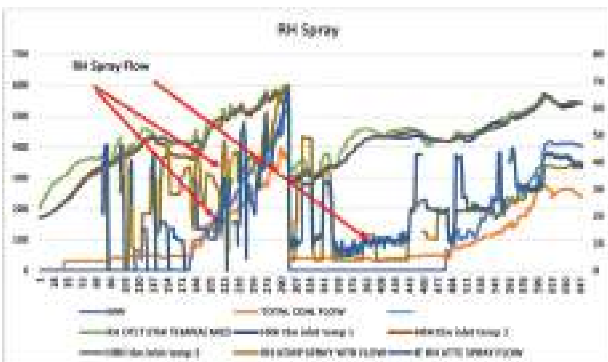


Figure 19: High Spray during start-up   *Fig 20: Vestibule Header Stub Joint Location RHS Tube*

SH/RH attemperation during early stages of start-up or low loas operation leads to condensate accumulation in the headers accompained with stages of flashing. The figure 20 , above

Figure 21: Damaged burners due to improper fuel/air distribution leading to non-optimal combustion

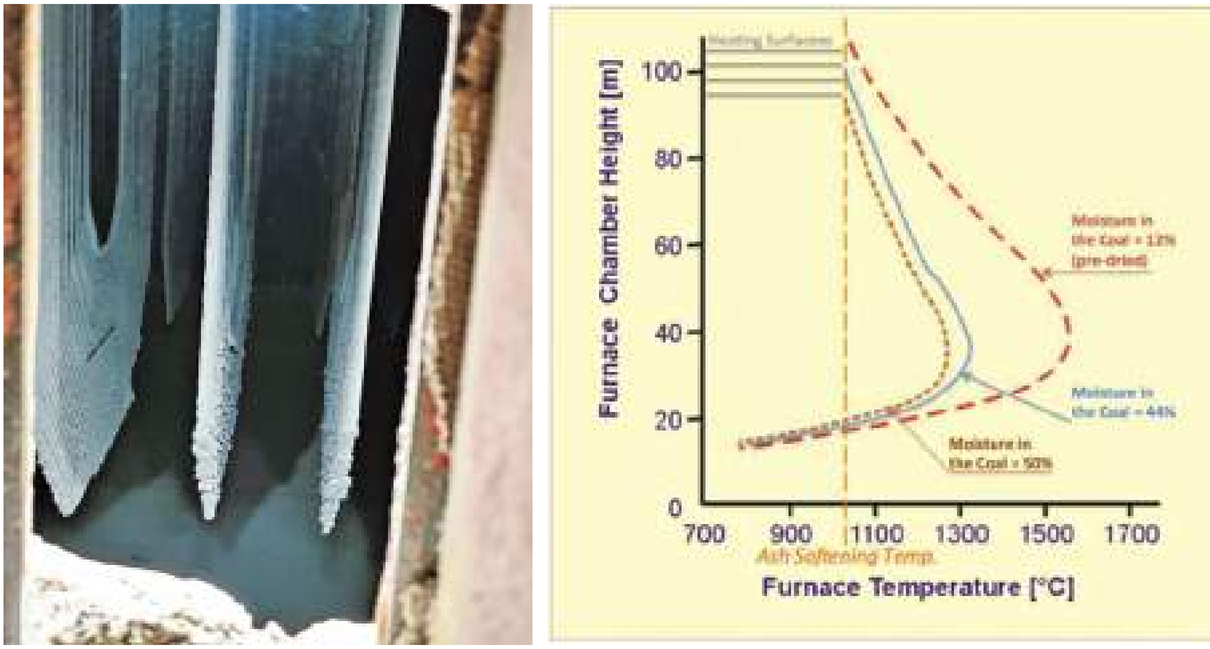


Figure 22: Fouling in Secondary SH

The ash properties and ash fusion temperatures of the coal directly influences furnaces slagging and convective surfaces fouling. Controlling the slagging and fouling can be challenging for plant operators. Some parameters must be monitored, like FEGT, ash fusion temperature (based on the analysis of the coal that is fed. There are some propriety chemical additives available in the market that can be considered.

Boilers are designed to burn coal of specified quality and any changes to the specified quality will significantly impact the performance and controllability of boilers. Moreover, with flexible operation, controlling the FEGT can be challenging and steam temperatures can vary rapidly with changes in FEGT. Operating frequency of soot blowers and LRSBs must be tuned to the particular grade of coal fired with a grading of fouling indices. The Furnace Exit Gas Temperature (FEGT) must be kept bellow the Ash Softening Temperature to control slagging (Figure 22).

Figure 23: Improper air/fuel distribution across coal pipes

The flow across each coal pipe of a mill needs to be balanced. The imbalance is normally addressed by providing orifices in the coal pipes, which is typically done for full loading of mills. However, tests at low load revealed a good degree of imbalance in coal flow across the pipes, although at higher loads, the imbalance in the same coal pipes were negligible. Variable orifices with online velocity and mass flow readings can balance the coal flow/distribution in coal pipes during dynamic conditions of flexible operation.

The velocity in the coal pipes must be high enough to prevent settlement of coal particles in the coal pipes (not less than 20m/sec). Moreover, velocity at the burner nozzle must be more than the speed of flame propagation to avoid backfire within the coal pipes (not less than 15m/sec).

Most of the plants do not have dynamic coal flow or velocity (in coal pipes) monitoring. A common practice is to do a periodical dirty air flow test mostly at higher mill loading. Some of the balanced (at higher loading) coal pipes were seen to be in a highly unbalanced state when the measurements were done at low mill loading. The dirty air flow tests are however not very accurate as it depends on a lot of factors, and it is a point estimation. A dynamic measurement system with trending have yielded good results.

DYNAMIC COAL FLOW Monitoring AND MANIPULATION System

Trending & Manipulation based on Real-Time Measurements

Four pilot studies/tests were carried out at different units for study of the air/fuel distribution in the burners.

The measurements are carried out for the following:

- Coal Mass Flow in each pipe
- Coal Roping Area identification
- Coal Temperature in each pipe
- Coal Velocity in each pipe
- Coal Flow Balancing
- DP across Variable Orifice

There are 3 Mass Flow sensors (microwave based) placed at 120º apart Measures are done for mass flow & indicates coal roping

The Velocity sensors (Electrostatic based) placed 500mm above the mass flow sensors. It measures coal particle velocity and temperature. The system has a monitoring software integrated with system.

Figure 24: Dynamic coal flow balancing using microwave sensors

BEFORE BALANCING

Corners	Mass Flow (TPH)	Percentage Mass Flow	Theoritical Equal (TPH)	Percentage Deviation
Corner 1	11.44	24.24%	11.80	-3.05%
Corner 2	8.96	18.98%	11.80	-24.07%
Corner 3	17.44	36.95%	11.80	47.80%
Corner 4	9.35	19.81%	11.80	-20.76%
	47.2	100%	TOTAL MILL	

AFTER BALANCING

Mass Flow (TPH)	Percentage Mass Flow	Theoritical Equal (TPH)	Percentage Deviation
11.3	23.96%	11.79	-4.16%
11.55	24.49%	11.79	-2.04%
12.48	26.46%	11.79	5.85%
11.82	25.06%	11.79	0.25%
47.16	100%	TOTAL MILL	

COAL PIPE	INITIAL SETTING BHEL Recommended Orifice Opening	FINAL SETTING Orifice Opening to achieve Balanced Flow
D1	100%	98%
D2	74.5%	85%
D3	70%	51%
D4	78%	76%

MASS FLOW TRENDS OF INDIVIDUAL PIPES INDICATING BALANCING OF PIPES

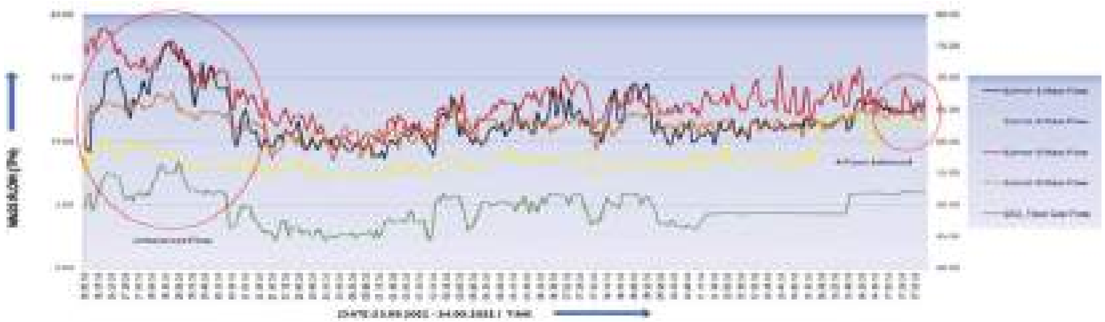


Figure 25: Balanced flows

The results of the coal flow balancing were encouraging. There was significant improvements in unburnt carbon, NOx and heat Rate.

Available Solutions

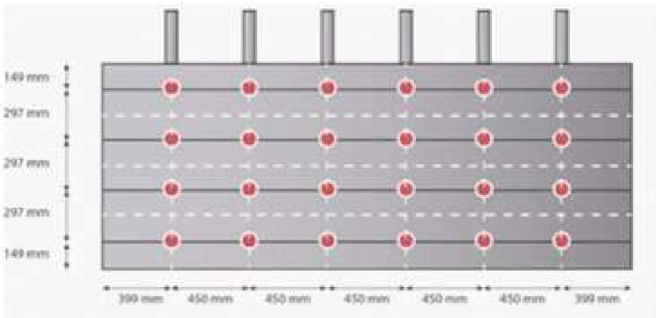
Combustion Optimisation to attain Minimum load

Fundamentals of Combustion

- Coal fineness
- Balancing of Coal flow across the coal pipes
- Fuel/Air ratio, Combustion air
- Furnace exit gas temperature
- Bottom Ash & Fly Ash Unburnt
- Flue gas temperature and excess air stratification
- Flue gas oxygen /Excess air level
- Coal mill inlet/outlet temperature
- Primary Air header pressure
- Pulverized coal flow velocity /Temperature of coal pipes
- Windbox pressure
- Burner Tilt
- Flame scanners
- Selection of burner

- Fuel Firing System Optimization Package:for low load Operation:
- Air/Fuel ratio
- Coal pipes dynamic balancing
- Auto mills start/Mill auto scheduler
- Coal analyzer
- Flame scanners modifications
- Burner modification

Dynamic Combustion Tuning



Temporary Grid of 24 Points at the Economizer Outlet Duct

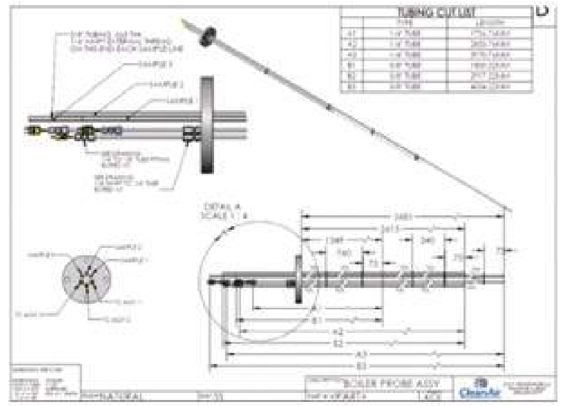


Figure 26: Grid Points for Dynamic Combustion tuning

Adaptive Predictive Controller (APC) and supporting solutions

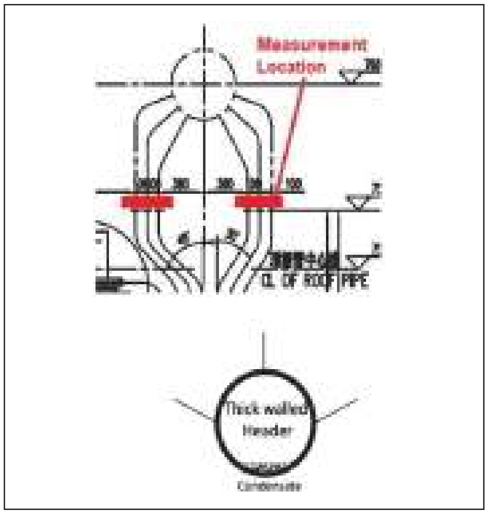
Adaptive Predictive Controller (APC) applications through the implementation of customized application solutions using Adaptive Predictive Controller (APC) applications designed for:

- Combustion optimization
- Steam temperature control
- Burner tilt control
- Intelligent soot blowing
- Real-time coal quality monitor

The APC solutions provides a no-code graphical programming interface for building rule- and model-based systems that can be used to fine tune and optimize business and/or plant processes. These systems are unique to each process they are applied to, being fully customized in response to the performance and nature of the process of interest, guided by the experience of domain experts with similar systems. Process experts can easily program their domain expert knowledge into the APC applications using the simple graphical programming environment. The platform can be used to deploy off-line big data applications and real-time monitoring and closed loop control applications.

The success of APC solutions depend on the availability of adequate data, instrumentation and a good control system. Many of the APC installations do not yield the desired results because of unresponsive control systems, unsuitable field devices and inadequate instrumentation.

Adequacy of Instrumentation[9]



- FEGT
- Coal Pipe temp, velocity, mass flow
- SA Flow (individual burner)
- Drain Flow, temperatures
- Coal Analyzer
- Correct Locations is important

Example:

1. How correct is the excess O2 measurement with air-in-leakages
2. Inadequate thermocouples at proper locations

Combustion Optimization System (COS)

The Combustion Optimization System (COS) application operates in closed-loop control of many aspects of the combustion process within the boiler (specific control parameters are unit specific). Common control parameters are:

- Air Damper Positions (Auxiliary Air, Fuel Air, and Overfire Air)
- Burner & Nozzle Tilt Positions
- Excess O2 Setpoint
- Windbox Pressure Control (direct or indirect)
- Mill Outlet Temperature Setpoints
- Mill Primary Air, Classifier, and Differential Pressure Control (as equipped)

Steam Temperature Controller (STC)

Steam temperature control within coal-fired boilers is subject to many factors, which makes the temperature response to different control actions highly variable. Traditional control is often PID based, which equates to using only a single indication, or crudely constructed combination of several indications, to control spray attemperator flow rates and burner tilt positioning. Operating units under variable loads and demands generally results in sub-optimal control and stability, which affects the remainder of the unit through a compounding series of swings (e.g. drum level, furnace draft, throttle pressure, turbine valves, fuel feed rate, feedwater flow rate, MW output). These instabilities are harmful in numerous ways.

[9] Author's research

Boiler Logic and Tuning

Logic modification, air & fuel curves calibration, and control tuning will be performed to allow automatic controls of:

- Fuel Master
- Air Master
- O2 Controls
- Boiler Master
- Burner Tilts
- Mill Controls
- Air Damper Curves

Online Coal Quality Monitoring

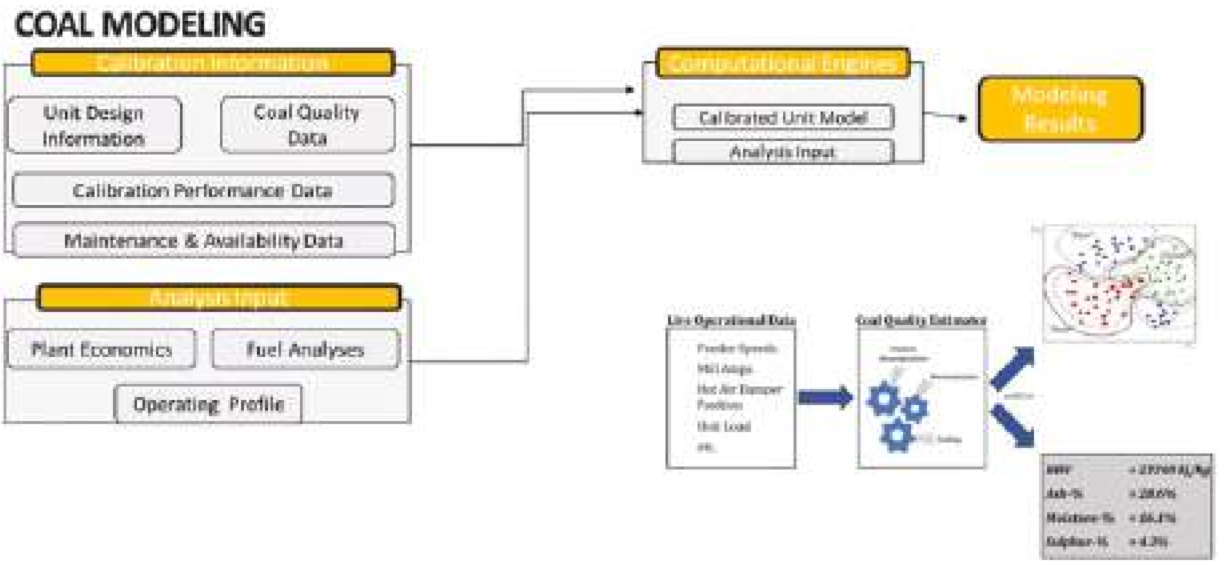


Fig 27: Coal Model for Real-Time Coal Quality Monitor

The innovative approach to managing coal-fired boilers provides a reliable and efficient solution to the challenges inherent to coal fuel variability. By leveraging a finite set of historical coal analyses (proximate and ultimate) and linking them to real-time operating conditions, the application accurately predicts the specific characteristics of the fuel in real-time. This information is a proprietary enhancement for improving optimization of processes and promotes more efficient boiler performance. The Coal Quality Monitor system provides primary outputs such as estimates of the fuel's heating value, moisture content, ash percentage, and sulfur percentage. These outputs provide a means of enabling site operators to anticipate changes in fuel characteristics and adjust their operations, accordingly, leading to reduced maintenance costs and improved overall efficiency.

Slagging and Fouling Inference System

Understanding of real-time slagging and fouling conditions within a boiler are crucial for proper maintenance and management of the unit. When sufficient instrumentation (e.g., temperature measurement) is available, local conditions at individual walls and panel surfaces within the boiler can be inferred, and the relative amount of fouling and slag currently present can be indicated.

Knowledge-based Soot blowing (KSB)

Every Unit is Unique.The Knowledge-based Soot blowing (KSB) application is an intelligent soot blowing program that effectively incorporates system knowledge from years of experience of site operators and engineers into a rule-based unit-wide soot blowing strategy.

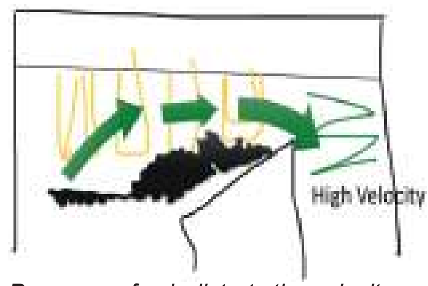
The Key Fly Ash Accelerated Erosion (FAE) Influencers are given by the following equation

$$\mathrm{FAE} = \frac{E_{i,j}}{E_{avg}} = \left(\frac{V_{ij}}{V_{avg}}\right)^{n} x \left(\frac{M_{ij}}{M_{avg}}\right) x\ C_p$$

Where:

Eij = Fly Ash Erosion Rate
Eavg – Plane Average FAE Rate
Vij = Gas Velocity at Location (I,J)
Vavg = Plane Average Gas Velocity
Mij = Fly Ash Loading at Location (I,j)
Mavg = Plane average Fly Ash Loading
Cp = Particle Size Adjustment Factor
n = Velocity Exponent (Range: 2.5 at 260C to 3.5 at 816C)

Presence of ash



Presence of ash distorts the velocity, path and temperatures

Increased erosion caused by imbalances of gas flow, temperatures and velocity, resulting with localized erosion- being exponentially influenced as temperatures increase. Ash deposits at the upper furnace, increase the FG velocity

TubeMOD10- US PATENT [US5050108A]

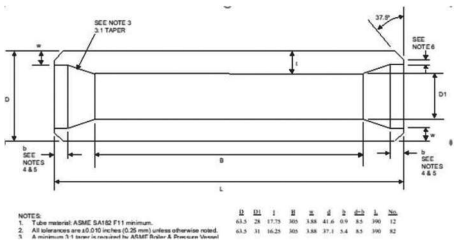
Intertek's (formely APTECH) Solution

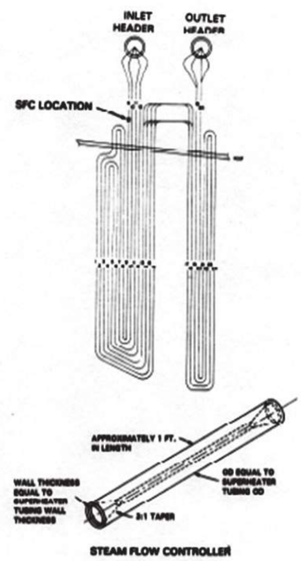
It is a method to extend the useful life of Boiler Tubes with Steam flow controllers (SFC).

Intertek developed SFCs as a means of precisely impacting frictional resistance through selected tubing. This provides controlled steam flow redistribution and temperature changes. The locations can be selected via the model and the impacts on flow, temperature, and life of all critical locations can be calculated.

[7] [10] Hilleman d (2018) Coal plants: American experience, modifying coal plants for generation flexibility,Presented at Greening the Grid workshop, New Delhi, India (Mar 2018)

Typical locations for installation of SFC are near the inlet header in the penthouse. However, SFCs can and have been designed for installation anywhere within the component.





Method for extending the useful life of boiler tubes

Abstract

A method for increasing the reliability and remaining useful life of a system of boiler tubes. The present condition of boiler tubes is ascertained and a temperature profile is developed. Additional operating parameters are obtained and used to model the tube system. The model is manipulated to predict a modification which will cause increased tube system life and reliability. The tubes are modified according to the model.

Steam flow controllers are short sections of thick walled tubing that are precisely machined to close tolerances. The tubing is installed at specific locations to increase the frictional resistance of these tubes. The modified tubing will see controlled flow decreases and temperature increases.

Fatigue Monitoring System

No matter how well a cyclic operation is done, there will always be some damages, which gets accumulated. It may take years before a failure to happen, but knowing the accumulated damages or the remaining useful life is important for planning and executing a proper inspection and maintenance strategy. While most of the turbines have a good fatigue monitoring system(provided by the OEMs), the boilers usually do not have this system(usually it is not provided by the OEMs)

.There are plenty of providers(including the OEMs) of boiler fatigue monitoring system and most work on the principle of estimating the fatigue and creep life of components- For example, Intertek's AWARE, EPRI, BHEL, L&T, SIEMENS and GE .

Conclusion

In many circumstances, a larger percentage of the power generation fleet must be flexible due to the change of the power industry toward higher penetration levels of renewable energy, demand response, and other developing technologies. To put it another way, it needs to be able to cycle up and down to supply the remaining electrical demand. Cycling of coal-based units is a difficult mode of operation and it needs a comprehensive approach- People, process and technology. The foremost thing for cycling units is to understand the factors that affect (both short-term and long term) on the life of the equipment, efficiency, loss of reliability and safety of the equipment.

Some Utilities have accomplished something that very few operators of coal-fired power plants have been able to do: turn a plant designed to run exclusively at baseload into one that can satisfy peak needs, turning on and off up to four times a day to meet the demand for electricity in the morning and afternoon. Changing operating procedures is essential to the owner's success. This includes tracking and controlling temperature ramp rates, developing a series of inspection programs for all impacted equipment, regardless of size, and providing ongoing training to reaffirm the abilities required for monitoring and inspections.

Despite being intended for baseload operations, the some of the original plant design have some cycling- friendly characteristics, which needs to be utilized. The advantageous features can be enhanced, with adjustments and improvements to procedure to increase the equipment's reliability. As per our study, cycling can be achieved in a cost effective in most of the plants with revisions of O&M procedures, upgrades of controls and instrumentation and combustion system upgrades. However, some plants may need major retrofits and replacements, especially the older plants.

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1. **Full Name:** Rajendra Ankushrao Chandgude
2. **Company Name:** Vasantdada Sugar Institute, Pune
3. **Designation:** Technical Adviser and Head (Sugar Engineering Department, VSI, Pune)
4. **Educational Qualification:** BE (Mech.), MIE, PG in Sugar Engineering, First Class Boiler Proficiency & Chartered Engineer
5. **Education Institute details:**

Qualification	Name of the Institution/ University
BE (Mechanical)	Savitribai Phule Pune University
MIE and Chartered Engineer	Institute of Engineers
PG in Sugar Engineering	Vasantdada Sugar Institute, Pune
First-Class Boiler Proficiency Engineer	Directorate of Steam Boilers, Mumbai

6. **Current Job Profile:**
    - Provide strategic leadership and oversight to department staff in extension and advisory services for sugar mills worldwide, ensuring alignment with organizational goals.
    - Support and foster research activities, including exploring and assessing new research areas.
    - Guide staff in preparing detailed Project Reports (DPR) for various sugar mill projects, including Greenfield, modernization, expansion, cogeneration, and Zero Liquid Discharge (ZLD).
    - Offer consulting services to establish and advance new and existing sugar mill projects.
    - Provide technical advice to enhance sugar mill performance.
    - Oversee educational activities, review course syllabi, and organize training programs and seminars for sugar mill staff and workers.
    - Promote faculty research, publications, and conference presentations.

- Represent the department in academic and administrative meetings.
- Develop and implement the department's strategic plan.
- Lead and mentor staff, fostering professional development and collaboration.

7. Experience:
    - He has 30 years of experience in engineering, operations, and maintenance, with a focus on the sugar industry. This includes 20-year tenure at Vasantdada Sugar Institute in Pune, where he held various positions ranging from Sugar Engineer to Technical Advisor and Head of Department.
    - In the past six years, he has served as the Head of the Engineering Department, providing strategic leadership and overseeing departmental operations.
8. Achievements and Awards:
    - Received the Lifetime Achievement Award from the Deccan Sugar Technologists' Association for dedicated service to the sugar industry.
    - Earned multiple awards from esteemed organizations such as STAI, SISSTA, and DSTAI for outstanding research contributions in sugarcane juice extraction, cogeneration, and sugar processing.
    - Consultancy Services: There has been a growing demand for consultancy services both domestically and internationally, including areas such as milling, cogeneration, project planning, coordination, and implementation.
    - Authored the book "Sugar Engineering Machines and Techniques in Marathi", drawing on extensive hands-on experience in the sugar industry.
    - Research and Publications: Renowned as an accomplished engineer, researcher, author, tutor, and consultant in the sugar industry throughout India, with over 45 research papers published in national and international journals.
    - Memberships:
        - Council Member of the Deccan Sugar Technologists' Association of India (DSTAI).
        - Member of the International Society of Sugar Cane Technologists (ISSCT).
        - Life member of several sugar associations, including STAI, SISSTA, DSTAI, and the Institution of Engineers (India).
        - Active participant in various committees of both government and non-governmental organizations for policy formation.

MAJOR CHALLENGES FACED IN THE OPERATION AND MAINTENANCE OF BOILERS IN SUGAR INDUSTRIES AND ITS REMEDIAL MEASURES

Abstract

India is the second largest producer of sugar in the world, after Brazil. The country has 732 sugar mills with capacities ranging from 2,500 to 20,000 tons of cane per day. The states of Uttar Pradesh, Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh, Bihar, Gujarat, Punjab Haryana, and Chhattisgarh have a large number of sugar mills. The annual sugar production capacity of the country is approximately 30-35 million tonnes, depending on rainfall and cultivation conditions. In addition to sugar, Indian sugar mills produce valuable by-products such as bagasse and molasses, which can be used to generate electricity and for the production of ethanol. Currently, sugar mills have co-generation plants with a total capacity of 7500 MW, with 65-70% of surplus power being exported to the grid.

Boilers are essential to the sugar and allied industries for fulfilling the sugar process heat and electrical power demands. Any stoppage in the boiler affects the entire sugar mill operation until the boiler is put back in operation. The sugar mills use steam boilers with working pressures ranging from 21 $kg/cm^2(g)$ to 125 $kg/cm^2(g)$. Recently, boilers have also been used to burn spent wash, i.e. waste generated in ethanol production thus contributing to zero liquid discharge in ethanol plants.

Sugar mills face challenges like a lack of automation, skilled manpower, etc. for operation and maintenance. There are issues during boiler start-up and shutdown like tube/pipe leakages, valve

leakages, water quality issues, accidents in ESP, troubles with rotating equipment such as feed pumps, bearing failures, and other operational problems.

This paper examines the challenges associated with boiler performance and reliability in the industry, including their causes and prevalence. It also offers solutions to enhance performance, improve operational efficiency, and reduce downtime. Emphasizing the need for training manpower in boiler operation, maintenance, and safety precautions is essential in today's context. The paper provides an overview of the requirements and importance of boiler operation and maintenance. Addressing these challenges can help sugar industries maintain sustainable and cost-effective operations.

Keywords: Bagasse, boiler, sugar mills, pressure parts, operation & maintenance

Introduction

Across the globe, sugarcane is an important crop in subtropical and tropical regions. Sugarcane is a significant crop for the production of sugar and ethanol in the world. India is the largest producer and consumer of sugar in the world. Approximately 28.30 million hectares of sugarcane are cultivated in 90 countries with a production of about 1.69 billion tonnes.

In India, there are 732 sugar mills, including 327 cooperatives, 362 privates, and 43 public limited companies. These mills have an average annual crushing capacity of 355 million tonnes and produce about 34 million tonnes of sugar each year. The average crushing capacity of these mills is around 4500TCD, with an installed cogeneration capacity of 7500MW and an ethanol production capacity of 3000-3500 million liters per year. The sugar industry plays a crucial role in the rural economy by providing livelihoods for around 50 million farmers, indirectly supporting 55 million unskilled workers, and directly employing 5 million skilled workers.

The sugar industry in India is undergoing a significant transformation in its energy usage. Currently, 42.10% of power is generated from fossil fuels and 57.90% from non-fossil fuels, with 2.2% coming from biomass, including bagasse-based cogeneration. India aims to install 500 GW of non-fossil energy capacity by 2030, with 50% from renewable sources, according to the Energy Conservation Bill 2022. This effort targets a reduction in carbon intensity by 1 billion tonnes and achieving zero emissions by 2070. The use of biomass from sugar plants can contribute significantly to this goal.

The Indian sugar industry is shifting from reliance on oil, gas, and fossil fuels to self-sufficient bio-energy production. Sugar mills are also diversifying from food production to producing bio-electricity, bio-ethanol, compressed bio-gas, chemicals, organic manure/potash fertilizers, and capturing CO2. Innovations such as 2G ethanol from bagasse, Sustainable Aviation Fuel (SAF), and hydrogen production from surplus bio-electricity are also emerging. Sugar mills are also adopting energy and water conservation practices and maintaining Zero Liquid Discharge (ZLD) norms.

This transition to bio-energy will help reduce India's carbon footprint and support a more sustainable and environment-friendly economy.

Basic needs of sugar mills:

- For a sugar mill to operate at full capacity with high recovery, it requires a consistent supply of high-quality, mature, and clean sugarcane. Ideally, the cane should be processed within 24 hours of harvesting.
- Steam is essential for the juice heating, evaporation, and crystallization process. Adequate power

is needed to run all auxiliary equipment in the sugar plant. Without sufficient steam and power, the plant cannot function.

- Clean, treated water is necessary for various processes, including sugar processing, steam generation in boilers, equipment cooling, and domestic use within the plant.
- Infrastructure, including space for machinery, and modern equipment for juice extraction, processing, and power generation is crucial for efficient plant operations.
- Technical staff and skilled personnel are vital for the efficient and safe operation of the plant. Additionally, unskilled workers are needed to support skilled staff and to perform various activities.
- Effective waste management and emission control are essential to minimize environmental impact. Systems are needed to handle and process by-products like bagasse and molasses. Emission control involves using equipment and procedures to reduce air and water pollution.
- Safety measures are critical for protecting workers. This includes providing personal protective equipment such as gloves, helmets, and goggles, along with clear safety protocols for machinery use and material handling. Emergency response plans and necessary equipment, like first aid kits and fire extinguishers, are also essential.

Fuels used in sugar mill boilers:

The following fuels are used in the sugar mill boiler.

a) **Bagasse:**

The basic fuel used is sugar cane residue bagasse. Sugarcane residue is a source of renewable energy and can be easily converted into thermal energy, also the major biomass i.e. sugar cane residue is an environment-friendly fuel available from operating sugar mills. Bagasse is the main source of fuel in sugar cane-based power generation.

b) **Sugarcane trash:**

Sugar cane trash i.e. the dry and green leaves left in the field at the time of harvesting can be collected along with the cane to provide an additional 7.5 to 10% biomass on cane as additional fuel to boost thermal energy.

c) **Sugarcane roots:**

Sugarcane roots also have significant fibers, if considered for power generation; it can further add 2 to 3.5% as additional fuel.

d) **Liquid fuels:**

Concentrated spent wash is also used as fuel for boilers in Spent Wash Incineration boilers. The spent wash from the distillery is incinerated completely to achieve ‘Zero Liquid Discharge’. With this Spent Wash Incineration Boiler, the power as well as the steam requirement of the distillery are met satisfactorily. The supporting fuels that can be used to incinerate spent wash in these boilers are bagasse and coal. The spent wash-to-coal ratio that can be attained is about 70:30 and for bagasse, it is about 60:40.

e) **Gaseous fuel:**

Methane gas generated by distillery influent that is washed by bio-methanation and processed to treat the wastewater originating from the distillation column of the ethanol production plant. It produces methane-rich gas, which has a high heating value.

Technological challenges before sugar mills:

The sugar mills are encountering challenges such as periodic declines in domestic sugarcane production due to droughts occurring every 4-5 years. This fluctuation in supply impacts sugar mills' ability to obtain an adequate amount of raw materials. Furthermore, the sugar recovery rate from the cane has decreased, resulting in an overall reduction in production.

Some sugar mills operate with old and obsolete machinery and are inefficient compared to modern technologies. This inefficiency affects their ability to produce sugar effectively. Some sugar mills are relatively small and unable to produce large quantities of sugar, which hinders their ability to compete with larger mills that can produce more sugar at a lower cost and in a shorter timeframe.

In recent decades, many sugar mills have adopted high-pressure and high-temperature boilers with new technologies to maximize power generation while minimizing fuel usage. In these modern boilers, it is crucial to maintain the quality of the feed and boiler water to ensure the efficiency, safety, and durability of the system. Unfortunately, many sugar factories are encountering issues with boiler tube failures, particularly when using high-pressure boilers, due to the use of poor-quality water.

Cogeneration boilers in the sugar mills have experienced failures such as boiler tube failure, etc., resulting in prolonged outages and significant losses of output power and money, increased downtime, and financial losses. By proactively using treated quality water, the industry hopes to reduce the negative impacts of tube failures and increase operating efficiency, and overall production.

Additionally, due to a lack of operation & maintenance training, awareness, and negligence among the boiler operators and management team many boiler working staff suffer from boiler accidents every year. Some reasons for boiler accidents include over steam pressure, low water level, tube failure, faulty design, faulty welding joints during erection, failure of safety devices, combustion failure, improper feed water treatment, improper preservation in idle condition, overheating, water and fire-side corrosion, and oxidation and erosion.

I. External challenges are as follows:

i. Quality of Fuel

ii. Boiler Feed Water

iii. Selection or Replacement:

iv. Automation

v. Skilled Manpower

i. Quality of Fuel:

- Mill wet bagasse directly burns in the boiler, so moisture% and pol% bagasse are important to maintain GCV and NCV for efficient boiler operation and better performance. Bagasse drying increases its calorific value. The last mill bagasse with 50% moisture content has a net calorific value of 7.54 MJ/kg. In contrast, dried bagasse with 10% moisture content has a calorific value of 15.65 MJ/kg, thus more than doubling the net energy value.

- The sugar mills are experiencing a shortage of manual labour for harvesting sugarcane, so mechanically harvested sugarcane is provided for crushing. Mechanically harvested cane contains about 6 to 12% trash, clay, soil, sand, stone, and other materials. Which further degrades the quality of bagasse/fuel and causes problems like clinker formation, etc.
- Spent wash generated in the distillery is used as fuel along with supplementary fuel sugarcane bagasse or coal in an incineration boiler. The spent wash contains impurities like chlorine, sulphur, and oxides of potassium, sodium, and magnesium. Keeping in view impurities in fuel, the boiler is designed to avoid fouling and slogging problems.
- The methane generated in the distillery bio-digester is not up to mark, so it affects the efficiency of the boiler.

ii. Boiler feed water:

- In high-pressure boilers, it is important to control corrosion and improve steam quality. Internal corrosion and deposition can lead to a significant increase in repair and maintenance costs.
- De-aeration is the process of removing dissolved oxygen (O2) along with traces of chlorides and solids so as to prevent pitting corrosion of metal surfaces. Oxygen and other gases are removed from feed water before they can enter the boiler. It is important to monitor the treatment system on a regular basis to control the entry of contaminants into the steam/water cycle.
- The process condensate of the first body of the evaporator set/exhaust condensate is used and its quantity is around 85 - 95%.
- Make-up water from DM or RO is used after treatment and its quantity is 7.5% to 15% of total water consumption. Conductivity and pH measurements are the basic operating parameters of the overall content of dissolved impurities and acidity/alkalinity.
- Approximately, 90% process condensate of the first body of the evaporator set is used as feed water. Due to frequent shutdown and maintenance problems, the process condensate may get affected by the sugar test. If the sugar content exceeds 200 ppm, it can result in severe damage to pressure parts, as well as issues such as foaming, fouling, corrosion, and unplanned shutdowns of captive and co-generation plants.

iii. Selection or replacement:

- Some sugar mills are experiencing issues with old boilers that have a very low efficiency of less than 60% on GCV. These boilers are more than 40-50 years old, operate at pressures of 21 to 32 kg/cm2(g), and have a small capacity.

  Issue: High bagasse consumption, incurs high repair and maintenance costs and creates more problems for the environment.
- The sugar mills have to select a high-pressure boiler suitable for the entire process operation with minimum manpower to minimize environmental issues along with high-efficiency operation with DCS.
- For bagasse-fired boilers, the optimal pressure range is 67 to 87 kg/cm2(g) with a superheated steam temperature of 515 to 540°C, as well as an efficiency of over 72% based on GCV. As for incineration boilers, the recommended pressure is 45 kg/cm2(g) with a superheated steam

temperature of 400°C, using agricultural residue biomass as supporting fuel and achieving an efficiency of about 65% based on GCV.

iv. Automation:

- The automation and operation of the old boiler having pressure below 45 kg/cm2(g), are very difficult due to their design and operation. The boiler only has feed water level control, pressure, temperature, and draft gauges provided.
- For boilers with pressure of 45 kg/cm2(g) and above, a PLC/DCS control system is installed for full monitoring and control through the DCS system only.
- Also, some sugar mills are thinking about remote monitoring and its control to eliminate human errors in the operations.

v. Skilled manpower:

- The sugar mills are facing the problem of skilled manpower due to being a rural industry and inadequate facilities provided by the sugar mills.
- Sugar mills lack awareness of highly skilled manpower recruitment and its benefits to the industry.
- There is a lack of awareness regarding innovative, energy-efficient technologies and training for employees.

II. Internal challenges are as follows:

i. Corrosion and Erosion

ii. Thermal stress on pressure parts

iii. Internal and external scaling

To address these challenges, it is essential to operate and maintain the boiler properly. By doing so, not only can costs be saved, but the impact on the environment can also be mitigated. Below are detailed explanations of the causes.

i. Corrosion and Erosion:

a. Corrosion:

- Corrosion can occur due to acidic conditions, oxygen ingress, and the presence of chlorides in the water.
- Severe corrosion may result in thinning of boiler tube metal, stress cracking, caustic embrittlement, and metal degradation.
- Weakened boiler materials can lead to leaks and failures leading to reduced efficiency & increased maintenance costs.
- The boiler operator must consistently monitor the quality of the boiler water to ensure that levels of dissolved solids, dissolved oxygen, and pH are maintained within the required limits.
- Several factors can contribute to corrosion in a boiler as below,

- ➢ The type of metal used
- Water quality
- The operating conditions
- The presence of impurities in the water, etc.
- The boiler metal gets corroded quickly due to the action of dissolved oxygen leading to the complete failure of the boiler system. Which results in
- Increased cost of maintenance and repairs.
- Leaking of rivets and joint areas.
- Reduced boiler life and possible chances of failure of the entire system.
- The dissolved oxygen sets free as the water is heated. This dissolved oxygen then reacts with the iron of the boiler to form a rust.
- Addition of Hydrazine/ Sodium Sulphite/Sodium Sulphide added to reduce the corrosion.

b. Erosion within the Boiler:

- Boiler tube metal can be externally attacked by erosion.
- As the flue gas stream travels from the furnace to the stack, it carries unburnt fuel, ash, and dust particles. In areas where the velocity is excessive, the flue gas stream can erode the tube surfaces, leading to metal loss and eventual tube failure.
- Boiler design typically prevents areas of excessive velocity, but changes in fuel (coal) quality can increase the ash and dust burden carried through the gas path. This may necessitate further screening of tubes in areas prone to erosion.
- Air flow through the boiler should be limited to that required for initial purging followed by an increase in flow as demanded by increased fuel input.

ii. Thermal stress on pressure parts

Thermal stress may reduce the life of the boiler and also, create failure due to creep and fatigue within the metal components. Thermal stress can be reduced by adopting the following corrective measures:

- Proper heat dissipation across the boiler water/steam circuit by maintaining water/steam flow at or above the minimum flow rates.
- Ensure proper flow rate through circulation pumps and maintain proper re-circulation.
- Maintain proper drum water level and designed values of furnace gas exit temperature.
- Check and ensure rates of metal temperature change and various temperatures during boiler start-up, load change, and shut-down.
- Ensure all equipment's in service to allow the boiler performance to be constant.
- Following operating information (as a minimum) to be displayed, simultaneously, as a continuous trend at the operating location:

- Boiler outlet steam pressure, temperature, and flow rate.
- Boiler water and fuel flow rate.
- ID, FD, SA, and furnace draft.
- Airflow rate as a percentage of the maximum unit load, drum level, etc.

iii. Internal and external scaling and deposits:

a. Internal Scaling:

- The scaling is caused by the formation of contaminated water on the heat-transferring surfaces of the boiler.
- Scaling results in a higher fuel consumption.
- Implementing water treatment processes such as demineralization, RO plant, and using softeners can minimize scaling.
- Regular blow-down and chemical cleaning schedules should be established to remove deposits.

b. External Scaling:

- In bagasse-fired boilers, soot accumulates on tubes and pressure parts and it acts as a bad conductor of heat.
- The soot accumulations shall be removed by regular soot blowing so as to reduce stack temperature.
- Both internal and external scaling increases flue gas temperatures going to the chimney. It is estimated 1% efficiency loss occurs with every 22°C increase in stack temperature.

III. Other Challenges

i. Breakdowns/Explosions:

a. Interruption in bagasse and combustion air supply:

- Total or partial interruption in bagasse (fuel) or combustion air supply may cause the boiler to operate inefficiently. A sudden interruption may cause the boiler to become unstable, leading to dangerous pressure build-ups or explosive reactions.
- Incomplete combustion can lead to the accumulation of unburnt fuel, which, when reignited, can cause a breakdown.
- Inadequate control of combustion can result in the accumulation of a fuel-air mixture that falls within the explosive range. This situation may occur in the furnace or Electrostatic Precipitator (ESP) areas.
- Bagasse particles that are incompletely combusted can accumulate in various parts of the boiler. These particles can become highly flammable and may ignite explosively under certain conditions.
- Maintaining proper operational procedures, ensuring reliable fuel and air supply, and implementing effective safety measures to prevent breakdown in bagasse boilers.
- Regular maintenance, monitoring, and adherence to safety protocols are crucial to mitigate these risks.

b. Precautions ESPs against fire and explosion:

- The flue gases of agro waste-fired boilers often contain very high-unburnt carbon; sometimes as high as 20 to 60%. The percentage of unburnt carbon increases when the boiler is not operated correctly.
- The basic action to prevent fire and explosion is to ensure complete combustion of the fuels. The dust with high-unburnt carbon tends to be sticky. It may result in hopper choking. This also leads to the accumulation of dust in the hopper. If there is any smouldering of unburnt carbon dust, this can lead to fire or explosion.
- There was an explosion in the ESP, which caused the casing to fall and damage the structure and electrical equipment. The inlet and outlet nozzles were also damaged, along with the flue gas ducting. Unburnt bagasse particles may have accumulated inside the ESP, leading to secondary burning and damage. It is important to follow the start-up procedure as per OEM instructions to prevent this. Additionally, there is CO formation due to unburnt bagasse in the hoppers. The hopper vibrators failed to work in removing the bagasse from the hoppers, and Ash bypass operation needs to be done during start-up.

ii. Pressure parts damages/explosions:

- The damage to the pressure parts in the boiler is caused by mechanical failures in components resulting from higher pressure, temperature, and steam/water starvation. These damages have been observed at welded joints and hanger supports for tubes. Operating the boilers at higher pressures and temperatures has been a significant cause of damage.
- To reduce damage, the boiler should not be operated at pressures and temperatures higher than its design limits. Exceeding these limits can cause thermal stress and corrosion, weakening the boiler components and potentially leading to failure of the pressure parts at higher pressures and temperatures.
- **Boiler pressure and temperature:**

The pressure and temperature inside the boiler are controlled by safety valves. There is a first safety valve located at the superheater header and a second at the steam drum. The temperature can be managed by a de-superheating station as well as the HP, IP, or LP bypass systems where they are installed. It is also important to monitor the firing rate to prevent over-firing.

iii. Operational problems:

a) Impact of sugar test:

- If a sugar test comes positive in the boiler feed water, it typically indicates a leak in the evaporator tubes. This allows the juice to mix with the exhaust steam, resulting in the presence of sugar in the feed water. If the feed water contains more than 200 ppm of sugar, it can cause serious damage to the boiler. This can lead to problems such as foaming, fouling, and corrosion, and may even result in an unexpected shutdown.

b) Priming, Carryover, and Foaming:

- **Priming:**

Priming is a condition in which water droplets are carried along with steam from a boiler. This can be caused by several factors, including:

- ➢ High water level in the boiler & Significant fluctuations in water level
- ➢ Sudden fluctuations in steam demand
- ➢ Impurities in the boiler water
- ➢ Reduced steam quality
- ➢ Increased corrosion and scaling
- ➢ Damage to valves and other equipment

To prevent priming,

- ➢ Maintain the proper water level in the boiler,
- ➢ Avoid sudden fluctuations in steam demand,
- ➢ Treat the boiler water to remove impurities, maintain low levels of salts in the water,
- ➢ Regularly remove sludge through blow-down procedures.

- **Carryover:**

Carry-over is a term used in a variety of contexts to refer to the transfer of something from one situation to another.

- ➢ Carryover causes a decrease in the efficiency of a boiler.
- ➢ Dissolved salts and solid particles have a chance of getting carried away into the turbine blades and finally getting deposited over the blades.
- ➢ Carry-over poses a serious problem to the parts such as turbine blades, steam traps, valve bodies, etc.

To prevent carryover,

- ➢ Ensure proper feed water treatment, Suggestions from the chemist should be considered regarding the boiler and feed water treatment,
- ➢ The main steam stop valve should be opened gradually,
- ➢ Maintain lower water levels,
- ➢ Leakage of any 'foreign' material into the boiler feed water system should be avoided.

- **Foaming:**

Foaming is the formation of bubbles in a liquid. It is caused by the presence of surfactants, which are molecules that have one end that is attracted to water and one end that is attracted to air. The formation of soap-like structures reduces the surface tension of water significantly, thus decreasing the boiler efficiency and fluctuation in water level.

- ➢ This can lead to contamination and scaling.
- ➢ Presence of various chemicals and solid constituents in the boiling water. The lubrication used in boilers serves as a source of oil, which is the primary source behind the effect of foaming. Formation of small bubbles at the water surface, which do not break easily.

To prevent foaming,

- Use of Anti-foaming agents such as castor oil. Proper treatment of water before entry into the boiler to remove the foaming agents (such as oil, and alkali).

iv. Operational inefficiencies:

Inefficient combustion due to improper fuel quality or air-to-fuel ratios can lead to reduced thermal efficiency and increased emissions.

a) Pressure and temperature control issues:

Fluctuations in pressure and temperature can occur due to inadequate instrumentation and control systems, impacting steam supply consistency. Upgrading control systems and regular calibration of instruments can enhance monitoring and control, ensuring stable operation.

b) Steam quality:

To reduce the contamination to one ppm in the outlet steam, 99.99% of the circulating water must be separated from the steam in the drum.

c) Sagging of superheater zone:

Several steam boilers are facing a serious problem of choking of screen tubes and superheater coils due to the nesting effect caused due to fused ash and sagging. The main causes are as under:

- Overloading of steam boiler.
- Inadequate induced draught, furnace height, residence time for burning less than 2.5 seconds, screen tube coverage, secondary air, screen tube pitch, and SH coil pitch.
- Very fine cane preparation.
- Obstruction in ID fan, duct, delivery.
- Too much scale inside coils.
- Very high bagasse pol.
- Metals in bagasse such as sodium, sulphur, vanadium, and salts.
- Overheating of coils due to less steam mass flow rate.
- Steam losses: at turbines 3-4%; at piping 3%

d) Pressure drop:

If the steam flow is higher than the design causing steam pressure loss. The corresponding pressure drop through the superheater need not exceed 10 percent of the boiler operating pressure.

e) Tube sizes:

Smaller diameters tend to result in higher pressure drops and make it more difficult to maintain good alignment.

f) Slag screen tubes:

The screen tubes are arranged across the boiler, on 12” centers. From front to rear the rows of tubes are spaced on 6” centers. The closest spacing of the forward superheater tubes, side spaced somewhat closer than the slag screen, a cavity or space is provided for access and to accommodate mechanical soot blowers. Recent designs, however, have called for greater spans between supports for horizontal superheater tubes and wider tube spacing or fewer tubes per row to avoid slag accumulation.

g) Water level in the drum:

Gross impurities in the steam may be caused by periods of abnormally high water level, due to operational upsets, in which the separating equipment is submerged, allowing the water to be carried over in gulps. This action may be called priming.

h) Steam separation:

Size of the steam drum where rapid load changes are anticipated, the steam drums should be large enough to prevent carry-over due to load change.

i) Operating:

Water level carried judicious lowering of the normal water level may relieve the tendency for moisture carry-over.

j) Flue gas leakage through the corner portion of water wall panels:

Missing of corner and side seal plates and ropes.

k) Super heater coil failures:

The coils failed during full load operation due to blockage of coils with foreign particles. The coil spool piece was replaced, Coils twisted during operation.

l) Air pre-heater:

Ash accumulation at the second pass top module may be observed during boiler operation if the load is less than 70%. APH bypass needs to be provided to avoid flue gas condensation in the tubes of the APH module, the boiler should be operated above 80% load to avoid draft fluctuation due to APH jamming.

m) Blow-down control:

Uncontrolled continuous blow-down is very wasteful. Automatic blow-down control can be installed that senses and responds to boiler water conductivity and pH. A 10% blowdown in a 15 kg/cm2 boiler results in a 3% efficiency loss.

v. Furnace and gas path implosions:

An implosion in a furnace or gas path happens when the pressure inside the boiler furnace or gas path becomes excessively negative. This causes the force exerted by atmospheric pressure on the outside of the structure to become strong enough to deform or collapse it.

Typical conditions leading to a furnace and gas path implosions include:

- A malfunction of the control or operating equipment that regulates the flow of air and flue gas through the boiler, leading to the creation of an excessively negative pressure within the furnace and gas path. This is normally the result of reduced airflow (due to failure of the Forced Draught

Fan or closure of dampers within the gas path) and the inability of the control system to reduce the throughput settings of the Induced Draught Fan.

- A rapid reduction in furnace gas temperature and pressure following a significant loss of fuel, a master fuel trip or any combination of these two conditions.
- Make sure to limit the maximum head and capacity for induced draft equipment to ensure satisfactory operation. In cases where high-draft-loss equipment is used for boiler installations, consider adding bypass or relief dampers in the ductwork to prevent excessive negative pressure conditions and potential boiler implosion.

Need for operation and maintenance:

The operation and maintenance program is designed to

- ➢ Continuously meeting steam requirements and improving operation quality.
- ➢ Lengthen the life of equipment.
- ➢ Maintaining the productivity of the processing unit.
- ➢ Maintain working performance and design efficiency.
- ➢ Prevent/minimize wear and tear through periodic lubrication.
- ➢ Repair equipment quickly in case of breakdown.
- ➢ Reduce operational and maintenance costs.
- ➢ Ensure safe working conditions and minimize environmental impact.

For proper operation of the boiler requires a planned program of operator training, knowledge regarding equipment, preventive maintenance, and an adequate maintenance inventory. If maintenance is not carried out properly, then internal components can rust or corrode, leaks can occur, debris can accumulate, etc. Regularly servicing your commercial boiler will prevent boiler breakdowns, higher breakdown costs, and additional expenses in the budget.

Regular maintenance will guarantee that the boiler operates efficiently, reduce the risk of emitting dangerous levels of carbon monoxide, and lower maintenance costs.

a. Maintenance models:

- ➢ Corrective Maintenance: Involves correcting mistakes in the system.
- ➢ Preventive Maintenance: Predetermined work to prevent wear and tear or sudden failure.
- ➢ Breakdown Maintenance: Reactive, occurs after equipment failure

b. Maintenance plan:

- ➢ Well-planned maintenance program to avoid downtime and costly repairs
- ➢ Maintain inspection schedules, SOPs, and boiler room log book
- ➢ Record daily, weekly, monthly, and yearly maintenance activities

c. Shift maintenance:

- Check boiler steam pressure and temperature
- Operate blowdown valve and monitor water chemistry
- Follow guidelines for feed water quality

d. Daily maintenance:

- Monitor bagasse moisture, steam pressure, and temperature.
- Confirm flame color, chimney emissions, boiler load, and soot blowers.
- Check flue gas temperature and air temperature after the pre-heater.
- Monitor CO2 or O2 levels in the flue gas.
- Check the draft at various points and inspect moving parts and bearing conditions.
- Analyze water every shift and regenerate soft water for low-pressure boilers or check stock of DM water/soft water.

e. Repairs and maintenance:

- Ensure that brick wall work, roofs, baffles, and ducting are leak-proof to prevent short circuits or air infiltration.
- Provide lagging and cladding for all steam piping, valves, and heat exchangers.
- Keep all pressure parts clean, both inside and outside, and duly painted with the recommended thermal paints.
- Allow for thermal expansion to enable free movement, in accordance with erection specifications.
- Balance all ID, FD, and SA fans statically, and if required, dynamically, to avoid vibrations and damage to the foundations.
- All pressure parts should be in good condition and leak-proof.
- Ensure all air pre-heater tubes are in good condition and leak-proof to prevent short circuits.
- Leak-proof the roof of the steam boiler building to prevent rainwater damage to lagging and cladding. Vents, startup lines, safety lines, etc., should be rerouted to vent from the side walls of the building. Any located on the roof should be removed and relocated.
- Maintain all feed water pumps for the steam boiler including the turbo pump in working condition at all times.
- Provide a means to pre-heat cold makeup water using excess exhaust steam or vapors from the evaporator bodies.
- Equip the evaporator station with provisions to achieve minimum steam consumption and maximum bleeding of vapors for optimal thermal efficiency.
- In the Boiling House, implement measures to minimize the use of live and exhaust steam

Operational performance:

a. Quality of fuel and its supply:

- Control the moisture of mill-wet bagasse to below 50%.
- Burn an optimal quantity of bagasse to ensure efficient combustion.
- Ensure a continuous supply of the required quantity of bagasse from the mills or reclaimed from the bagasse yard.
- Maintain the preparatory index of sugar cane at the cane preparatory devices between 85% and 87%, and avoid powder formation of cane to minimize fly ash and unburnt bagasse losses from the chimney.

b. Excess air and combustion:

- Control the quantity of excess air to below 35%.
- Adjust ID, FD, and SA draughts to ensure the draught is balanced at the furnace, or within ±5 mm.
- Achieve complete combustion of bagasse, observing the flame colour in the furnace to be golden yellow, and maintain the temperature at approximately 1050°C.
- Maintain the temperature of pre-heated air up to 200°C.
- Avoid the entry of cold air into the furnace from bagasse feeders, ducting, and doors.
- Maintain the flue gas temperature below 160°C.

c. Feed water and its quality:

- Maintain the feed water temperature above 85°C.
- Ensure that feed and makeup water are free of sugar, silica, and total hardness.
- Maintain a normal working water level in the steam drum always below the centreline of the drum by 50 mm.
- Avoid foaming, priming, carryover, and water hammering to ensure the safety of super-heater coils and steam turbines.
- Keep the water level easily visible and always above the low-set point to prevent the risk of water loss and serious damage to pressure parts due to overheating and burning.
- Maintain the pH of feed water and boiler water at the required levels, and remove oxygen by adding high-quality chemicals in liquid form from a reputable manufacturer.
- Collect all hot condensate water from steam traps and send it to the hot water storage tank.
- Ensure that the TDS in the boiler water.
- Ensure all steam lines, joints, and steam traps are leak-proof to avoid steam losses.
- Collect all hot condensate water from steam traps and send it to the hot water storage tank.

d. Utilities and its operation:

- Operate soot blowers regularly to prevent the deposition of soot on the external surfaces of pressure parts.
- Remove accumulated ashes regularly from the furnace, passages, economizer, air preheater, and ducting leading to the ID fan and chimney.
- Minimize resistance in dust collectors, monitored by the difference between the inlet and outlet draught values.
- Follow strict steam boiler start-up procedures to avoid overheating of superheater coils and resultant failures.
- Properly lag and clad all steam pipelines, valves, steam turbines, juice heaters, evaporator bodies, vacuum pans, and all heat exchangers, as well as hot water, hot juice, and syrup pipelines.
- Avoid overloading the boiler MCR capacity and operate the steam boiler at low steam pressure and temperature to prevent priming and carryover, ensuring the safety of the boiler and steam turbines.

Energy Conservation and principles of efficiency:

Adopting modern concepts such as high-pressure boilers, TG sets, condensing and cooling systems, automation, VFD drives, energy-efficient motors, reactive power management, choice of transmission gears, high-efficiency pumps, proper sizing of all equipment, reducing energy losses due to leakages, radiation, and friction, and minimizing downtime are important aspects to consider for energy conservation.

To improve the thermal efficiency of the steam boilers and save more fuel/bagasse, it is essential to regularly check and follow the operational parameters and maintenance checkpoints.

Efforts to improve sugar content in sugarcane have led to a decrease in fiber percentage, so it's important to minimize heat energy losses and enhance the boilers' thermal efficiency to conserve valuable fuel resources. To achieve this reduction,

- ➢ increasing the feed water temperature to the boiler by 60-70°C can lower the flue gas temperature by 100°C, typically through an economizer.
- ➢ 1% decrease in CO2 concentration results in a 1% decrease in boiler efficiency. Conversely, reducing the flue gas temperature by 150°C leads to a 1% increase in boiler efficiency.
- ➢ Raising the temperature of the air entering the combustion chamber by 100°C can decrease the flue gas temperature up to 130-140°C.
- ➢ In the economizer, a 90°C rise in temperature leads to a 1% increase in efficiency, while in the air heater, a 20°C rise in temperature results in a 1% increase in efficiency.
- ➢ A blowdown rate of 5% results in an estimated fuel loss between 1.75% and 2.2%.
- ➢ Maintaining the deaerator temperature above 99°C can reduce oxygen levels by 0.3 ppm.
- ➢ It is crucial to maintain the combustion chamber air temperature above 180°C.

- The feed water pH should be kept between 8.5 and 9.5, and it is essential to maintain a regular logbook of boiler records.
- Proper calibration and maintenance of all instruments are vital.

Conclusion

To maintain the boiler's optimal functionality and achieve the desired performance, it is crucial to focus on effective operation and maintenance practices.

When considering the various challenges such as corrosion, scaling, low efficiency, pressure/ temperature control issues, breakdowns, and maintenance requirements, it is imperative to implement specific and detailed corrective measures.

Effectively addressing corrosion and erosion involves implementing advanced reduction techniques and conducting regular monitoring to ensure long-term protection and maintenance. Furthermore, a comprehensive approach to water treatment is essential to mitigate scaling and related issues. Adhering to industry-standard practices for repairs and maintenance ensures the longevity and efficiency of the boiler system. Additionally, integrating automation and control systems can significantly enhance the overall operational effectiveness.

By carefully following these detailed strategies for repairs, maintenance, and efficient operation, we can ensure the sustainable generation of steam and power. while effectively managing pollution control measures.

Acknowledgment

The author is thankful to Adviser Shri Shivajirao Deshmukh and Director General Shri Sambhaji Kadupatil for encouraging the study on "Major challenges faced in the operation and maintenance of boilers in sugar industries and its remedial measures"

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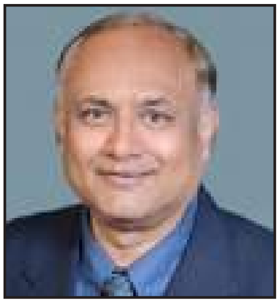

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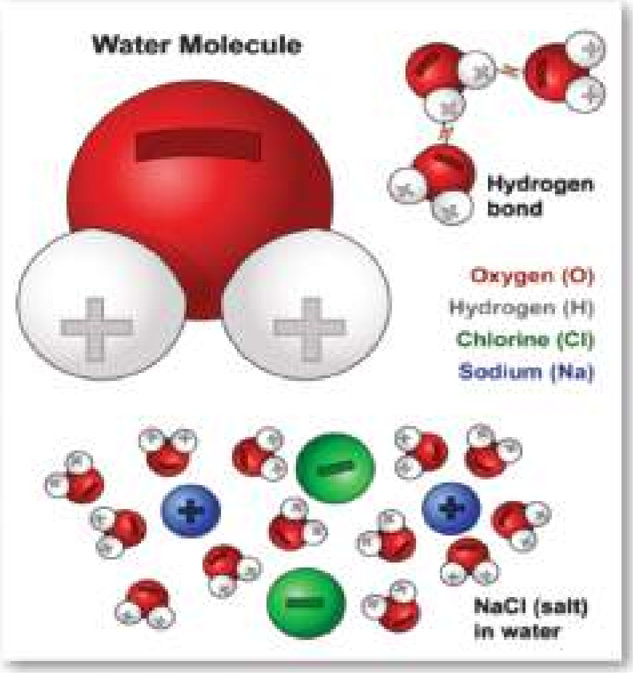
WATER CHEMISTRY INTRODUCTION

Two hydrogen atoms are located 105O apart, adjacent to the oxygen atom, so that the molecule is asymmetrical, positively charged on the hydrogen side and negatively charged on the oxygen side. The hydrogen of one water molecule attracts the oxygen of the neighbouring molecule. The energy required to rupture Hydrogen bonding and liberate a water molecule to form vapor is much greater than other common chemical compounds. Hence steam has the highest energy content and is used for transferring energy in industries.

Hydrogen bonding produces a crystal arrangement that causes ice to expand beyond its liquid volume so that the density of ice is lower than liquid and it makes ice float on water. If this was not so lake would freeze from the bottom up and life would never exist in water.



Water is often called a universal solvent. Water molecules in contact with crystal orient themselves to neutralize the attractive forces between the ions in the crystal structure. The liberated ions are then hydrated by these molecules preventing them from recombining and recrystallizing.

Osmotic pressure – If a membrane separates two aqueous solutions, water will pass from the more dilute into the more concentrated one. - Ex. Common Salt addition in a pickle for food conservation.

Viscosity – As water temperature increases internal friction/viscosity reduces thus dissolved gases and salts can diffuse more rapidly. This phenomenon aids the process of sedimentation and degassing.

The Sources of Fresh Water are Rain Water, Surface Water, River Water, Lake Water, and underground sources such as open and bore wells.

- **Terms in Water Chemistry**

pH

pH = Log 1/ [H+] = -log10[H+]

It is a measure of the Acidity & Alkalinity of water that can be expressed in terms of hydrogen ion concentration.

pH scales range from 0 – 14. pH at 7 is neutral. pH < 7 is Acidic. pH > 7 is Alkaline

DISSOLVED SOLIDS

Various Cations and Anions dissolved in the water but not the sum of cations and anions. Anions and Cations are arithmetically equal for electrical neutrality. The various Cations are Calcium, Magnesium, Sodium, Potassium, and iron. Similarly, the various Anions are Carbonates, Bicarbonates, Chlorides, Sulfates, Chlorides, Nitrates, and Silica.

CONDUCTIVITY

Ability to carry electrical charge due to dissolved solids. It is measured in Micro Siemens/cm at a given temperature or as micro Mhos/cm. Both units are identical. It is a measure of ionic impurities present in water.

TOTAL SUSPENDED SOLIDS

Matter suspended in water such as dirt and silt. It is measured by the gravimetric method in ppm.

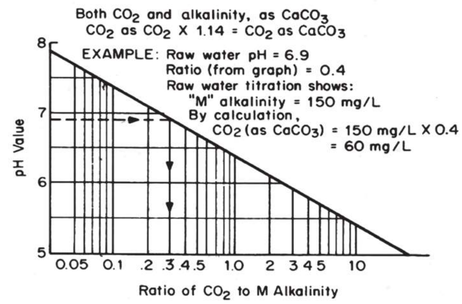
TURBIDITY

It is caused by the suspended matter. It is measured in NTU by the light scattering method using a Nephelometer. The higher the obstruction to the light path more is the Turbidity.

ALKALINITY

It indicates the presence of bicarbonates, carbonates, and hydroxyl ions in water. It is **NOT TO BE CONFUSED WITH ALKALI.** Alkalinity indicates the capacity of the aqueous solution to react with acid (H ions). The Methyl Orange indicator gives yellow color with all OH, CO3, and HCO3 alkalinity. Methyl Orange turns orange in the presence of acid at pH = 4.3. Phenolphthalein Alkalinity is due to OH and CO3. Please note that OH and HCO3 alkalinity do not exist together. The presence of HCO3 is Mild Alkalinity. The presence of CO3 is a slightly strong Alkalinity. The presence of OH indicates very strong Alkalinity. Between pH 4.3 – 8.3 Balance of Co2 and HCO3 exists.

In the pH range of 4.3 to 8.2, there remains a balance between excess CO2 and bicarbonate ions which is measured by the pH. Water containing 1 mg/L of Co2 and 100 mg/L of Alkalinity has the same pH as one containing 10 mg/L of CO2 and 100 mg/L of Alkalinity. In the first case, the addition of 1 mg/L of CO2 would produce a large change in the pH, whereas in the second case, the same addition will not produce a noticeable change. Hence Alkalinity moderates or buffers the pH.



Approximate relationship of carbon dioxide, alkalinity, and pH value.

pH	**Alkalinity**
10.2	OH- $CO3^{-2}$
8.3	HCO3- $CO3^{-2}$
4.3	HCO3- CO_2
Below 4.3	Free Mineral Acidity CO_2

P/M Alkalinity	**OH Alkalinity**	**Carbonate Alkalinity**	**Bicarbonate Alkalinity**
P = 0	0	0	M
P = M	M	O	O
P = ½ M	0	M	0
P < ½ M	0	2P	M-2P
P > ½ M	2P-M	2(M-P)	0

TOTAL HARDNESS

Hardness indicates the presence of calcium and magnesium ions in the water. Temporary Hardness is due to the salts of bicarbonates. Permanent Hardness is due to the salts of chlorides, sulfates, and nitrates.

CHLORIDES

Salts of chlorides are highly soluble in water. Chlorides in the fresh surface water supplies range from 10 to 100 mg/l. The seawater chloride level is over 30,000 mg/l. The chloride content of sewage water is typically 20 to 50 mg/l above the concentration of municipal supply. The recommended upper limit for chlorides is 250 mg/l in drinking water based entirely on taste, not on any physiological hazard. The high chloride level in the boiler water leads to corrosion.

SILICA

Silica is present in almost all minerals. It is found in freshwater from 1 to 100 mg/L. Silica is objectionable in the boiler feedwater makeup because it forms scales in the boiler itself. It also volatilizes at high temperatures and redeposits on the turbine blades. Lime soda softening, adsorption on magnesium precipitates, adsorption on ferric hydroxide, and anion exchanger are removal processes for silica.

ORGANIC MATTER

Organic carbon breaks down in boilers by hydro thermolysis leading to the formation of organic acid anions, which cause corrosion of steam–water cycle components. The typical sources are naturally occurring organics in make-up water due to plant decay or condensate recovery in the sugar and food industry.

Water Impurity Removal

IMPURITIES		EFFECT	REMOVAL MECHANISM
Soluble Gases	H2S	Corrosion Inside Boiler	Aeration
	O2		Deaeration
	CO2		Degasification, Chemical Treatment
Suspended Solids	Turbidity	Sludge, Scale Carryover	Clarification, Filtration, Chemical treatment
	Organic Matter	Carryover, foaming, and corrosion	
Dissolved Solids	Oil & Grease	Foaming, Deposition	Coagulation, Clarification, filtration
	Hardness Ca & Mg	Scaling inhibits heat transfer, and the Boiler tube burns through	Lime Soda Softening, Zeolite Softening
	Na, Alkalinity, Sodium Carbonate	Foaming, Corrosion, embrittlement	Ion Exchange Column, Dealkalizer, DM Plant, RO Plant, Chemical Treatment
	Sulfates	Hard Scales when Calcium is present	DM Plant, RO Plant
	Chlorides	Corrosion, Priming, and Foaming	DM Plant, RO Plant
Dissolved Solids	Na, Alkalinity, Sodium Carbonate	Foaming, Corrosion, embrittlement	Ion Exchange Column, Dealkalizer, DM Plant, RO Plant, Chemical Treatment
	Sulfates	Hard Scales when Calcium is present	DM Plant, RO Plant

	Chlorides	Corrosion, Priming, and Foaming	DM Plant, RO Plant
	Iron, Manganese	Rusting, Resistance to Heat transfer	Aeration, Filtration, DM Plant
	Silica	Scaling	Clarification, Filtration, Ultra Filtration, DM Plant

Water Constituent Vs. Technology

Problem	Softening	De Alkalization	Demineralization	Reverse Osmosis
Hardness removal	✓	✓	✓	✓
pH Change	×	✓	✓	✓
TDS Change	×	✓	✓	✓
Dissolved Oxygen	×	×	×	×
Silica	×	×	✓	✓

PROBLEMS IN BOILER

- **Deposits / Scaling: Reasons are Hardness, Metal Oxides, Silica, and Organic matter**

- **Corrosion: Presence of Free carbon dioxide, Oxygen, low PH, and organics.**

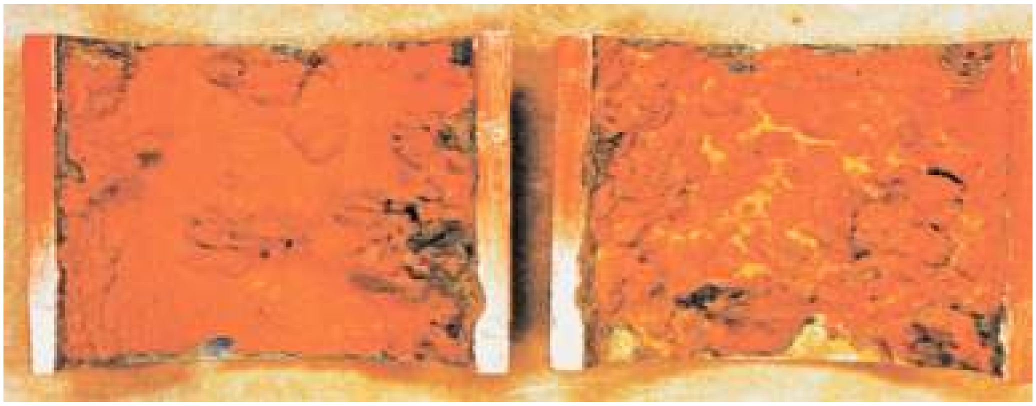
- **Carry over the transport of moisture and impurities with steam**

Transport of moisture and impurities with steam

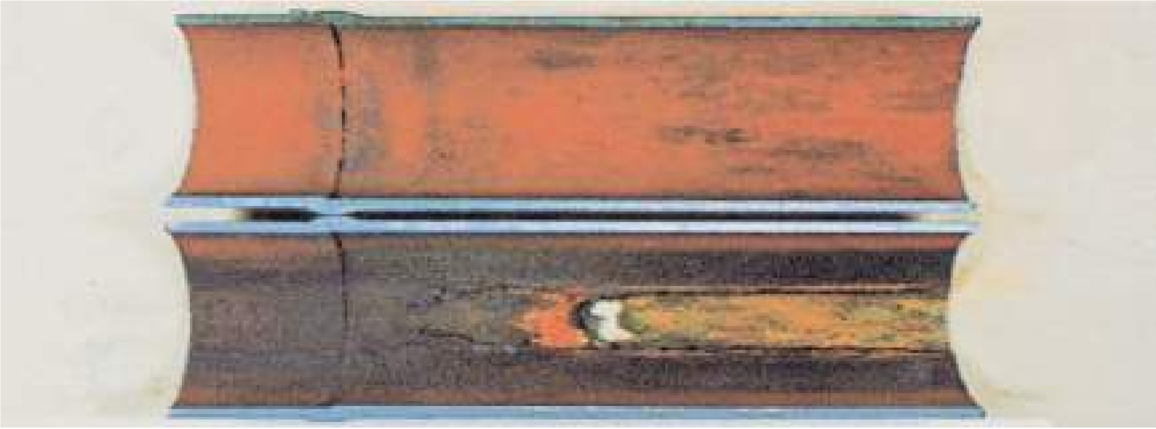
Corrosion

Corrosion in the Boiler area is due to Insufficient Oxygen removal and in the Steam and condensate area, it is because of Insufficient Oxygen removal, Low pH values, and Formation of Carbon Dioxide.

Corrosion of Fire Tube Boiler by dissolved oxygen



Corrosion of an economizer tube



Corrosion of Condensate line

Carry Over

The mechanical cause of Carryover is improper construction of boiler internals. Maintenance of too high a water level in the boiler drum also leads to carryover. On-off firing / on-off feed water addition and Steam demand exceeding boiler capacity are some of the other causes of carryover.

Chemical causes of Carryover are improper cleaning of a new boiler, High level of suspended solids, High alkalinity, and Oil or organic impurities in the boiler water. Improper water treatment control also leads to poor steam quality, Deposits in condensate lines Decreased boiler efficiency, and limited steam production.

Boiler Internal Chemical Treatment

Low-pressure boiler up to 300 PSIG uses soft water. Require high use of internal chemicals to maintain heat transfer surfaces. A higher dosage is required for oxygen corrosion prevention. A medium-pressure boiler from 300 to 900 PSIG uses DM water with a Deaerator for oxygen removal.

Chemical dosages are low. High-pressure boiler from 900 to 1200 PSIG uses DM water with thermal Deaerator. Chemical dosages are low. Precision dosing via automation is required.

Oxygen Scavenging Chemicals

- Sulfites
- Hydrazine
- Carbohydrazide
- Hydroquinone
- Diethylhydroxylamine (DEHA)
- Methylethylketoxime (MEKO)
- Ascorbate/Erythorbate

Oxygen Scavenger Dosage Summary

Oxygen Scavenger	Operating Pressure (PSIG)	mg/L Active per mg / L Oxygen
Sulfite	0 – 600	6-8 + 5-50 residual
Sulfite	601-900	6 – 8 + 5-20 residual
Hydrazine	>2500	5.00
Carbohydrazide	>2500	5.00
Hydroquinone	>2500	3 – 7.00
DEHA	>2500	6.00
MEKO	< 1800	25.00
Ascorbate/ Erythorbate	< 1500	30.00

SCALE & DEPOSITION CONTROL

The internal chemical treatment program is designed for depositing sparingly soluble salts and silica. The hydrothermal reaction of iron with water produces a stable protective film of **Magnetite FeO4** pH range from 9 to 11. Corrosion inhibitors are used to control this pH or by control of Alkalinity breakdown. It is vital to ensure oxygen removal by Deaerator / Oxygen scavenging.

Program Comparison

Program	**Advantages**	**Disadvantages**
Carbonate Cycle	Simple & Inexpensive. No added boiler solids. No special control or testing. Dosage not critical	Can’t tolerate high heat loads. Dirty boiler. Not suitable for critical system

Phosphate Precipitation	Tolerates variable load. Best in low & Medium pressure boilers with some hardness in the feed water	A large amount of boiler sludge. The boiler will show some deposits. Not suitable for clean critical systems.
Chelant	Clean boiler. No added boiler solids. No boiler sludge. Best for critical systems.	Required monitoring by trained personnel. Not best with variable loads and with variable feed water quality. Prone to heavy corrosion in case oxygen enters the boiler.
All Polymer	Clean boiler. No added boiler solids. Minimum boiler sludge. Useful over a wide pressure range. Safe chemicals	Required monitoring by trained personnel. Not best with variable loads and with variable feed water quality. Polymer degrades at high temperatures.
Chelant-Phosphate		
	Advantage of phosphate program with less sludge. No Chelant residue.	Required monitoring by trained personnel. Not best with variable loads and with variable feed water quality.
Chelant-Phosphate-Polymer	Optimized program. Reduce phosphate and Chelant dosage. No Chelant residue.	Required monitoring by trained personnel. Not best with variable loads and with variable feed water quality.

IS 10392-1982 is the Specification for feed water and Boiler water for low and medium-pressure land boilers.

Sr. No.	Characteristics	Requirement for Boiler Pressure		
1.	**FEED WATER**	Up to 2.0 MN/m2	2.1 to 3.9 MN/m2	4.0 to 5.9 MN/m2
	Total Hardness as CaCO3 mg/l	10.0	1.0	0.5
	pH Value	8.5 – 9.5	8.5 – 9.5	8.5 – 9.5
	Dissolved Oxygen mg/l max	0.1	0.02	0.01
	Silica as SiO2 mg/l max	------------	5.0	0.50
2	**BOILER WATER**			
	Total Hardness of filtered sample as CaCO3	------------------- NOT DETECTABLE -------------------------		
	Total Alkalinity as CaCO3 mg/l max	700.00	500.00	300.00

	Caustic Alkalinity as $CaCO_3$ mg/l max	350.00	200.00	60.00
	pH Value	11.0 – 12.0	11.0 – 12.0	10.5 – 11.0
	Residual Sodium Sulphite as Na_2SO_3 mg/l	30 – 50	20 - 30	--------------
	Residual Hydrazine as N_2H_4 mg/l	0.1 to 1.0 (if added)	0.1 – 0.5 (If added)	0.05 – 0.3
	Ratio Na_2SO_4/ Caustic Alkalinity as NaOH	Applicable to riveted boilers only		
	Phosphates as PO_4 mg/l	20 – 40	15 - 30	5 – 20
	Total Dissolved Solids mg/l max	3500	2500	1500
	Silica as SiO_2 mg/l	Less than 0.4 of caustic alkalinity		15.0

The boiler feed water and boiler drum water conforming to the above standards ensures fairly trouble-free operation of the boiler. In the case of the shell-type boiler, the limit of boiler water TDS can be relaxed up to 5000 mg/l. The total alkalinity in the boiler drum water should be about 20% of the TDS.

- **Boiler Water Chemistry – Technology Innovations, Advancements, and Environmental Considerations**

Water is a scarce resource. 71% of the earth's surface is water. Freshwater is only 2.5%. 69% is locked as ice. Only 0.7% is available via lakes, rivers & groundwater. With the increasing human population, urbanization, and industrialization the per capita availability of water is decreasing every day. Based on the study titled **"Reassessment of Water Availability in India using Space Inputs, 2019"** conducted by Central Water Commission, the average annual per capita water availability for years 2021 and 2031 has been assessed as 1486 cubic meters and 1367 cubic meters respectively. Annual per-capita water availability of less than 1700 cubic meters is considered as a water-stressed condition whereas annual per-capita water availability below 1000 cubic meters is considered as a water scarcity condition.

In light of the above, it is crucially important to conserve every drop of water. Increasing the productivity of water is the call of the day. A typical Water treatment plant consists of various filters followed by either a resin-based system or a membrane-based system or a combination of both for generating suitable grade water as boiler feed water.

EFFICIENT FILTERS

These filters generate wastewater in the backwash cycle. It is of paramount importance to reduce the wastewater generation quantity and at the same time improve the product water quality. The new generation media Activated Filter Media (AFM) is manufactured by up-cycling post-consumer green glass bottles to produce water filtration media. It is an activated amorphous alumina-silicate with a positive charge organic adsorption (OAD) number greater than 10, the activated hydrophilic surface has cation bridging, hydrogen bonding, and entropic interactions with organic molecules. AFM can be recovered and upcycled for reuse again and again for water filtration or can be directed into high-value uses. The advantages of AFM are: -

- The backwash water requirement is reduced by up to 50%.
- Increased run phase and reduced backwash could give 15% energy savings.
- Reduced chemical consumption, chlorine & flocculants

EFFICIENT RESIN-BASED WATER PURIFICATION SYSTEM

The resin-based water purification system generates wastewater in the regeneration cycle. Countercurrent regeneration, sometimes called reverse flow regeneration or counterflow regeneration, is a method where the regenerant flows through a direction opposite that of service mode. Suppose service flow proceeds from top to bottom. In that case, countercurrent regeneration is done by introducing the chemical solution into the bottom of the tank and letting it leave the tank through the top, as it is done during backwash. In this case, the regenerant comes into contact with the less exhausted resin layers first and then through the more exhausted portions. This results in a more efficient regeneration process and fewer chances of contaminant leakage. At the same time, less regenerant volume is required. Regeneration by countercurrent methods produces much higher quality water than regeneration by cocurrent. The countercurrent regeneration method permits the volume of service water necessary for regeneration to be considerably reduced.

Uniform size resin / monosphere resins because of their more uniform size these resins offer certain advantages. The five principal advantages are listed below:

1. Stronger beads. 2. Lower pressure. 3. Improved capacity or lower regenerant usage. 4. Reduced rinse volumes due to reduced diffusion paths. 5. Increased surface area – slower surface fouling.

EFFICIENT MEMBRANE-BASED WATER PURIFICATION SYSTEM

Advancements in membrane materials and design are fueling innovation in the reverse osmosis system market. Manufacturers are investing in research and development to enhance membrane performance, durability, and fouling resistance. Thin-film composite (TFC) membranes, nanocomposite membranes, and novel membrane surface modifications are some of the technological innovations driving improvements in RO system efficiency and longevity.

Energy consumption is a critical consideration in RO system design and operation. As sustainability concerns gain prominence, there is a growing emphasis on developing energy-efficient RO systems that minimize power consumption and operating costs. Innovations such as energy recovery devices, high-pressure pumps, and membrane fouling mitigation strategies are being integrated into RO systems to optimize energy efficiency and reduce environmental impact.

The integration of smart technologies and IoT (Internet of Things) capabilities is transforming the landscape of RO system monitoring, control, and maintenance. Smart RO systems equipped with sensors, data analytics, and remote monitoring capabilities enable real-time performance tracking, predictive maintenance, and automatic optimization of operating parameters. These advancements enhance system reliability, efficiency, and operational flexibility, driving their adoption across various industries.

Advanced Membrane Materials such as "Modified Surface Membranes" are Membranes treated with hydrophilic (water-attracting) coatings, such as polyvinyl alcohol (PVA) or polyethylene glycol (PEG), which help reduce organic fouling. Hydrophilic surfaces resist the adsorption of hydrophobic organic molecules, thus minimizing fouling potential. "Nanocomposite Membranes" incorporate nanoparticles such as silver, titanium dioxide (TiO2), or graphene oxide into the membrane structure. These nanoparticles provide antibacterial, photocatalytic, or hydrophilic properties, reducing fouling and enhancing the degradation of organic pollutants. "Superhydrophobic and Omniphobic Membranes" are membranes with superhydrophobic or omniphobic (resisting wetting by both water and oil) surfaces, which repel foulants more effectively than conventional membranes.

"Electrically Conductive Membranes" allow for in-situ cleaning by applying an electric field. The electric field can induce electrochemical reactions on the membrane surface, breaking down organic foulants and preventing their buildup. This approach is especially effective for biofouling and organic fouling in high-COD/BOD waters.

"Responsive Membranes" are pH-Responsive and Temperature-Responsive Membranes. These membranes can change their surface properties in response to external stimuli such as pH or temperature. For example, a pH-responsive membrane might become more hydrophilic at certain pH levels, facilitating the removal of organic matter during cleaning cycles.

Process modification in the reverse osmosis "Vibratory and Rotating Membranes" Instead of static filtration, dynamic systems where membranes vibrate or rotate can prevent foulants from settling on the surface. These mechanical movements help to maintain a clean membrane surface and enhance filtration efficiency. "Shear-Enhanced Filtration" introducing shear forces, such as air scouring or fluid mixing, at the membrane surface can dislodge particles that would otherwise contribute to fouling.

The research trends and future directions are: -

Bio-Inspired Membranes: Research is exploring bio-inspired membranes, mimicking biological systems that naturally resist fouling. For example, mimicking fish scales, lotus leaves, or shark skin textures can lead to membranes with enhanced antifouling properties.

Self-Healing Membranes: Membranes that can repair themselves after minor damage or fouling are a growing area of interest. Self-healing polymers can extend membrane life and reduce the frequency of cleaning.

Membrane Additives: Incorporating antimicrobial agents, such as silver nanoparticles or copper ions, into membrane materials can reduce biofouling by inhibiting microbial growth on the membrane surface. Fouling-inhibiting coatings that actively repel organic molecules or microorganisms, such as zwitterionic or fluorinated polymers, can prevent the initial attachment of foulants.

Low-Energy Membranes: Research is focused on developing membranes that require lower energy inputs, such as those operating at lower pressures, to reduce operational costs while maintaining high efficiency in reducing COD, BOD, and TDS.

Renewable Energy-Powered Membrane Systems Integrating renewable energy sources like solar or wind power to run membrane processes can make water treatment more sustainable, particularly in decentralized or off-grid applications.

GREEN BOILER WATER CHEMICALS

Using “green chemicals” for boiler water treatment is a growing trend in the industry as companies seek more environmentally friendly alternatives to traditional chemical treatments.

What Are Green Chemicals?

Green chemicals, also known as environmentally friendly or sustainable chemicals, are substances that have a reduced impact on the environment and human health compared to conventional chemicals. These chemicals are designed to minimize toxicity, reduce waste, and use renewable resources.

Benefits of Green Chemicals in Boiler Water Treatment

1. Environmental Impact: Green chemicals often have a lower environmental footprint, leading to less pollution and reduced harm to ecosystems.
2. Safety: They tend to be less hazardous to human health, reducing the risk of chemical accidents and exposure.
3. Sustainability: Many green chemicals are derived from renewable resources, promoting sustainability in industrial processes.
4. Compliance: They help in meeting increasingly stringent environmental regulations and standards.

Types of Green Chemicals for Boiler Water Treatment

1. Corrosion Inhibitors: These chemicals prevent the deterioration of metal surfaces in the boiler. Green alternatives use organic compounds that are less toxic and more biodegradable.
2. Scale Inhibitors: These prevent the formation of scale deposits, which can impair boiler efficiency. Green options involve polymers derived from renewable sources.
3. Oxygen Scavengers: These chemicals remove dissolved oxygen from the water to prevent corrosion. Green versions include substances that are less harmful and have lower environmental impact.
4. pH Adjusters: Used to maintain the proper pH balance in the boiler water. Green pH adjusters may include organic acids or other less harmful agents.

Examples of Green Chemicals

Phosphonate-Based Inhibitors: Some phosphonates are biodegradable and less harmful compared to traditional phosphate treatments.

Natural Polymers: Derived from plant sources, these can be used as scale inhibitors or dispersants.

Implementation Considerations

1. **Compatibility:** Ensure the green chemicals are compatible with your existing boiler system and other treatments.
2. **Effectiveness:** Verify that they provide the same level of performance as traditional chemicals.
3. **Cost:** Evaluate the cost-effectiveness, as some green chemicals may be more expensive.
4. **Training:** Staff may need training to handle and apply these new chemicals correctly.

Switching to green chemicals for boiler water treatment is a step towards more sustainable and safer industrial practices. While they offer numerous benefits, it's important to thoroughly assess their compatibility and performance to ensure they meet the operational requirements of your boiler system.

- **CONCLUSION**

It is necessary to do external and internal treatment to the boiler for ensuring that all the parameters of Feed Water, Boiler Water, and Steam Condensate are in limits. This will ensure that no scaling, no corrosion, and no carryover will occur and hence boiler operation will be trouble-free and maintenance-free.

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Experience:	18 Years
Specialization	High Temperature Mechanical behavior, Creep, Fatigue
Sponsored Research Projects Completed	- 11 - AUSC, BRNS, UGC-DAE
Awards	• TR Anantharaman Faculty Fellowship at University of Colorado, USA • INAE Faculty Mentorship • GE Fund Scholarship • National Doctoral Fellowship • Publications in International Journals - 46

Materials for High Temperature Power Plant Applications and Creep Testing

Coal has been India's primary source of energy, with over 60% of power generation depending on coal. India desires to adopt clean coal-based power generation technologies to minimize carbon dioxide emissions and achieve the highest possible energy efficiency and reducing the coal required per unit of power generated. There is an excellent scope for setting upclean coal technology based Advanced Ultra Super Critical (AUSC) power plants inIndia with reduced carbon dioxide emission. Underthe National Mission Programme on Clean Coal(Carbon) Technologies, development of AUSCthermal power plants was identified as one ofthe projects to be taken up on priority.

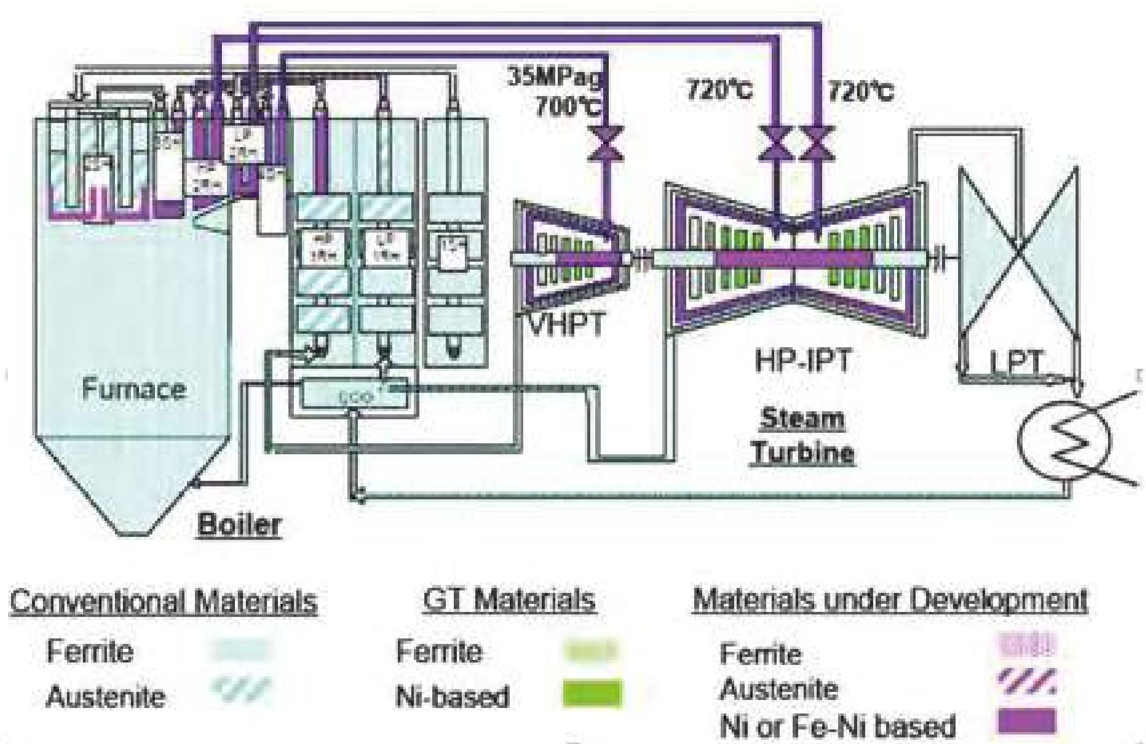
To achieve higher plant efficiency of at least 46%, resultingcarbon dioxide mitigation and reduced amount of coalper MWe, steam parameters of 310 kg/cm^2 and 710ºCand 720ºC as the main steam and reheat steamtemperatures, respectively are aimed at.

The selection of materials for different components of the AUSC plants of such steam temperatures would have to be based on:

- Sufficient high temperature mechanical strength, stress to rupture of 100 MPa for1,00,000 hours
- High thermal conductivity as well as low thermal expansion coefficient for lower thermal stresses
- Satisfactory corrosion resistance in steam and flue gas environment
- Good formability and weldability
- Moderate creep-fatigue interaction
- Economy

The candidate materials to be used in the AUSC plants are:

- Grade-23 steel for water walls
- Grade-91 steel for superheater and reheater tubing
- 304HCu austenitic stainless steel
- Nickel-base Alloy 617 for the final stage of superheater and reheater tubing
  At the hottest zone



Schematic layout of the proposed Indian AUSCplant(Ref: Jayakumar *et al.*, 2014)

Creep and Creep-fatigue interaction (CFI) are considered to be the major damage mechanisms during the service life of the components. The mechanical testing set-up, ASTM standard, procedures, data acquisition and analysis, and reporting of creep as well as CFI data will be discussed in brief.

An overview of emerging creep testing involving miniature specimens; namely Small Punch Creep will also be presented.

Name: Santosh Asangi

Organisation: TKIL Industries Pvt Ltd
(formerly known as thyssenkrupp Industries India Pvt Ltd)

Designation: Sr. Vice President – Energy Division

Education: BE (Mechanical), Post graduate Diploma in Business Management.

Education Institute Details: College of Engineering Pune

Experience: Over 30 years' experience in Boiler & Power Plant Industry

Current Job Profile:

Mr. Santosh Asangi has been in the Boiler & Power Plant industry since 1991. He has served in reputed Boiler manufacturing companies in various engineering and managerial capacities. He has an illustrious experience of 20 years in Thermax Limited and 5 years in SAPL (Parsons in Saudi Arabia).

Santosh Asangi is closely associated with the Power Plant EPC business from his early days & has been actively involved in providing innovative EPC solutions to Cogeneration and Power Plant for the captive industry in the country.

He has extensive experience in various types EPC projects ranging from coal based power plants, waste recovery based power plants for steel and cement industry, BFG & COG gas based Cogeneration plants, Gas Turbine based combined cycle and cogeneration plants.

He is currently heading the Engineering department of Energy division and is responsible for proposal and post process engineering activities of Boilers and balance of plant equipment packages. He is leading a team of engineers and designers to meet the engineering deliverables of the project. Addressing the technical queries related to plant / project commissioning and assisting the site team in trouble shooting activities.

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BIOMASS FUEL UTILISATION

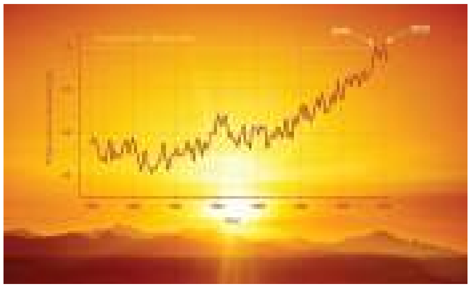
COMPREHENSIVE OVERVIEW OF EMERGING TRENDS IN BOILER DESIGN

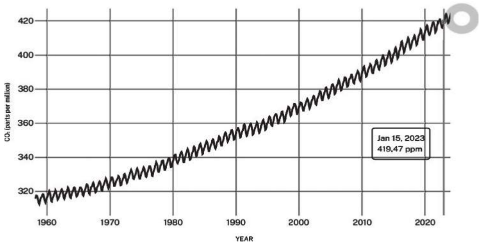
INNOVATIONS IN FUEL HANDLING SYSTEMS

ADVANCES IN EMISSION CONTROL TECHNOLOGIES

BRIEF INTRODUCTION TO GREEN HOUSE GASES

Burning fossil fuel will generate green house gases (CO2) causes global warming *Biomass is considered as Renewable source of Energy: CO2 Neutral*

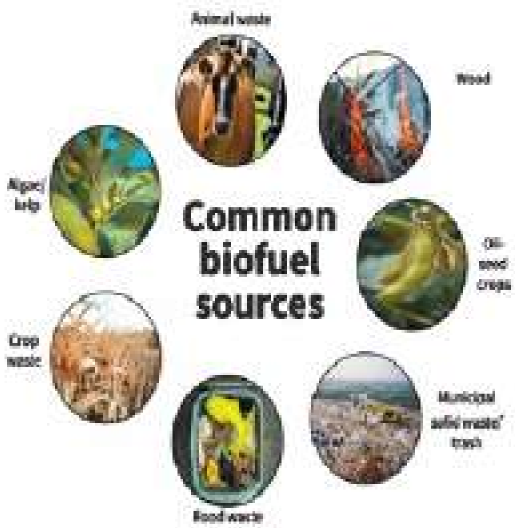




Green house gases can be reduced by

- Increasing plant efficiency
- Substitution of fossil fuels with renewable fuels
- Mix of renewable fuels with fossil fuels
- Absorption of CO2 from Atmosphere

MAJOR BIOMASS FUELS IN INDIA



Bagasse
Peanut shell
Rice husk
Soya husk
Saw Dust
Mustard Husk
Paddy straw
Corn Cob
Cotton Stalk

TYPICAL ELEMENTAL ANALYSIS OF BIOMASS

Particular		Bagasse	Peanut Shell	Rice Husk	Soya husk	Saw Dust	Mustard Husk	Paddy Straw	Corn Cob	Cotton Stalk
Proximate Analysis (As Received Basis)										
Carbon	%	23.5	38.80	36.67	45.22	36.92	38.68	33.36	45.97	43.23
Hydrogen	%	3.25	4.60	4.57	5.15	4.59	5.10	3.98	5.54	7.24
Oxygen	%	21.75	36.38	32.88	37.66	32.08	35.88	28.50	39.80	33.59
Moisture	%	50.0	10.77	9.44	5.83	18.22	12.50	20.00	6.50	7.00
Sulphur	%	0.0	0.02	0.18	0.01	0.03	0.23	0.19	0.03	0.02
Nitrogen	%	0.0	1.38	1.25	0.80	0.90	0.11	0.51	0.68	1.20
Ash	%	1.50	8.01	15.01	5.13	7.26	7.49	13.46	1.06	7.50
Chlorine	%	0.1-0.2	0.1-0.2	<0.1	0.2-0.3	0.1-0.2	0.3-0.5	0.5-1.4	0.4-0.5	0.3-1.2
Gross Calorific Vale	kcal/kg	2270	3200	3150	3800	3200	3350	3000	3950	4530
Bulk Density	gm/cc	0.21	0.20	0.15	0.17	0.86	0.42	0.11	0.21	0.21
Ash Analysis										
Silica Dioxide SiO_2	%	54	23.97	91.42	5.80	62.1	33.58	54.35	17.77	68.00
Aluminium Oxide Al_2O_3	%	6.51	6.51	0.78	7.50	11.55	1.31	1.10	14.56	0.24
Iron Oxide Fe_2O_3	%	7.96	2.39	0.14	3.00	4.76	9.34	0.70	6.63	0.31
Calcium Oxide CaO	%	7.4	12.82	3.10	25.82	9.64	23.90	7.09	14.60	2.86
Magnesium Oxide MgO	%	7.4	5.53	0.01	9.12	1.02	7.45	2.80	8.59	1.95
Titanium Dioxide TiO_2	%	1.46	0.27	0.02	0.24	0.48	0.00	0.10	0.15	0.02
Sodium Oxide Na_2O	%	0.86	2.08	0.21	5.28	1.44	3.69	7.66	0.08	0.49
Potassium Oxide K_2O	%	6.19	28.58	3.61	32.23	1.65	20.02	14.23	21.20	9.79
Phosphorus Pentoxide P_2O_5	%	1.81	3.79	0.00	5.87	0.38	0.45	2.3	9.49	0.64
Sulphur Trioxide SO_3	%	1.78	1.9	0.72	4.69	0.34	0.08	3.40	6.93	0.94
Chlorides as Cl	%	0.98	1.58	0.00	0.45	0.85	0.08	6.27	0.21	0.22

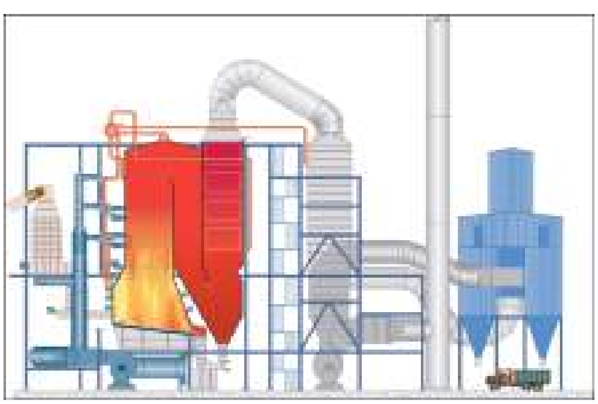
BIOMASS IN PELLETS FORM

Composition	Value	Unit
Carbon	38.12	% Wt
Hydrogen	4.35	% Wt
Oxygen	30.78	% Wt
Nitrogen	1.57	% Wt
Sulphure	0.17	% Wt
Moistrure	11.38	% Wt
Ash	13.64	% Wt
GCV	3544	kcal / kg

POWER PLANT BOILERS FOR BIOMASS FIRING

Following types of boilers are capable to fire 100% Biomass fuel or Biomass cofiring with Coal

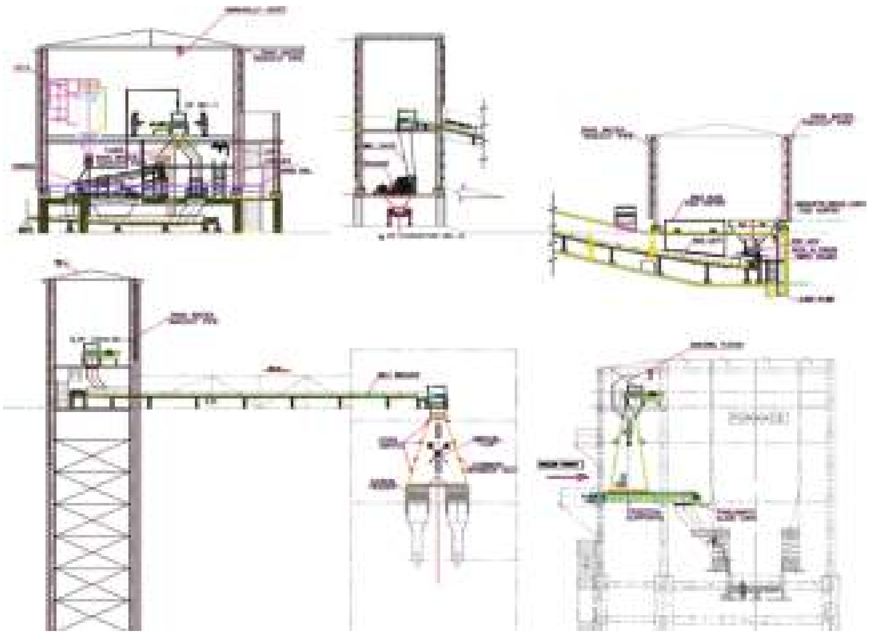
- Vibrating Grate type Boilers
- Atmospheric Fluidised Bed Combustion (AFBC) Boilers
- Circulating Fluidised Bed Combustion (CFBC) Boilers



HANDLING SYSTEM FOR BIOMASS BRIQUETS

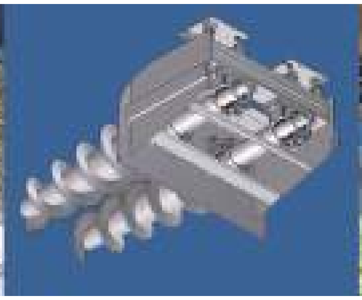
Feed Hoppers

- Belt Conveyors
- Crushers
- Inverted bin for storage
- Live bottom screw feeders



BIOMASS FEEDING SYSTEM FOR PADDY STRAW

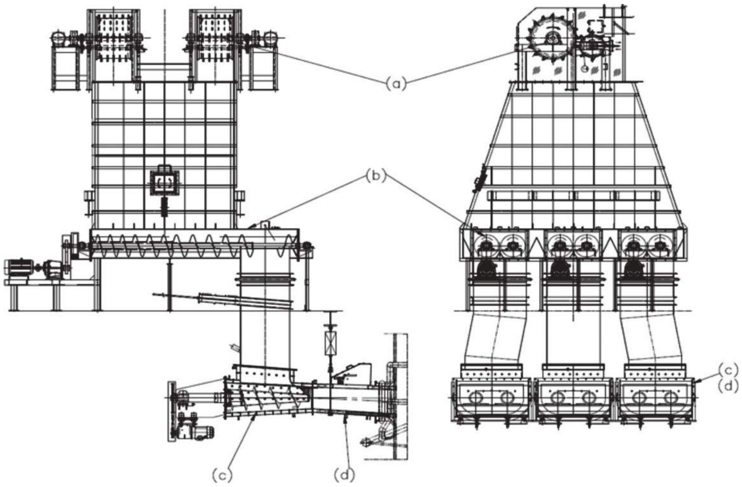
Bale with String



Conical feed Stoker

Bale Breaker

a. Bale Breaker
b. Live Bottom Screws
c. Feed Stoker
d. Water Cooled Tunnel



EMISSION NORMS IN INDIA

	Unit	Power Plant Boilers*	Process Boilers		
			Agro based fuels	Natural Gas	Other Solid fuels
Sulphur Dioxide (SO_2)	mg/Nm3	100	-	-	600
Oxides of Nitrogen (NO_x)	mg/Nm3	100	-	-	300
Particulate Matter (SPM)	mg/Nm3	30	250**	100**	100**
Mercury (Hg)	mg/Nm3	0.03	-	-	-
Emission values are at 6% O_2 dry vol for Solid fuels and 3% O_2 dry vol for liquid/gas fuels					

* Boilers connected turbine for Power Generation

** SPM values mentioned here are applicable for Boiler capacity ≥10 tph

SOURCES OF EMISSION IN POWER PLANT BOILERS

Sources of SOx Emission:

SOx is generated from Sulphur in fuel: $S + O_2 \rightarrow SO_2$

$$SO_2 + 2H_2O \rightarrow H_2SO_4 + H_2$$

Sources of NOx Emission:

- Thermal NOx: formed through high temperature oxidation of Nitrogen. Will be significant at >1200 Deg C and very low at <1000 Deg C temperature.
- Fuel NOx: formed through high temperature oxidation of fuel bound Nitrogen. Formation of fuel NOx is totally dependent on air to fuel stoichiometric ratio in the primary combustion zone.
- Prompt NOx: produced in fuel rich conditions through complex series of reactions between hydrocarbon radicals and molecular Nitrogen in flame zone. Prompt NOx formation is negligible in solid fuels combustion due to non-availability of hydrocarbon radicals.

Source of Particulate Matter (SPM) Emission:

- Fly ash generated from fuel ash after combustion
- Fly ash generated from limestone addition
- Dust generated from bed material

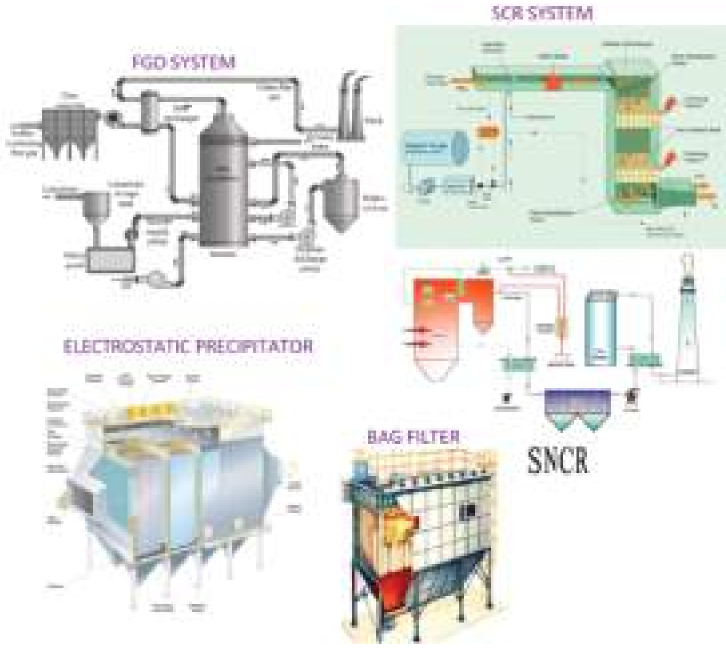
SOURCES OF EMISSION IN POWER PLANT BOILERS

SOx Emission Control Systems:

- Limestone Dosing in Furnace through gravity feeding or pneumatic injection
- Flue Gas Desulphurisation System (FGD) using Limestone

NOx Emission Control Systems:

- Selective Catalytic Reduction (SCR) technology: The reducing agent ammonia/urea solution is injected into the gas stream prior to entering a reactor, where the reducing reaction takes place on a bed of several layers of porous catalyst at lower temperatures (200-400 ° C). The catalyst is typically made from a combination of titanium, vanadium, and tungsten
- Selective Non-Catalytic Reduction (SNCR) technology: The reducing agent urea/ammonia is injected directly into the flue gases at high temperature in a suitable way, without the need to use a catalyst
- Inherent features of Boiler Technology with split combustion and lower temperature profile in furnace



Particulate Matter (SPM) Emission Control Systems:

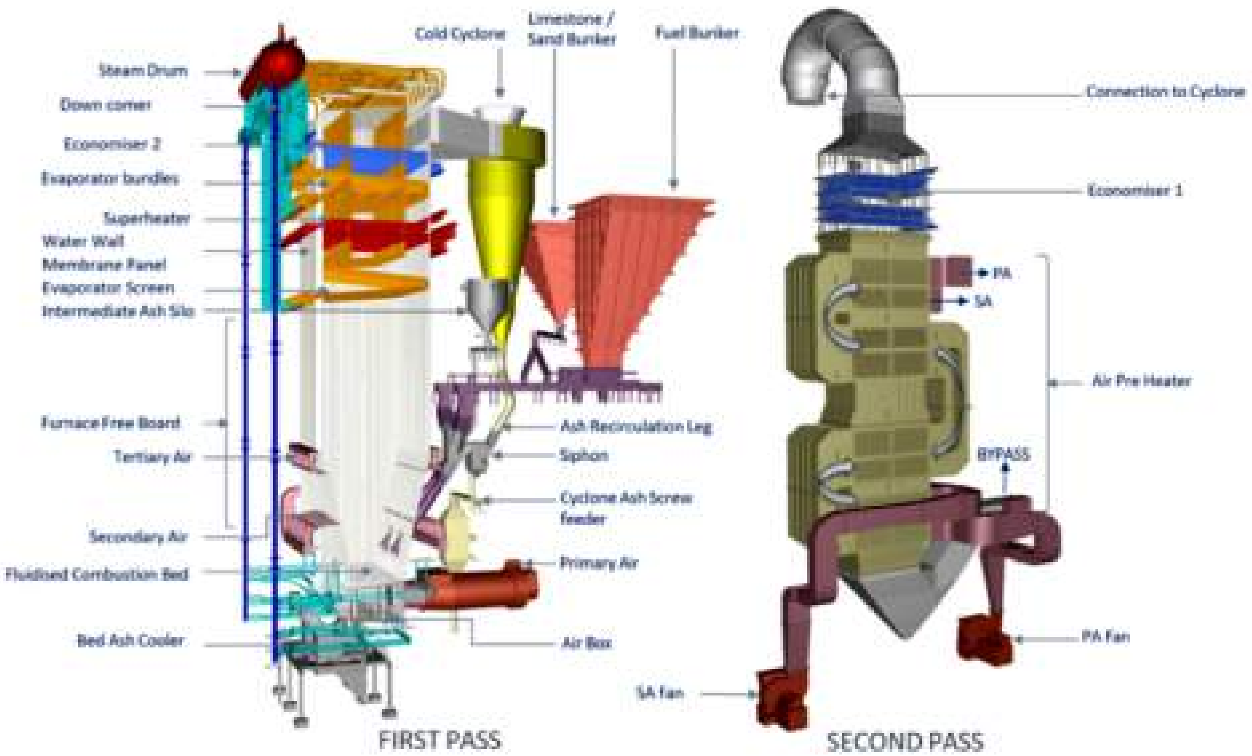
- Electrostatic Precipitator (ESP) or Bag Filters

TYPICAL NOx / SOx EMISSION IN POWER PLANT BOILERS

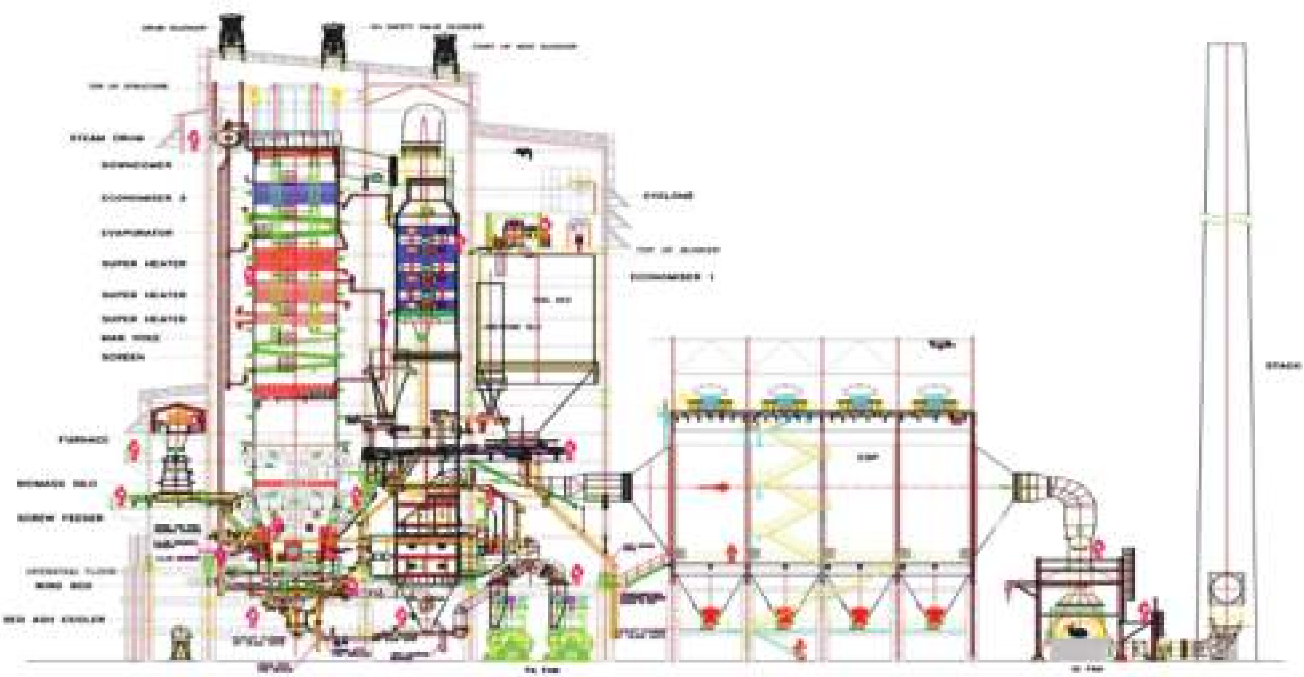
		NOx mg/Nm3	SOx mg/Nm3	
Grate type Boiler	100% Coal firing	>100	>100	*NOx emission values are without any DeNOx system*
AFBC Boilers	100% Coal firing	>100	>100	
CFBC Boilers (TKIL)	100% Coal firing	≤ 100	≤ 100	*SOx emission values are with Limestone dosing*
Grate type Boiler	100% Biomass firing	>100	≤ 100	Emission values are at 6% O2 dry volume basis
AFBC Boilers	100% Biomass firing	>100	≤ 100	
CFBC Boilers (TKIL)	100% Biomass firing	>100	≤ 100	
CFBC Boilers (TKIL)	*Biomass cofiring with Coal up to 50% by wt*	≤ 100	≤ 100	

Based on the above table it is evident that both SOx and NOx emission limits are achievable in TKIL CFBC Boilers without any additional systems for emission control.

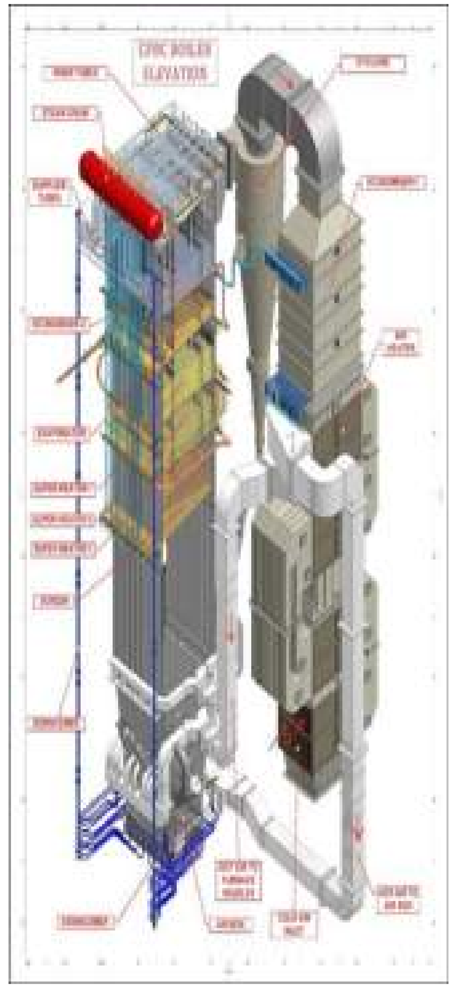
TYPICAL ARRANGEMENT OF TKIL CFBC BOILER



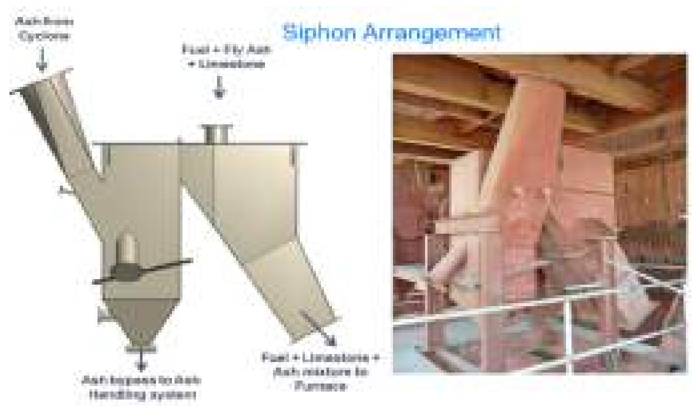
TYPICAL ARRANGEMENT OF TKIL CFBC BOILER WITH BIOMASS COFIRING



INHERENT ADVANTAGES OF TKIL CFBC BOILERS FOR BIOMASS COFIRNG

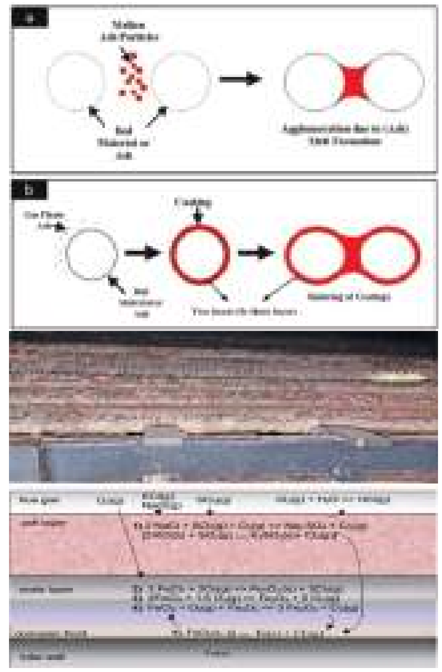


- Cold Cyclone: Cold Cyclone provided for dust collection operates at flue gas inlet temperature of <500 Deg C, which helps to maintain the bed temperature at around ~850-880 Deg C. It is ideal bed temperature for biomass firing
- Furnace pressure: Furnace is under negative pressure at fuel feed point, which avoids biomass carryover from primary zone and back firing. Also makes biomass feeding system simpler compared to positive pressure furnace.
- Furnace Velocity: Primary Zone operating Velocity is low which avoids biomass carryover from primary zone
- Combustion Air Split: To ensure complete combustion, air is introduced in four stages. Stage 1: Primary air (PA) through bed, Stage 2: Secondary air (SA) at free board, Stage 3: Tertiary air at much higher elevation above SA air nozzle, Stage 4 : Dilution air after tertiary air to control the furnace temperature fluctuation.
- Low NOx Emission: NOx emission <100 mg/Nm3 without any DeNOx system due to staged combustion & lower bed/ furnace temperature
- Furnace Height: Furnace is very tall tower type since all the pressure parts are placed inside the furnace in addition to free board height, which ensures very high residence time.
- Self-Cleaning: Majority of pressure parts are placed in first pass before cyclone faces huge quantity of recirculating coarser ash which ensures self-cleaning of heat transfer surfaces.



- Fly ash recirculation: Fly ash from ESP hoppers and bed ash is recirculated back to furnace to ensure optimum bed/furnace temperature
- Siphon: Fuel, Cyclone ash, limestone, fly ash from ESP hopper are mixed in Siphon before feeding to furnace which helps to control the bed temperature
- Risk of fouling: Dilution of Biomass Alkaline content by Coal ash. Low risk of fouling
- High Efficiency: TKIL Cold Cyclone CFBC Boiler provide high efficiency
- Ash Circulation: Sufficient ash is generated from Coal which eliminates bed material make-up

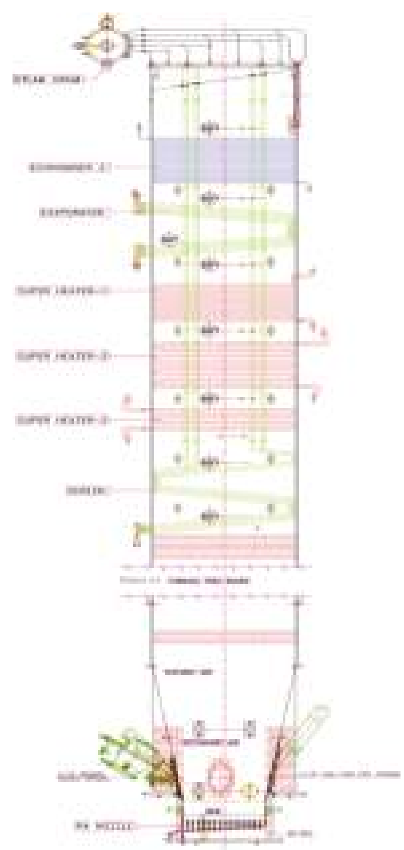
CRITICAL ELEMENTS OF BIOMASS AFFECTING BOILER DESIGN



Percentage of Biomass co-firing shall be restricted based on

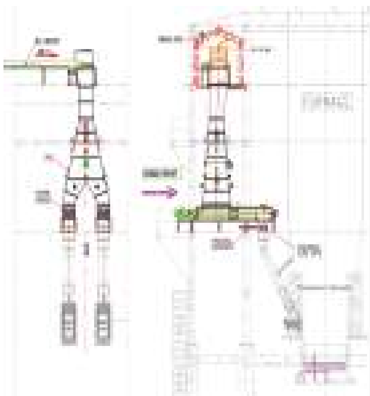
- Initial Deformation Temperature (IDT): Biomass fuels have lower softening point due to high (Na_2O + K_2O) in ash which causes bed agglomeration. (Na_2O: 920 deg C, K_2O: 707 Deg C)
- Alkali content (Na_2O+K_2O): Higher Alkali content in ash causes fouling on heat transfer surfaces
- Chlorine content in fuel: Higher Chlorine content in fuel causes high temperature corrosion on super heater tubes
- Flue Gas Volume: Flue gas generated from Biomass fuel is very high compared to coal
- Fuel Density: Bulk density of Biomass fuel will be in the range of 150 to 210 kg/m3 which results in huge volume of fuel and handling/ feeding system should be designed for such high volume.
- Ash Content in Coal: Coal used in co-firing with Biomass should have ash content >6% to have adequate recirculating solids.

TKIL BOILER DESIGN APPROCH FOR BIOMASS COFIRING

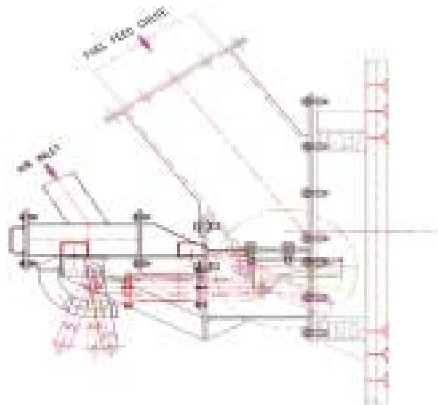


- Firing Capability: Up to 50-55% by weight Biomass can be fired with Coal without any major changes in Boiler design compared to 100% Coal firing.
- Temperature Profile: Bed temperature, furnace temperature & Superheater area flue gas temperature is kept adequately lower than IDT with the help of four stage combustion air split & fly ash/ bed ash recirculation
- Residence time: Furnace height selected to maintain adequate residence time
- Super heater staging: Super heaters are split into three stages as SH1, SH2, SH3 and provided lower surface area for SH3 & SH2 to optimise the tube metallurgy.
- Superheater Flow pattern: Parallel flow pattern to avoid the contact of high temperature steam with high temperature flue gas.
- Super heater tube material: SH3 / SH2 are provided with corrosion resistant material to avoid Chlorin corrosion
- Fuel feeding system: Inverted bin with live bottom screw feeder and pneumatic spreader for biomass
- Soot blowers: Sonic Horn type soot blowers for Economiser & APH which are placed downstream of Cyclone

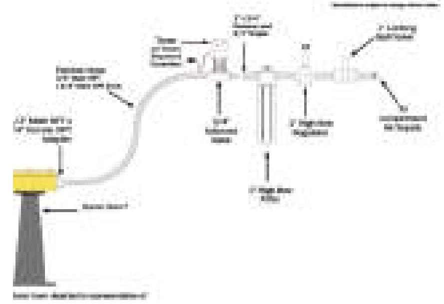
Biomass Feeding System



Pneumatic Spreader

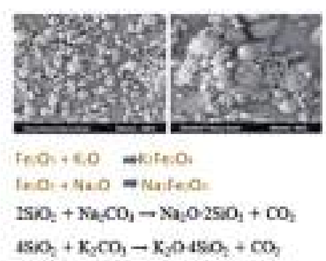


Sonic Horns

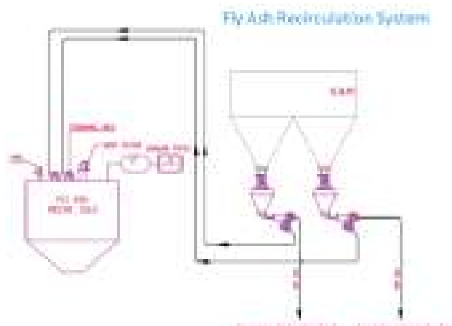


RECOMMENDATIONS/ GUIDELINES FOR BIOMASS COFIRING

- Furnace gas velocity should be selected suitably for Biomass co-firing and 100% Coal firing
- Bed Temperature should be maintained around 850 Deg C to avoid bed agglomeration
- Alkali content (Na2O+K2O) should be <6% in total ash mixture to minimize the fouling effects.



- Iron oxides in ash helps to avoid Alkali effects. Dolo char can be used for cofiring with Biomass.
- Avoid high silica bed material. High Alumina refractory is preferred.
- Net Chlorine content after mixing with Coal should be <0.15%. If chlorine content is >0.15%, steam temperature must be reduced <540 Deg C.
- Up to 30% co-firing Biomass can be premixed with Coal in yard. Separate biomass handling system and feeding system should be provided for >30% Co-firing.
- Coal with higher ash content is preferred to avoid Bed material make-up and to reduce Alkali concentration
- Fly ash recirculation from ESP hopper should be stopped once in 24 hours diverted to storage silo to limit the Alkali content in ash



- Bed ash recirculation should be stopped once in 24 hours & diverted to storage silo to limit the Alkali content in ash.
- Boiler load to be maintained >70% MCR to ensure the self cleaning of tube surfaces.
- FGR (Flue Gas Recirculation) can be adopted to maintain the furnace temperature

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DISTRIBUTED CONTROL SYSTEM (DCS) FOR POWER PLANT APPLICATION

Abstract

Safety is paramount in every industry, with a particular emphasis on human life, injury prevention, and the secure operation of plants. However, a significant challenge arises from the lack of knowledge in selecting appropriate plant control systems. Many individuals opt for conventional control systems without fully understanding their limitations, leading to accidents, injuries, reduced plant efficiency, and damage to the company's brand and reputation.

The implementation of a robust Distributed Control System (DCS), such as the tkII-Valmet DCS, plays a pivotal role in ensuring plant safety and preventing potential hazards. By leveraging advanced technologies and comprehensive control mechanisms, tkII-Valmet DCS aims to mitigate risks, prevent accidents, and maintain fail-safe conditions even during critical events such as blackouts, equipment failures, or tube leakages.

In essence, the adoption of tkII-Valmet DCS for plant operations not only enhances safety protocols but also safeguards human lives, promotes operational efficiency, and protects the overall integrity of the plant environment

Introduction

The Distributed Control System (DCS) serves as the cornerstone of an automated process control system, integrating various subsystems to ensure comprehensive control, visualization, and reporting of industrial processes. DCS plays a pivotal role in fulfilling essential functions, including:

DCS plays a pivotal role in fulfilling essential functions, including:

- Automatic regulation to maintain parameters within specified limits.
- Program (logic) control for executing predefined sequences of operations.
- Remote control capabilities for initiating start-up, shutdown, or adjusting set points from a centralized location.
- Management of alarms and notifications to alert operators of critical events or deviations.
- Collection and processing of process and equipment data for analysis and decision-making.
- Graphic presentation of process and equipment condition data to facilitate monitoring and diagnostics.
- Detection and alarm systems to identify emergencies and deviations from preset limits, ensuring timely intervention.
- Event logging to record operational events and deviations for analysis and audit purposes.
- Registration and archiving of process parameters for historical reference and regulatory compliance.
- Report generation to document process performance and compliance with operational standards.
- Data exchange capabilities with external systems for integration with enterprise-level applications and analysis tools.
- In essence, DCS serves as a comprehensive control and monitoring solution, enabling efficient and safe operation of industrial processes while facilitating data-driven decision-making and regulatory compliance.

Use of DCS in Plant Automation:

Power plants play a crucial role in electricity generation by employing a series of key process units. These units are intricately interconnected, forming a complex network of sub-processes that rely on various pieces of plant equipment. To effectively manage and optimize these processes, a power plant's Distributed Control System (DCS) architecture must align with the intricate process structure.

DCS implementation in power plants facilitates integrated monitoring and control across all process units. Key automation features include:

- Automatic boiler control: DCS regulates boiler operations to maintain optimal operating conditions, ensuring efficient steam generation.
- Burner management system: DCS oversees the combustion process, optimizing fuel consumption and minimizing emissions while ensuring safety.
- Turbine speed and load control: DCS adjusts turbine speed and load based on electricity demand fluctuations, maximizing efficiency and stability.

- Sequence control and protection: DCS coordinates the sequence of operations and provides protection mechanisms to prevent equipment damage or failure.
- Interlock logic: DCS implements interlocks to enforce safety protocols and prevent unsafe conditions during plant operations.

By leveraging DCS in power plants, operators can expect improvements in plant efficiency, reliability, and safety. The seamless integration of automation features enables precise control over critical processes, leading to optimized performance and enhanced operational efficiency.

Figure 1

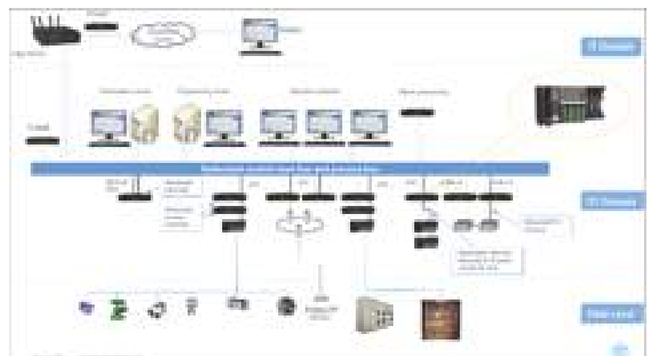

Figure 2

- Program (logic) control for executing predefined sequences of operations.
- Remote control capabilities for initiating start-up, shutdown, or adjusting set points from a centralized location.
- Management of alarms and notifications to alert operators of critical events or deviations.
- Collection and processing of process and equipment data for analysis and decision-making.
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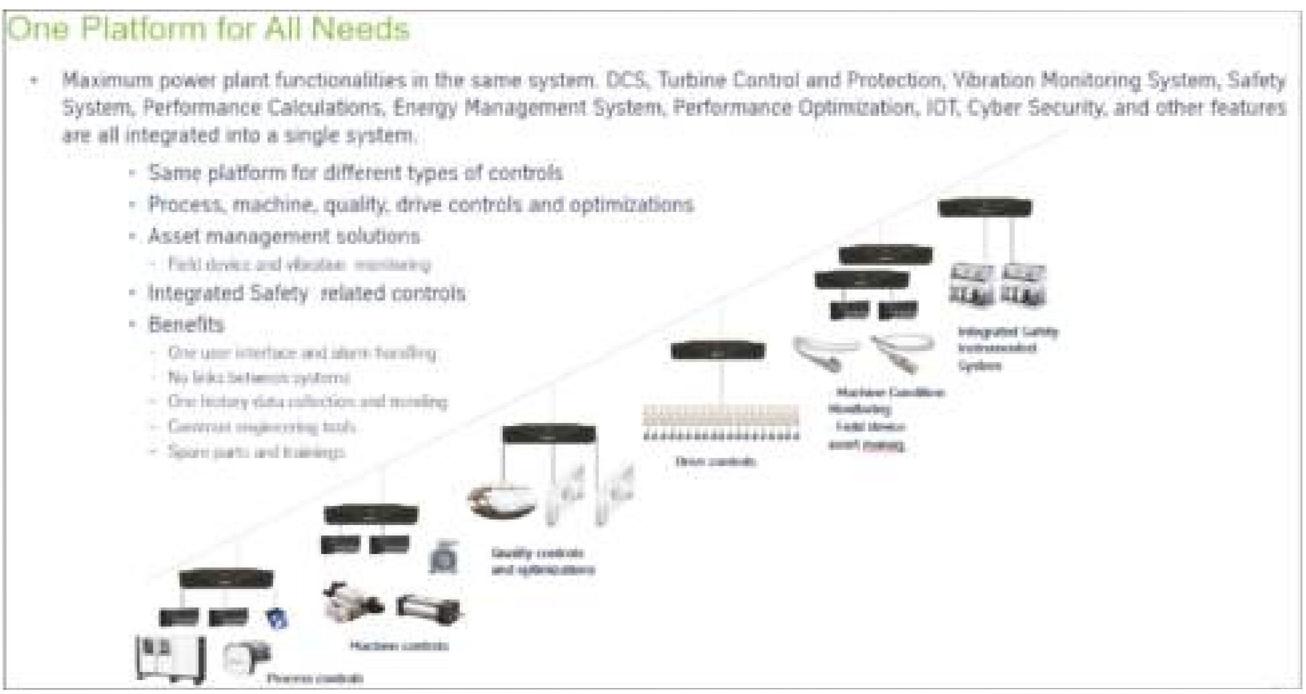
Level	Equipment's	Function
Field Level	All field process Instruments, including the electrical system	Measure the process parameters and equipment's operation using the local electrical system.
OT (Operation Technology) Domain	Distributed Control System includes Supervisory Control and all kinds of control systems.	Operate and control the entire plant as per the CLCS, OLCS, and safety interlocks.
IT Information Technology) Domain	Computing system, Cloud storage and Analysis software's	Collect the data from DCS for Analysis and feed back to DCS



Benefits of DCS:

- High Reliability:

  DCS ensures reliable operation through redundant components andfault- tolerant architecture, minimizing downtime and maximizing plant uptime.

- Enhanced Response Time:

  With DCS, operators can quickly respond to changes in process conditions, optimizing control strategies to maintain operational efficiency.

- Enhanced Plant-Operator Interface:

  DCS offers an intuitive and user-friendly interface for plant operators, facilitating efficient monitoring and control of plant operations.

- Increased Plant Data Accessibility:

  DCS provides real-time access to plant data for engineering and management personnel, enabling informed decision-making and proactive maintenance.

- Availability of Process SCADA Replay:

  DCS allows operators to replay process SCADA data for easy diagnosis of issues, aiding in troubleshooting and problem resolution.

- Historical Storage and Retrieval System:

  DCS includes a robust historical data storage and retrieval system, allowing for analysis of past performance data to optimize processes and ensure regulatory compliance.

- Availability of Operator Training Tools:

  DCS offers operator training tools to improve operator skills and competency, ensuring safe and efficient plant operation under varying conditions.

- Enhanced Process Safety and Reliability:

  By implementing advanced control algorithms and safety interlocks, DCS enhances process safety and reliability, reducing the risk of accidents and equipment failures.

- Improved Process Efficiency, Quality, and Equipment Life:

  DCS optimizes process control and automation, leading to improved process efficiency, product quality, and extended equipment life, ultimately enhancing overall plant performance and profitability.

Solutions in tkII-Valmet DCS:

- Complete Plant Operation Safeguards:

  tkII-Valmet DCS provides comprehensive safeguards to ensure the safe and efficient operation of the entire plant, including advanced monitoring and control features.

- Explosion Prevention System:

  Incorporating an explosion prevention system, tkII-Valmet DCS offers robust measures to mitigate the risk of explosions within the plant environment, enhancing safety for personnel and equipment

- Performance Calculations:

  tkII-Valmet DCS includes performance calculation capabilities, allowing for real-time assessment and analysis of plant performance metrics to optimize operations.

- Energy Management System:

  With an integrated energy management system, tkII-Valmet DCS enables efficient utilization of energy resources, minimizing wastage and optimizing energy consumption throughout the plant.

- Performance Optimization:

  Leveraging advanced algorithms and control strategies, tkII-Valmet DCS facilitates performance optimization across various plant processes, enhancing overall productivity and efficiency.

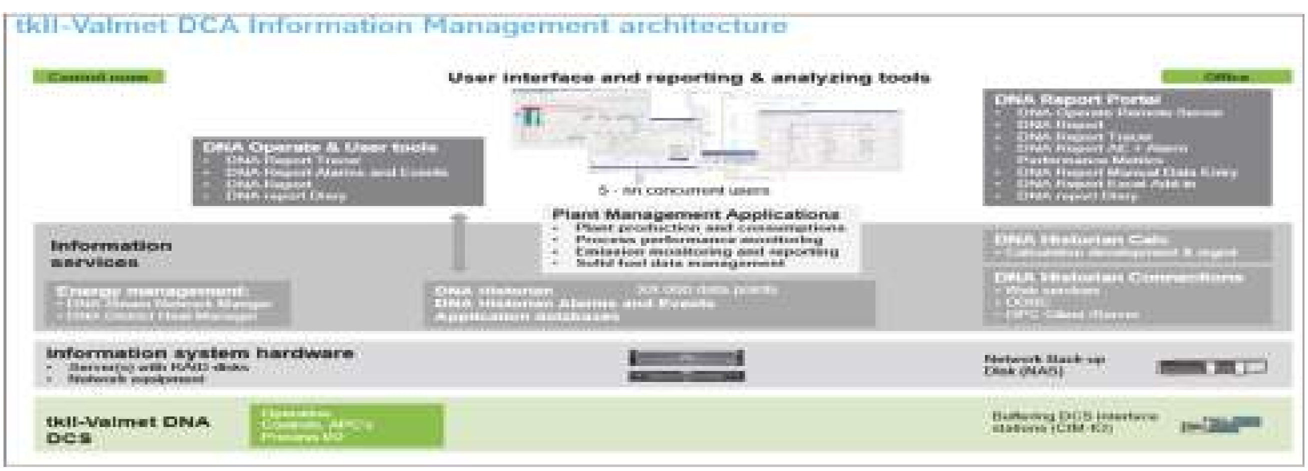
- Internet of Things (IoT):

  tkII-Valmet DCS integrates IoT technologies to enable connectivity and data exchange between various plant components and external systems, enhancing operational visibility and efficiency.

- Cybersecurity:

  tkII-Valmet DCS prioritizes cybersecurity with robust measures and protocols to protect plant operations and data from cyber threats, ensuring the integrity and security of the control system.

In summary, tkII-Valmet DCS offers a comprehensive suite of solutions designed to enhance plant safety, efficiency, and performance while incorporating advanced features such as explosion prevention, performance calculations, energy management, IoT integration, and cybersecurity.



Explosion Pentagon in Circulating Fluidized Bed Combustors

An explosion in circulating fluidized bed combustors can be triggered by entrapped combustible or volatile gases in the lower furnace, particularly during tripping or blackout events. This phenomenon involves several key elements:

Elements Involved:

- Dust Cloud: Suspended particles within the combustion chamber.
- Confinement: Enclosed areas such as furnace and ducting where pressure can build up.
- Fuel: Combustible materials such as coal in slumped bed or producer gas.
- Ignition Source: Smoldering particles present in the bed and freeboard region.
- Oxygen: Supplied from primary air (PA) and secondary air (SA) fans.

Prone Areas:

- Boiler Furnace: Particularly vulnerable areas include the first and second pass of the furnace where combustible materials and ignition sources may be present.
- Primary Air Path: Including PA ducting from air preheater (APH) outlet to high-pressure gasifier (HGG) inlet, SA duct, and tertiary air (TA) duct.

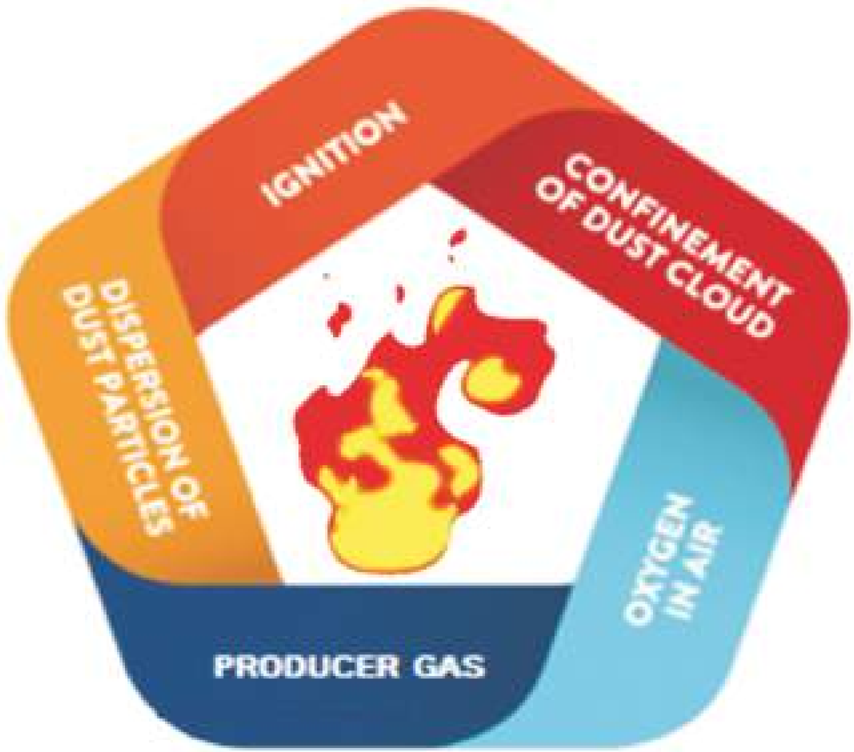
Understanding these elements and prone areas is essential for implementing safety measures and preventive strategies to mitigate the risk of explosions in circulating fluidized bed combustors.

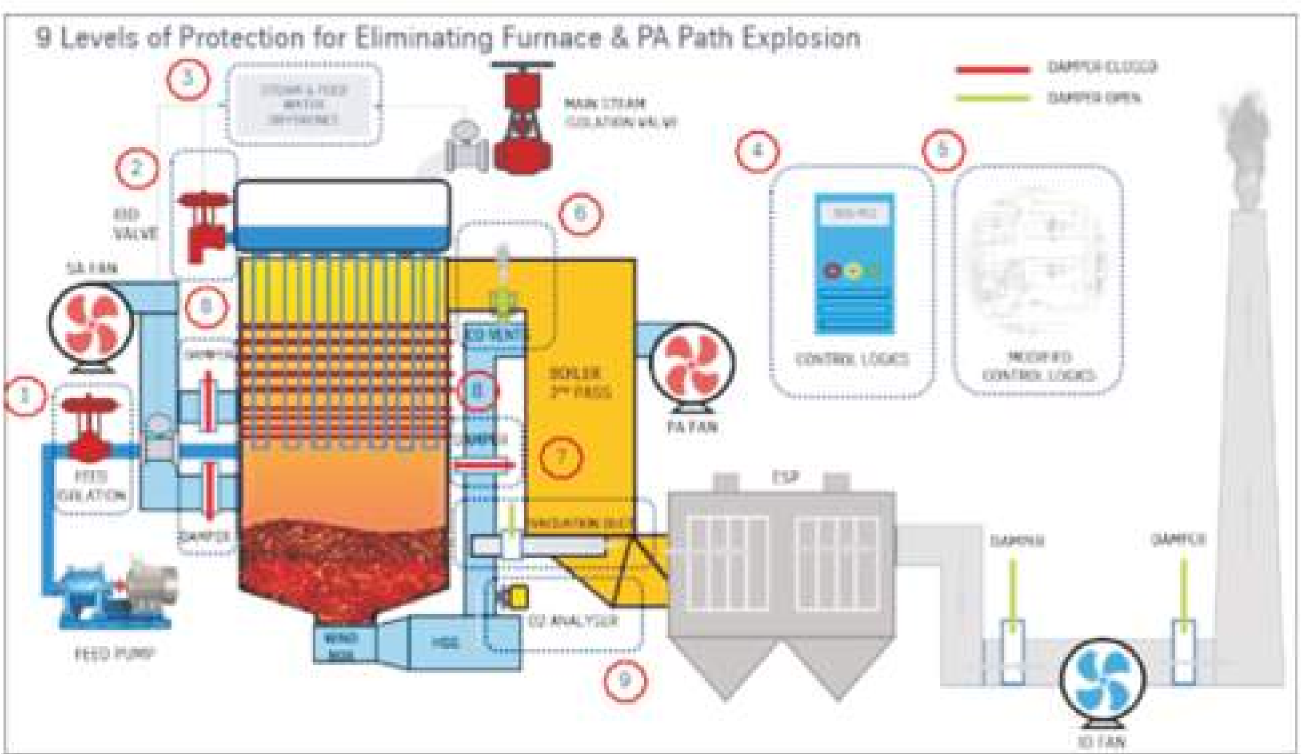
9 Levels of Protection with Explosion Prevention System

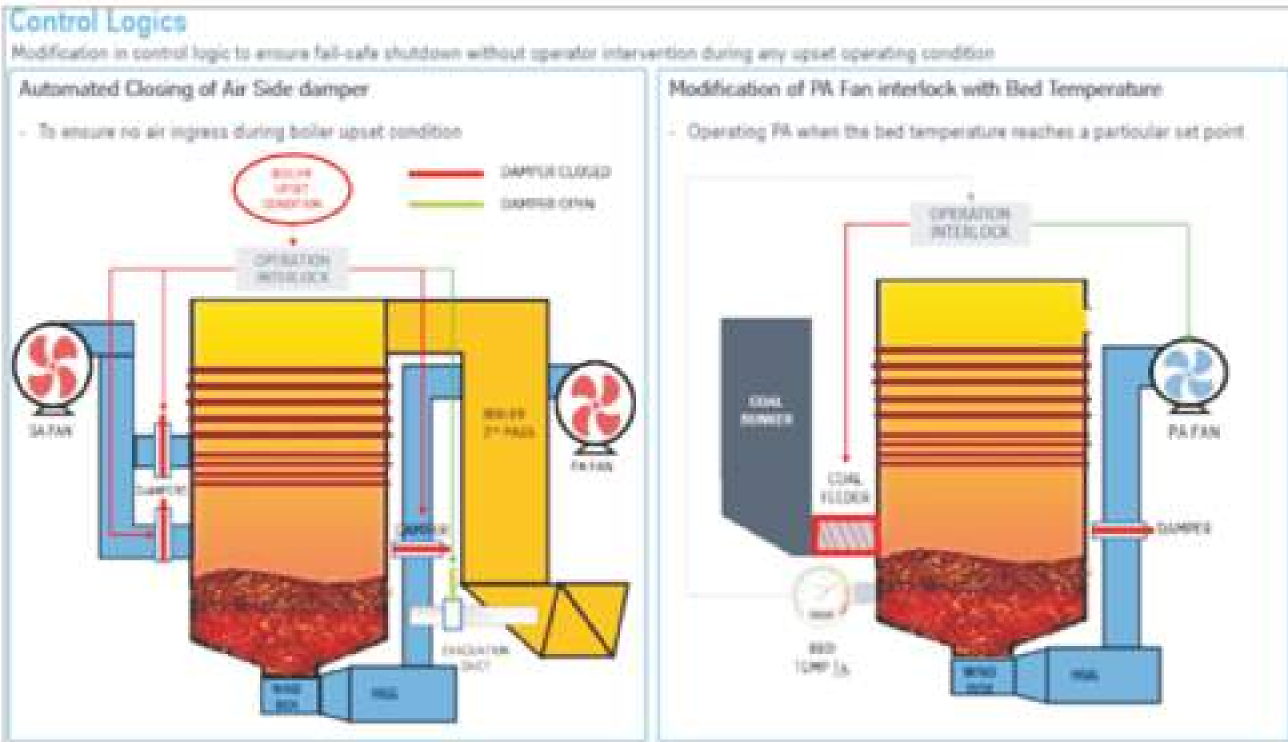
Developed by thyssenkrupp Industries India Pvt. Ltd., the 9 Levels of Protection form a comprehensive explosion prevention system designed to eliminate the risk of furnace and primary air (PA) path explosions in industrial settings.

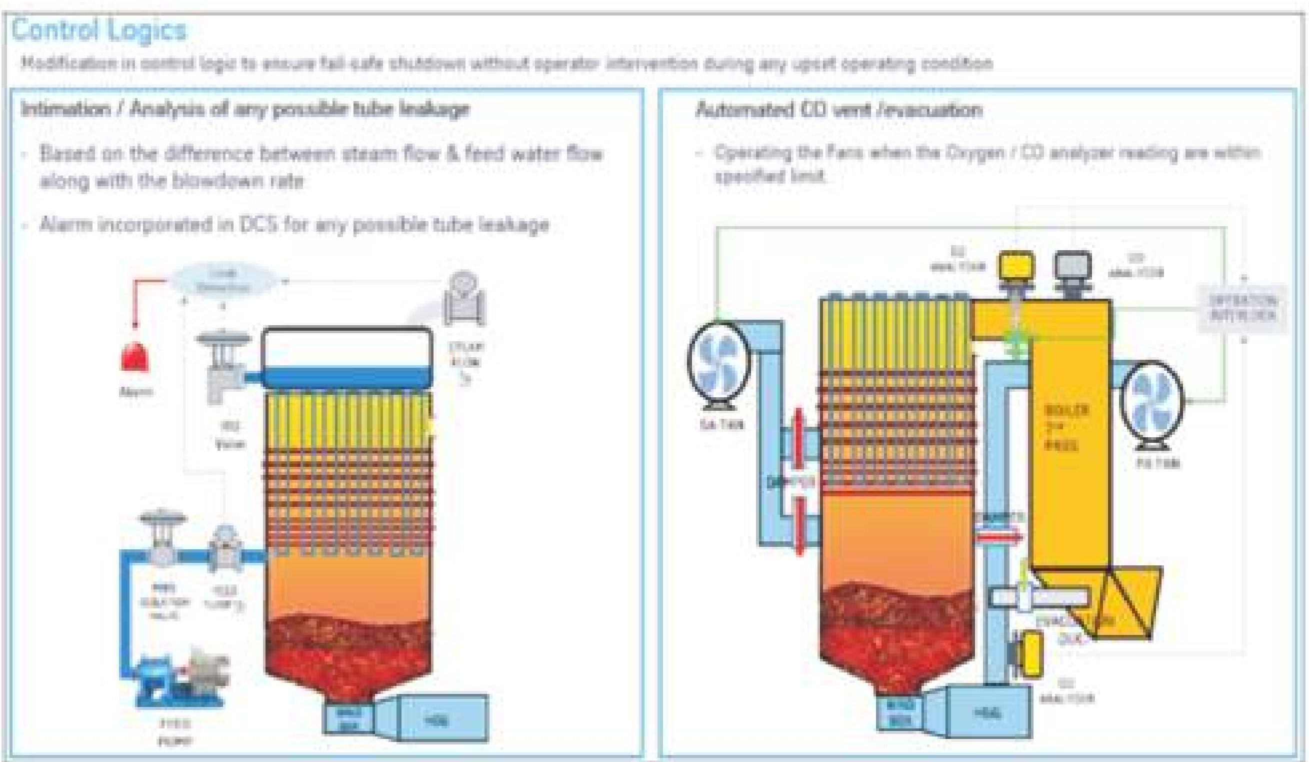
This innovative system integrates multiple layers of protection to ensure the safety and integrity of critical components within the combustion process. By addressing potential ignition sources, controlling combustible material dispersion, and implementing advanced monitoring and control mechanisms, the 9 Levels of Protection offer a robust solution to safeguard against explosions in furnaces and PA paths.

thyssenkrupp Industries India Pvt. Ltd.'s commitment to safety and technological excellence is reflected in the development and implementation of this explosion prevention system, providing peace of mind and enhanced safety for industrial operations.


IGNITION
CONFINEMENT OF DUST CLOUD
OXYGEN IN AIR
PRODUCER GAS
DISPERSION OF DUST PARTICLES


9 Levels of Protection for Eliminating Furnace & PA Path Explosion
DAMPER CLOSED
DAMPER OPEN
MAIN STEAM ISOLATION VALVE
SA FAN
PA FAN
CONTROL LOGICS
MODIFIED CONTROL LOGICS
ESP
FEED PUMP
O2 ANALYSER
ID FAN


Control Logics
Modification in control logic to ensure fail-safe shutdown without operator intervention during any upset operating condition
Automated Closing of Air Side damper
- To ensure no air ingress during boiler upset condition
DAMPER CLOSED
DAMPER OPEN
OPERATION INTERLOCK
SA FAN
PA FAN
Modification of PA Fan interlock with Bed Temperature
- Operating PA when the bed temperature reaches a particular set point
OPERATION INTERLOCK
COAL BUNKER
COAL FEEDER
PA FAN
DAMPER


Control Logics
Modification in control logic to ensure fail-safe shutdown without operator intervention during any upset operating condition
Intimation / Analysis of any possible tube leakage
- Based on the difference between steam flow & feed water flow along with the blowdown rate
- Alarm incorporated in DCS for any possible tube leakage
Alarm
Automated CO vent /evacuation
- Operating the Fans when the Oxygen / CO analyzer reading are within specified limit.
SA FAN
PA FAN

Why DCS?

- **Improved Process Monitoring and Control:**

  DCS facilitates the seamless integration of different control elements, enabling real-time monitoring and simultaneous control of various operations. This integration enhances operational precision and ensures maximum efficiency at each stage of power plant operations. With a comprehensive perspective spanning from ore handling to final outcomes, DCS empowers operators to make well-informed decisions quickly.

- **Scalability for Complex Operations:**

  Power projects often involve complex processes, requiring a scalable and flexible control system. DCS excels in managing these complexities due to its adaptable architecture, allowing for simple expansions and alterations. Whether handling variations in production volume or integrating new technologies, DCS ensures that the control infrastructure adapts to the ever-changing demands of the power sector.

- **Improved Safety Protocols:**

  In the high-risk power industry, DCS plays a critical role in enhancing safety procedures. Automated control and enhanced monitoring in DCS trigger rapid response mechanisms when anomalies or potential threats are detected early. By proactively addressing risks, power plant staff can work in a safer environment with reduced accident risk and increased regulatory compliance.

- **Remote Accessibility and Maintenance:**

  DCS offers the advantage of remote accessibility, particularly as remote operations become more common. Operators can oversee and manage power plant operations from a centralized location, eliminating the need for on-site exposure to risks. Additionally, DCS enables predictive maintenance, minimizing downtime by facilitating prompt diagnosis and resolution of equipment concerns.

- **Integration with Advanced Technologies:**

  DCS seamlessly integrates with cutting-edge technologies, including Artificial Intelligence (AI), Machine Learning (ML), and Industrial Internet of Things (IIoT). This integration enhances decision-making and maximizes operational efficiency by analysing large-scale datasets with sophisticated algorithms. DCS provides valuable insights for enhanced resource management, preventive maintenance, and overall process optimization.

- **Embracing Edge Computing for Real-Time Processing:**

  DCS is well-positioned to leverage edge computing technologies for real-time data processing. By processing vital data closer to the source, DCS reduces latency and improves control system responsiveness. Integrated edge computing in DCS enables mining facilities to make split-second decisions, crucial for process optimization and operational safety.

- **Cybersecurity as a Top Priority:**

  As power plant operations become increasingly digitally reliant and networked, the importance of cybersecurity cannot be overstated. Future DCS implementations will prioritize robust cybersecurity measures to safeguard vital control systems from potential threats. This includes the deployment of proactive threat detection systems, continuous monitoring, and the implementation of sophisticated encryption techniques to ensure the security and integrity of power plant operations.

- **Sustainable Mining Practices:**

  The power plant industry is placing greater emphasis on environmental sustainability. DCS will play a crucial role in maximizing energy efficiency, reducing waste, and implementing eco-friendly policies. Through advanced control algorithms integrated into DCS, power plant operations can minimize their environmental impact while aligning with global sustainability targets.

- **Human-Machine Collaboration:**

  In the future, DCS will not only augment human expertise but also enhance it through human-machine collaboration. DCS will act as an intelligent assistant for operators, enabling more intuitive control and monitoring of power plant processes. This collaboration will be facilitated by the integration of augmented reality (AR), virtual reality (VR), and user-friendly interfaces into DCS, empowering operators to make informed decisions and optimize plant performance.

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Brief profile

- Served in BHEL, Cethar vessels Limited and in Veesons Energy systems in Design, erection & commissioning of Boilers.
- Has over 40 years of experience in the boiler field and has the expertise in design, construction, operations and trouble shooting.
- Worked as consultant for Thermax limited, Nestler limited, Thermal systems Hyderabad, ISGEC John Thomson- and Enmas Andritz.
- His company- Venus Energy Audit System- provides design audit, construction audit, shut down audit and operational audit of boilers.
- His IBR approved manufacturing company – Sri Devi Boiler Spares and Equipment at Bangalore supplies pressure parts spares for boilers.
- His company Sri Devi Engg supplies non pressure part spares from Pollachi, TN.
- He has done numerous trouble- shooting of boilers in India & abroad. He has covered FBC boilers, CFBC boilers, PF boilers, Travagrate boilers & pusher grate plastic fired boiler, MSW fired boilers.

UNDER DEPOSIT CORROSION FAILURES IN BOILERS

By K.K.Parthiban, Venus Energy Audit System

Abstract

Boilers undergo corrosion failures due to long term and short term incidents. Author shares his experience on diagnosis of tube failures related to under deposit corrosion in boilers. The deposits could occur due to deviations in feed water chemistry / boiler water chemistry / condensate chemistry / poor preservation practices / improper operational cleaning / improper commissioning / improper chemical distribution system. Some case studies are covered in this paper. This paper covers the causes and the action taken to clean up the boiler.

CASE STUDY 1

This is the case of 60 TPH, 62 kg/cm2 g, 480 deg C lignite cum agrowaste fired AFBC boiler. This boiler is a cogeneration boiler meeting the steam & power requirement of a paper mill. Tube failures were encountered in front waterwall and the rear waterwall several times nearly after 14 years of operation.

The failed waterwall tubes were available for inspection. The tubes have been undergoing under deposit corrosion failures. There have been several failures in the front waterwall followed by the rear water wall. One failure was reported in the side waterwall too. There is a mechanism of pre-boiler corrosion resulting in accumulation of corrosion products in evaporative circuit of the boiler. The feed water is from three sources. They are the makeup water from DM plant, condensate return from paper mill and the TG condensate return.

- The makeup water system piping and tank can corrode due to low pH and dump iron into the boiler evaporative section. This iron later gets oxidized and deposit inside the evaporator tubes.
- The condensate return from paper machine comes with iron during start up and during interruptions. This is due to pH corrosion and due to oxygen corrosion. Oxygen corrosion will result in particulates which are usually accumulated at the strainer of feed pump or at the lower most part of the boiler. However, the iron released due to low pH gets oxidized in boiler circuit and deposit in low flow circuits. In this boiler, the front waterwall tubes & rear waterwall tubes are low flow circuits. This is because there are no independent downcomers for the front & rear waterwall to ensure positive circulation.
- TG condensate can get contaminated by copper or iron depending on metallurgy. Any material wetted by water is subject to corrosion. The corrosion rates differ based on the condenser tube material used and the pH / oxygen conditions in the condenser / condensate.

A.FAILURE MECHANISM

Copper and iron oxide deposits are porous in nature and their deposits sites allow concentration of chemicals under the deposits. The mechanism is known as wick boiling. While the bulk water pH may be as per the recommendation, whereas under the deposits, the pH conditions would be even 14. Hence caustic attack occurs. There will be no metallurgy or microstructure change around the failure location. The failure analysis reports confirm this.

B.REVIEW OF FAILURE ANALYIS REPORTS BY OTHERS-by external lab

The report confirms deposits and pits below deposits on the waterside. Pits have been even 2.5 mm deeper. Internal deposit analysis was not carried out. The iron / copper deposits would be always on the fire side only, where the boiling is taking place. There are no metallurgical changes or mechanical property changes in the failed tube. See photos 1-4 showing deposits and tube pitting. See photo 5 which is part of the report by the external laboratory,

C. REVIEW OF FAILURE ANALYIS REPORTS BY OTHERS-by NALCO

The analysis of a failed tube was carried out by chemical supplier too. The report says that the deposit is iron oxide. No copper is reported in the internal deposit analysis. Nalco has reviewed the water & condensate chemistry and certified it to be OK. This confirmation is applicable for the particular period of observation only. During start up the iron levels would go up in the paper mill condensate.

However, no data is available on time versus iron levels in the paper mill condensate. Engineers informed that the condensate is diverted to drain until the color of condensate is clear. However, data is required on pH / iron levels in paper mill condensate during a cold startup & a restart after the paper break. It is learnt that during product change the steam drawl is cut to paper machine. Such situations are present at least once every month.Nalco has cautioned that the iron in feed water should be below 0.01 ppm. This is true. However, the deposits might have occurred during an incident causing an upset in feed water or boiler water chemistry. Nalco had recommended acid cleaning and passivation.

D. REVIEW OF FAILURE ANALYIS REPORTS BY OTHERS-by Thermax

By this time, more damages have been reported. Plant engineers have carried out only thickness measurements. Normally borescope analysis is done to know internal deposit levels. This is carried out from handhole plates at top headers. Thermax report is based on the tube sample removed from boiler. The internal deposit analysis report (EDAX spectra report) confirms copper. See photo 6-8. The presence of phosphorous, magnesium and calcium confirm that there had been breach of the cooling water from condenser tube failure. Thermax had rightly pointed out that the failures are due to deposits caused by transport of corrosion products from pre-boiler system. However, at times it can be internally generated due to low pH situations. Low pH occurs when there is cooling water leakage after the condenser tube failure. This raises the iron level in deposits. The reports show the photos of pitting corrosion beneath deposits. This is the failure mechanism.

E. CONDENSER FAILURE HISTORY

- The condenser was originally with SS 304 tubes in the air removal section. During a chemical cleaning attempt 3 year back, the SS tubes had failed. HCL had been used for cleaning. The failed tubes were replaced with admiralty brass. Admiralty brass life will be less where there is presence of oxygen.
- A year later, there had been tube failures in condenser. Around 30 - 40 tubes have been reported to have leaked. This is a major incident in which the cooling tower water would have leaked in.
- 2 years later one condenser tube had failed. Three shifts had passed in taking a decision to shut the boiler. During this time, cooling water would have entered into the boiler. The feedwater hardness was reported to be 5 ppm. The feed water conductivity rose from 15 to 24. There should have been considerable organism transported to boiler.
- A month later, some more condenser tubes failed. It is possible that these tubes are in the air removal section wherein the admiralty brass tubes have been substituted in place of SS 304 tubes. However, when there is a leak and when there is a time delay in isolation of the boiler, there will be scaling in boiler. The cooling tower water quality being unusually good here, direct scale related damage had not taken place. In this incident, hardness values had been 0.5 to 2.0 ppm. The boiler was in operation for two shifts with contaminated TG condensate.

- In all the above cases, the mapping of condenser tube failure was important. The condenser failure pattern was not analyzed. The cause of failure was not fixed. This was required to eradicate the source of the problem. Plant engineers were requested to keep the condenser tube layout in a big drawing sheet along with air removal pipe location. In the same drawing all failures must be marked date wise. In fact, it applies to boiler as well.
- It is recommended to monitor copper, ammonia in TG condensate. Dissolved oxygen monitoring is required as copper alloy are sensitive to residual oxygen levels. Thermax, the boiler supplier had specified Fe <0.1 ppm, Copper as < 0.002 ppm and residual hydrazine as < 0.02 ppm. In fact, these parameters are not monitored at many plants.

F. CONDUCTVITY MONITORING IN TG CONDENSATE

The present arrangement to measure condensate conductivity was inspected. See photo 10 in annexure. There is a conductivity meter installed in the condenser discharge piping. This is directly installed with an online probe. Removal and cleaning are not possible unless the plant is shut. Further the pH measurement is not online. Conductivity must be measured after the sample passes through a cation column. With this, even small leakage levels can be easily identified. The samples must be passed through sample cooler station so that it is cooled close to 25 deg C. The probe requires periodical cleaning and replacement for measurement accuracy.

G. THE CONTAMINATION CONTROL OF THE PAPER MILL CONDENSATE

- The quality of the return condensate depends on the paper break / paper machine shut down periods. During a startup of the boiler, the pH can be stabilized after a time period only. Hence, transport of iron from the paper mill can be prevented only by measuring the iron level and discarding the return condensate. However, draining is being done based on visual observation of the colour. So far, the iron level was not measured during start up and on other incidents. It is recommended to establish a standard practice based on dissolved iron data. For this purpose, samples shall be collected & analyzed. At least 3 samples shall be collected for correctness of the analysis
- Magnetic separator (twin basket type) will help to trap the loose iron corroded on the low pH condensate. Condensate polishing system can have a filtration system too. A product supplied by Metso for high purity condensate can be seen in reference 1 in annexure.

H. REVIEW OF CHEMICAL DOSAGE PRACTICE

Plant engineers shared the data on chemical dosage practice. From commissioning time, that is, for the first four years, Thermax chemicals have been used. They were Maxtreat 3330, Maxtreat 3006 and TSP. Maxtreat 3330 is a 3 in one filming amine and oxygen scavenger chemical. During this period no abnormality is reported. However, this chemical is sensitive to copper tubes. Only thing is that in this period the tubes in the air removal section were of SS 304. During this period also ammonia was not monitored.

- For some reason, the treatment practice was changed to Eloguard for a year.
- A year later, the treatment practice was changed to Nalco chemicals.
- Nalco 1250 is an oxygen scavenger which is basically a carbohydrazide chemical. This chemical will break down and generate ammonia. Ammonia can cause corrosion of brass in the presence of oxygen. Hence dissolved oxygen measurement should be adopted in order to optimize the dosage of th carbohydrazide chemical. It was learnt that recently residual amine level was being checked to limit the ammonia in condensate. The limit is 1 ppm.

- Nalco 5711 is a condensate corrosion inhibitor which is basically a blend of volatiles neutralizing amine and ammonia designed to improve the pH in the steam and condensate system. Now it becomes necessary to monitor the condensate pH very closely so that excess dosage of chemical can be avoided. Otherwise, the excess ammonia will again lead to corrosion of Admiralty brass tubes. Online pH measurement system is advised in the TG condensate system after CEP.
- Nalco 444 is basically TSP. Boiler does not have any copper materials. TSP remains in boiler water and does not carry over to the steam, unless there is a mechanical carryover issue inside the drum. The purpose of this chemical is to maintain the boiler water pH.
- There is no need to change from Nalco chemicals to other chemicals. It is necessary to add online pH monitoring system for the TG condensate to optimize the dosage of Nalco 5711. It is necessary to add dissolved oxygen meter at the economiser inlet to optimize the dosage of Nalco 1250. It is advised to inspect the deaerator for the proper condition of its internals.
- As per OEM specification the feed water pH should be 9.3 to 9.6. This is not correct for copper containing system. It is recommended to maintain 8.8 to 9.2. The boiler water pH can be 9.4 to 10.5. However, it is advisable to keep the TSP level between 5-10 ppm to avoid caustic corrosion of low velocity evaporator circuits.

I. ANALYSIS RESULT OF TUBE SAMPLES COLLECTED BY US

- Three water wall tube samples were collected during the visit for internal deposit analysis. Two of them are from rear water wall and one from left water wall. The internal deposits were pictured by boroscopy camera and presented in photos 1-4 in annexure. The accumulated deposits at insidetube surfaces were removed separately & quantity collected was expressed as to gm /m2 of tube internal surface area. See table 1. The accumulated deposits were analyzed with EDAX spectra by external laboratory and the results are attached in table 2 in annexure. The results indicated presence of iron, copper and zinc to serious levels. It proved that there was corrosion going on in the condenser tubes. It also indicates that the iron is either generated within the boiler or being transported from paper machine.

J. OFFLINE CHEMICAL CLEANING

Off-line chemical cleaning, when done in proper manner will provide a clean internal surface in all evaporator sections of the boiler. It is necessary to carry the chemical cleaning by circulation method to ensure proper removal of the loose oxides which are present inside the boiler.

- Circulation has to be done circuit wise to have a flushing velocity of 1 m/s so that the removed deposits do not accumulate in any circuit.
- The two drum manhole shall be provided with temporary cover plate and chemical inlet piping. There are two stubs in front wall bottom header, which can be used for circulation. Similarly, there are two stubs in rear wall bottom header, which can be used for circulation. For left & right waterwall cleaning, hand hole stubs which are present in the two ends of bottom header should be used.
- It is recommended that the circulation flow is from top to bottom of the tubes so that the flow of loose dislodged deposits would be easier.
- It would be necessary to replace the drain valves of bottom headers as the glands would be subject to acid solution.

- It would be necessary to isolate all level gauges and level transmitters. A temporary level gauge is recommended at the drum so that the drum level is maintained without dumping the chemical into the superheater section. It is necessary to plug the saturated steam lines with wooden plugs. This will call for removal of the demister sections.
- It would be necessary to remove the turbo separators and the chevron dryers so that iron oxide deposits are removed completely out of the system.
- It would be necessary to flush the system with pH conditioned water, properly after cleaning. Improper flushing will lead to tube failure. For proper flushing, the handhole plates in upper headers are to be made use of. Approach and access platform shall be made for proper cleaning of the top headers.
- After carrying out the flushing, passivation is to be done.

K. CAUSES OF TUBE FAILURE

- The deposits indicate copper, zinc and iron oxide.
- Iron comes from the plant condensate. There can be iron oxide generation due to condenser tube leakages causing low boiler water pH.
- Condenser tube material change from SS 304 to admiralty brass in air venting zone was the cause for copper deposits.
- The corrosion products have accumulated in low flow circuits and led to under deposit corrosion. The front waterwall and rear waterwall do not have exclusive downcomers to ensure good circulation velocity. Many other boilers have separate distributor downcomer pipes to front & rear waterwall bottom headers.

L. RECOMMENDATIONS

- Offline chemical cleaning is a must to prevent further failures.
- Panel replacements would help to reduce the risk of tube failures after the chemical cleaning.The corrosion pits are reported to be 2 mm.
- Online iron dispersant dosage to 5 -10 ppm for 2-3 days will remove loose iron oxide deposits which can be flushed out from bottom drain points. For this purpose, the steam load & steam pressure must be reduced. This will provide temporary relief. At the same time there can be some leakages when the deposits are removed. This is a better situation as compared to operation with the present deposits.
- Online dissolved oxygen measurement is required to optimize DEHA dosage. Ammonia shall not exceed 1 ppm in TG condensate.
- Online pH meter and Online cation conductivity meters are advised for TG condensate. This is to know the contamination due to condenser tube failure.
- If it is a practice to extend the boiler operation after the condenser tube failure, then the under deposit related failures will continue.
- It is advisable to switch over to SS material for air removal zone in the condenser as per original design.
- Waterwall tubes are not to be plugged. Spare tube with half fin on either side shall be procured and kept ready. When a tube fails, change the tube. Plugging is not allowed in Waterwall. Bed coils can be plugged at header outside the boiler.

CASE STUDY 2

This is the case of a low pressure boiler in a paper industry. The water wall tubes had failed at the roof where the tubes are sloped. See photo 12 & 13. Deposits and corrosion pits were seen in several tubes.

This boiler is with polyamine treatment chemical such as Eloguard 86. The chemical is dosed at DM plant outlet. The makeup waterpH & return condensate pH are boosted to 8.8 -9 with this chemical. This chemical is supposed to be with deoxygenating agents. No separate oxygen scavenger is used. In any case the oxygen induced corrosion of the machine's internal surface cannot be avoided. Polyamine treatment is with a filming amine component which forms a protective film.

See the theory outlined in photo 13. But one has to take a wipe off of the machine on every machine shut to check whether the protection is really present. Photo 15 shows the status of the machine. The reason for this could be a compromise on the filming component in the chemical formulation. Spare dosing pump and sufficient chemical stock are a must.

CASE STUDY 3

This is the case of a 125 TPH, 88kg/cm2 g- 515 deg C pressure cogeneration AFBC boiler in a chemical industry. This boiler is with conventional phosphate based treatment. The return condensate is passed through a condensate polishing system. During COVID period, the boiler was under wet preservation. But the water used was not prepared with pH booster and oxygen scavenger for boiler filling. The boiler had corroded, and the corrosion products remained in the circuit. This boiler bed coils are with rifle bore tubes. The rifle bore tubes became sites for resting of the corrosion products. See photo 16 & 17. After identifying the root cause, the boiler was boiled out with iron dispersant for 8 hrs and flushed out from the bottom handhole plates.

The same boiler underwent condenser tube leaks after about a year. The bed tubes failed again due to under deposit corrosion. Whenever there is a major condenser tube leak, the boiler water pH drops, and this causes instant corrosion of water touched metal surfaces. See Photo 18& 19. The studded bed tubes have with thermal stresses due to studding. When the corrosion product halts here, it is easy for the tube to corrode and cause leaks with pinholes. The boiler needed a chemical boil out, but this was skipped. Both the boilers suffered bed coil failures due to under deposit corrosion.

- The mechanism of caustic corrosion under the deposit is explained below:

Corrosionoccurs when pH of the boiler water is outside the recommended range of 8.8 -10.2 . Caustic corrosion is also called caustic attack. Caustic corrosion develops from deposition of feed water corrosion products in which NaOH can concentrate to high PH levels. At high PH level, the tube steel's protective magnetic oxidecoating is solubilized, and rapid corrosion occurs as per the reaction given below:

$4NaOH+Fe_3O_4=2NaFeO_2+Na_2FeO_2+2H_2O$

With the destruction of protective magnetic oxide layer, concentrated NaOH reacts with the tube material and forms atomic hydrogen as per the reaction

$Fe+2NaOH=Na_2FeO_2+H_2$

The atomic hydrogen so produced reacts with Fe_3C of pearlite constituent and forms CH_4 which ultimately causes hydrogen damage. The corrosion deposits accumulate at locations where flow is disrupted such as, welds with backing rings, at bends, in horizontal tube weld, inclined low flow circuits and at high-heat input locations.

CASE STUDY 4

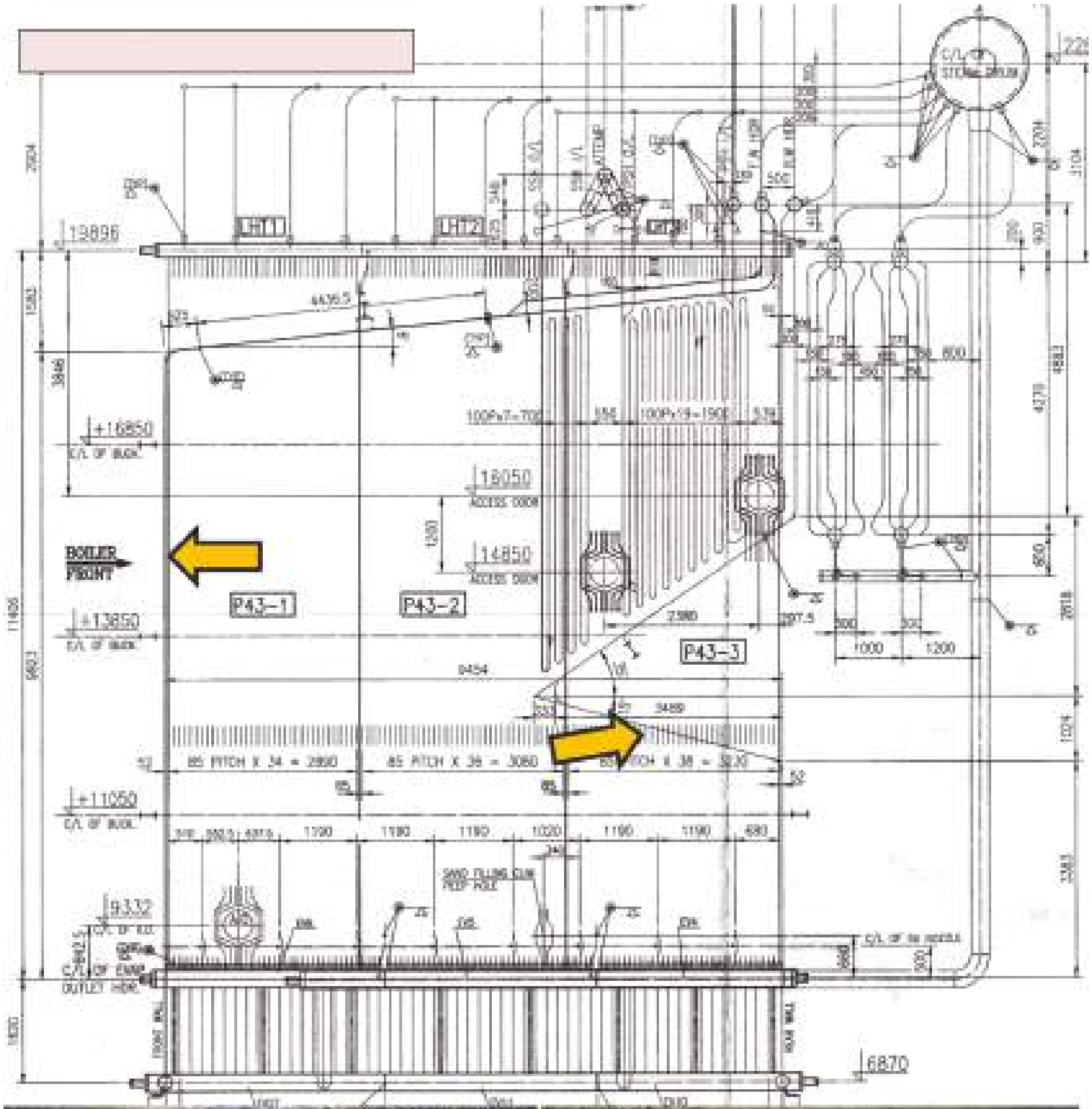
This is a case of battery of boilers with operating pressure of 66 kg/cm2 g- 495 deg C pressure AFBC boilers meant for cogeneration. The steam drum was seen to be reddish indicating that the treatment was not adequate protection for the paper machine. See photo 20. To facilitate online removal of iron deposit, polymer-based iron dispersant was introduced to prevent under deposit failures. Further filming amine chemical was added to protect the condensate touched surface to prevent online corrosion.

CASE STUDY 5

This is the case of 125 TPH,106 kg/cm2 g- 540 deg C pressure CFBC boiler meant for captive power generation. This boiler had beenonpolyamine based treatment. The boiler had been idle on account of high coal prices almost for one year. The boiler was under wet storage with DM water. The boiler was simply filled with DM water and hydrazine was injected into the steam drum. The circulation arrangement provided was not sufficient to homogenize the chemical in all part of the boiler. Within 15 days of boiler operation a furnace tube showed up under deposit corrosion. See photo 21 & 22. This failed tube was already under an erosion protection shield (in the startup burner area). There was wingwall SH failure as well due to hydrogen crack as the pH of the water did not meet the requirements.

- The correct water to be used for preservation should be with 200 ppm of hydrazine for oxygen removal and sufficient ammonia or morpholine to attain a pH of 10.
- This water must be premixed at DM plant itself and should be stored in a tank of suitable capacity for the complete filling of the boiler including superheater, when nitrogen blanketing is not followed.
- The superheater section should always be filled first to avoid transport of sludge / loose iron dust to the super heater sections. The wingwall superheater had cracked at the hard faced zone.
- This plant is with air cooled condenser (ACC). ACC should have been under dry preservation using dehumidified air or nitrogen. But no preservation was followed for ACC. Hence after the unit started, the corrosion products from ACC got transferred to the boiler.
- The deaerator, surge tank and CST were not under preservation too.

Altogether there was sufficient scope for the corrosion product to generate within boiler and in the pre-boiler & condensate system. The deposit halted at the vicinity of the weld joint and corroded the tube. The boiler was cleaned with iron dispersant at low pressure and put back online.



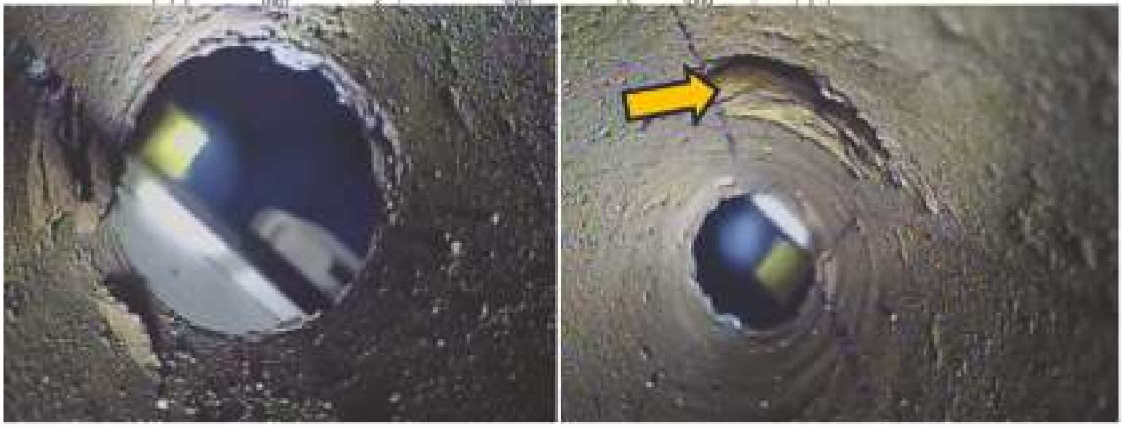


Figure 1 & Photo 1 & 2: The figure shows the failure locations. Number of under deposit corrosion failures took place in front waterwall, rear waterwall. Once side waterwall suffered failure.

Photos 3 to 4: The photos above show the deposits in the tube samples.

Considering the accumulated deposits + overall length deposits

S.no	Description	Internal Deposit (g)	Length (mm)	Area (m2)	Deposit - g/m2
1	Left wall tube sample	4.4	400	0.0536	82.08
2	Rear wall tube sample - tube no-13	9.4	890	0.1193	78.81
3	Rear wall tube sample - tube no-14	10.7	1035	0.1387	77.14

Considering only overall length deposits

S.no	Description	Internal Deposit (g)	Length (mm)	Area (m2)	Deposit - g/m2
1	Left wall tube sample	2.9	400	0.0536	54.10
2	Rear wall tube sample - tube no-13	7.1	890	0.1193	59.53
3	Rear wall tube sample - tube no-14	6.9	1035	0.1387	49.75

Table 1: The calculation sheet above shows the deposit density, gm/m2, as scrapped from base metal. This is not alarming. A uniform deposit density above 200 gm/m2 (for 66kg/cm2 operating pressure) calls for chemical cleaning. However, this is the case of non- uniform deposit calling for immediate chemical cleaning.

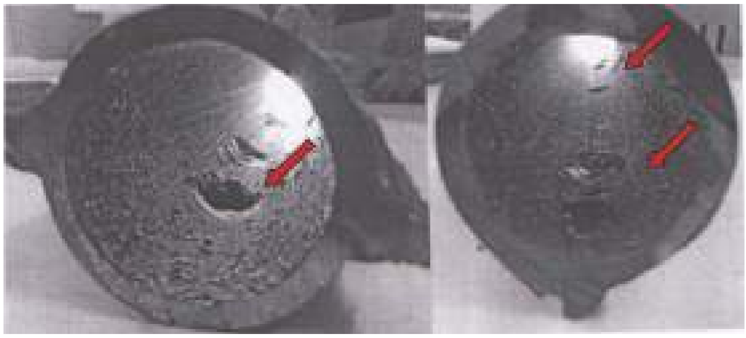
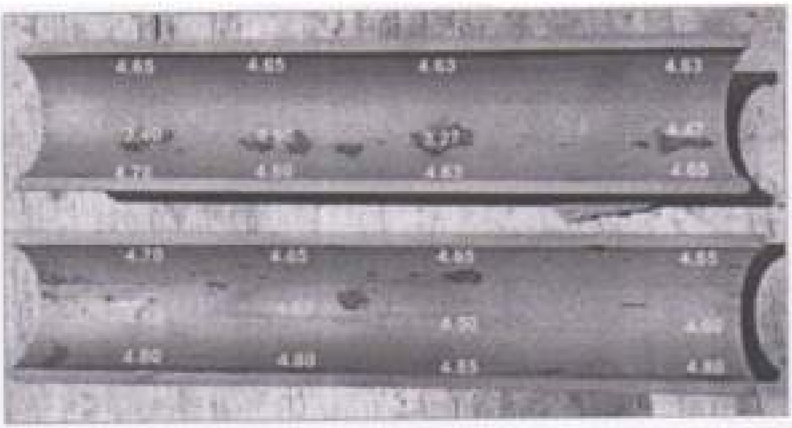
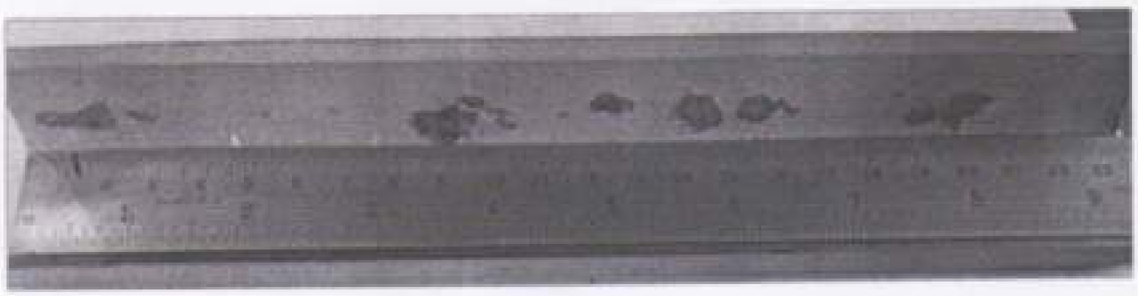


Photo 5: The report from external lab confirmed that it is pitting corrosion.



Photograph No 07. Thickness measurement – wall loss at pitting location only. Min thickness 3.27 mm



Photograph No 08. -Tube internal pitting. Pit size max 2.1 mm in length

Sr. No.	Element	Spot-1 (VJ23PR0012)	Spot-2 (VJ23PR001B)	Spot-1 (VJ23PR001C4)
1	Na	0.57	-	-
2	Mg	11.23	1.19	1.06
3	P	11.93	10.42	1.98
4	Ca	9.89	23.69	3.89
5	**Cu**	**11.97**	**19.76**	**3.52**
6	Zn	7.33	5.48	13.44
7	Fe	9.71	10.83	29.69

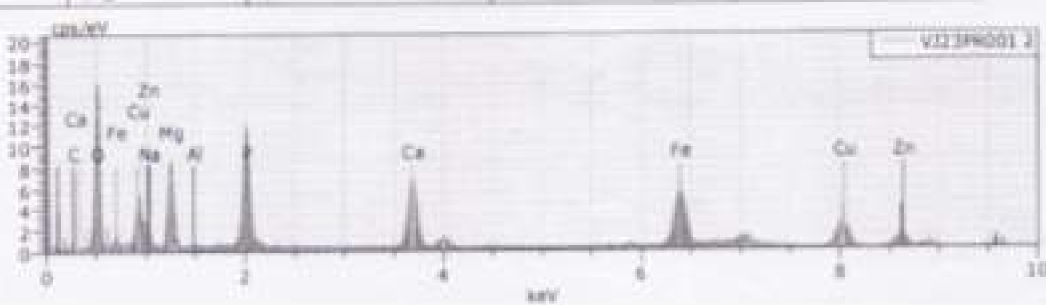
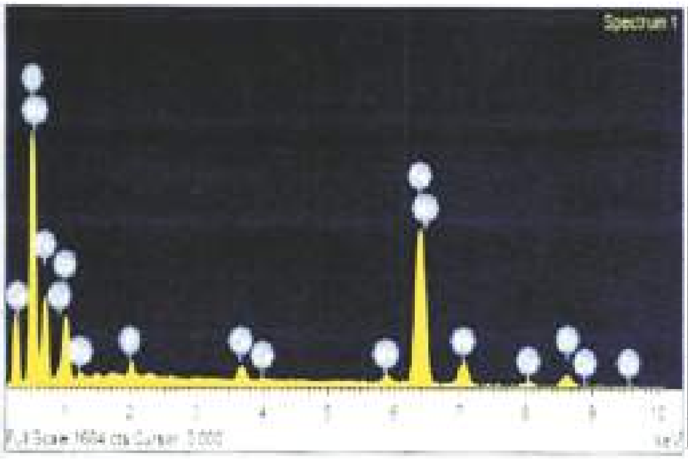


Photo 6 -8: The above are the reports from Thermax lab. Deposit spectra says that it is raw water along with copper.



	Deposit 1	Deposit 2	Deposit 3
Element	% wt	% wt	% wt
Oxygen	11.19	12.54	9.51
Magnesium	0.87	0.99	0.83
Phosphorous	4.92	1.32	1.28
Calcium	3.85	0.84	0.89
Manganese	0.91	2.45	0.81
Iron	31.58	61.38	62.51
Copper	34.03	4.57	7.38
Zinc	12.64	15.93	16.79

Photo 9& Table 2: Photo above shows the Energy dissipative analysis of Xray.
The table shows the consolidated report of three deposit samples analysed by us at another laboratory.

Freshwater allows	Gauge BWG	Velocity FPS	Possible applications		
			Main body	Air removal section	Periphery
Once-through system					
Admiralty brass	18	8 max	X		
90-10 copper nickel	20	10 max	X	X	X
70-30 copper nickel	18, 20	15 max		X	X
304 stainless steel	22	5 min	X	X	X
Recirculating system					
90-10 copper nickel	20	10 max	X	X	X
70-30 copper nickel	18, 20	15 max		X	X
304 stainless steel[1]	22	5 min	X	X	X
Once-through system					
90-10 copper nickel	18, 20	8 max	X	X	X
85-15 copper nickel		20 max	X	X	X
70-30 copper nickel	18, 20	15 max	X	X	X
"Super" stainless steel	22	5 min	X	X	X
Titanium	22	5 min	X	X	X

1. Low chloride content waters only.

Table 3: The above table shows the recommendations for selection of material for condenser tubes. It may be noted that admiralty brass is not recommended in air removal section.

Photos10 & 11: The left side photo shows the conductivity meter installation at present.
This does not allow examination / replacement of the probe. Moreover, condenser tube leakage is better detected by cation column conductivity measurement. The right side photo shows the cation conductivity measurements at another plant.

High gradient magnetic filter

HGMF

The Metso HGMF High gradient magnetic filter provides proven highest efficiency in removing iron and copper corrosion particles from boiler condensate.
The HGMF maintains this efficiency even during heavily contaminated flows and with varying flowrates.

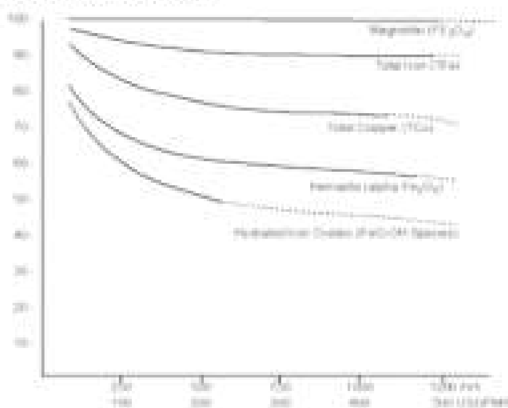
Design

- Increases plant thermal efficiency by processing hot condensates from high pressure boilers.
- Removes high levels of iron and copper particulates from boiler condensates during startups and upset conditions.
- Processes boiler condensates hotter than those that can be accepted by resin bed polisher systems.
- Decreases losses in condensate and heat values during production upsets.
- Reduces iron and copper particulate buildup rates in boilers.
- Increases time spans between boiler cleanings.
- Allows more hot condensates to be used during mill restarts - even during first hours.
- Reduces dependence on alternate boiler feedwater sources.
- Increases boiler availability and reliability.
- Reduces boiler cleaning and waste disposal costs.
- Treats water and oil emulsions in steel rolling plants.
- Removes corrosion products in municipal heating systems.

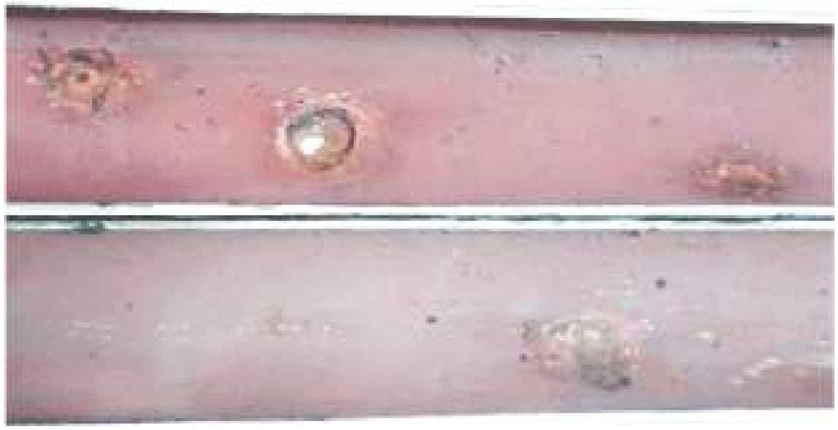
The filter can be used alone or in conjunction with other polishing steps. When used alone, for high pressure power and recovery boilers, the filter produces acceptable feedwater. When used in conjunction with other polishing steps, the filter significantly increases the duty cycles of these steps.

The design of the Metso HGMF filter allows it to function with high efficiency under various conditions and widely ranging flowrates.

During mill and boiler startups when high contamination is present, the Metso HGMF performs with the same high efficiency. The filter returns more condensate at higher values to the boilers than other polishing techniques can achieve and less condensate is lost to the sewer. As a result, the HGMF filter is less dependent on alternate feedwater sources.



Reference 1: For cogeneration boilers serving process industries experience higher level corrosion products in condensate return . It is prudent to use magnetic filters as CPU (condensate polishing unit) to eliminate under deposit corrosion in boiler side.



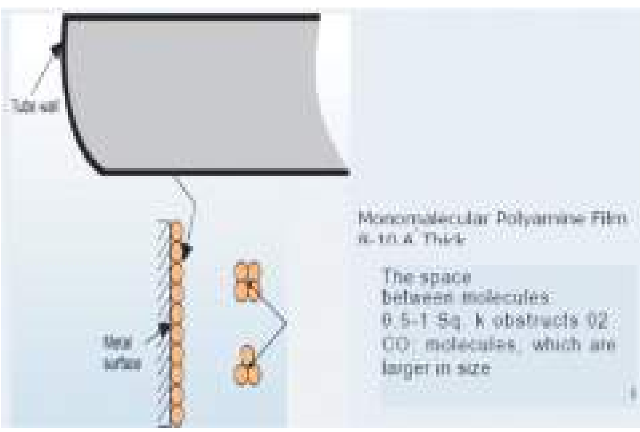


Photo 12 -15: Paper mill boiler suffered from under deposit corrosion after prolonged operation without appropriate descaling of the boiler. The iron oxides get transported from machine cylinders. Use of filming amine generally reduces the boiler corrosion rate. The rub off is from inside of the drying cylinders.

Photo 16 & 17: Treated water – pH corrected & de-oxygenated water was not used in this boiler during boiler idle storage (during COVID period). Soon after the light up, the bed coils suffered under-deposit corrosion. The bed coils being of rifle bore design, the corrosion product could easily get trapped between the rifle profiles and caused localised under deposit corrosion. The boiler is with TSP treatment and hence chemical concentrates under the deposit.

Photo 18 & 19: Two AFBC boilers with common TG underwent under deposit corrosion after the condenser tube leak incident. The boilers were run for more than a week after the condenser tube leak incident. Rifle bore tubes are sensitive to under deposit corrosion. The boiler had to be chemically cleaned.

Photo 20: The above is a photo of steam drum in a paper mill with several boilers. The drum inspection revealed high level of iron dust. To facilitate online removal of iron deposit, polymer-based iron dispersant was introduced. Further filming amine chemical was added to protect the condensate touched surface to prevent online corrosion.

Photo 21 & 22 : The failed furnace tube near burner zone shows iron oxide deposit inside. There is a weld which can easily allow a deposit of suspended iron. The failed edge is typically a under deposit corrosion type.

Full Name: PRAMOD PRABHAKARRAO KATE.

Company Name: VYANKATESHA ENGINEERS & CONSULTANTS, NAGPUR.

Designation: BOILER TECHNICAL CONSULTANT.

Educational Qualification: B.E. (Mech).

Education Institute Details: VISVESVARAYA NATIONAL INSTITUTE OF TECHNOLOGY (VNIT NAGPUR).

Current Job Profile:

- Providing Expert Services as Boiler Technical Consultant as Proprietor of M/S Vyankatesha Engineers & Consultants, Nagpur.
- Technical Consultancy services regarding Failure analysis of pressure part components giving root cause of failure & preventive and corrective actions & condition assessment studies.
- Technical consultancy services regarding Inspection of Pressure Part Components during Shut down of Boiler at Furnace Water Wall, Platen SH, Final SH, Reheater, LTSH, Economizer & Air Preheater, Flue Gas Ducts. Data Collection & analysis of Data & furnishing Action Plan & Advice for any Boiler Performance, Combustion & Thermal Efficiency Improvement.
- Technical Consultancy Services for Root Cause Analysis for different types of Failures occurred in last few years.
- Providing Expert Services for Third Party Vetting of Capex Schemes (DPR & Non-DPR) for MSPGCL Power stations regarding Boiler, Turbine, Testing, Electrical, Ash Handling Plant, Coal Handling Plant, Water Treatment Plant as per new MERC Regulations 2021.
- Conducting 2/3 days Training Programs for Boilers Engineers, Operators & Managers regarding Boiler Tube failure mechanisms, causes & Remedial measures, Performance & Combustion Optimization, Weld Control & Material Philosophy, Ash Deposition like Slagging, Fouling, Clinkering & different Case Studies.
- Technical Consultancy Services regarding review of Existing Maintenance Practices & suggestions for Improvement & Analysis of Boiler Operating Philosophy & the preventive solutions & best practices to mitigate the issues for reduced Reliability & Availability of the Boiler.

- Technical consultancy services regarding major (R&M) schemes & Life Extension Programs consisting increasing heating surface area of pressure part components, Capacity Enhancement of Coal Pulverizers & ID fans, Modification in Air Preheater & design, manufacture, supply, installation, testing, and commissioning of electrostatic precipitators to reduce dust burden keeping in view of stringent pollution control norms.

Experience:

- 38 + years of experience of Boiler Pressure Parts, ESP, Coal Mills, Air Preheaters, Fans and various boiler auxiliaries and mountings & Basic design aspects.
- Member of Committee for Studying Unchahar (NTPC) Accident & giving guidelines & directions for safe working of boilers at Maharashtra State.
- Appointed as Technical Consultant for Root Cause Analysis of ESP Explosion at Daund Sugar Ltd, Boiler at Daund, Distt – PUNE (Maharashtra).
- Appointed as Technical Consultant for Root Cause Analysis of Spiral Water wall deformation at 1x660 MW BHEL Supercritical Boiler at Bhusawal Project during commissioning.
- Worked as Co-opted Member of Seven Member Inquiry Committee for the Accidents occurred at various places mentioned below, as per Rule No. 6 of the Boiler Accident Inquiry Rules, 2021 with reference to the Senior Development Officer, Department for Promotion of Industry and Internal Trade, Ministry of Commerce and Industry, Government of India letter No. P-30018/3/2022-Boiler, dt. 13.12.2022. under the chairmanship of the Director, Steam Boilers, Maharashtra State at Gas Turbine Power Station, MSPGCL, Uran (Maharashtra), M/s. A.A. Energy, Wadsa (Maharashtra), M/s TC TERYTEX, Dera Bassi (Punjab), M/s ShreeNidhi Agro Processing, Sangli (Maharashtra).

Achievements –

- Merit rank holder for Class XII (HSCE) and BE (Mech).
- Member of Central Task Force Committee for Boiler Tube Failures (BTF) at MSPGCL for 15 years.
- Implemented Perfect Action Plan including Short-Term & Long-Term measures, Condition Assessment & adopting Best Maintenance Practices & Achieved considerable enhancement in availability and reliability of boilers & reduction in Generation Loss due to Boiler Tube Leakages (BTL)
- Member of Board of Examination of Boiler Proficiency Examination conducted by Office of Directorate of Steam Boilers, Maharashtra State.

BOILER ACCIDENTS –CASE STUDIES

SIGNIFICANT LOSSES DUE TO BOILER ACCIDENTS –

- **Human Life:** Fatalities due to explosions, burns, or other injuries. • Injuries: Non-fatal injuries, such as burns, scalds, or trauma.
- **Property Damage:** Destruction or damage to buildings, equipment, and surrounding structures
- **Economic Losses:** Costs associated with:
  - Repair or replacement of damaged equipment.
  - Production downtime or lost revenue.
  - Medical expenses for injured personnel.
  - Legal fees and compensation claims.
- **Environmental Damage:** Release of hazardous materials, such as fuel or chemicals, into the environment.
- **Reputation and Business Losses:** Damage to a company's reputation, loss of customer trust, and potential business closure.
- **Regulatory Penalties:** Fines and penalties imposed by regulatory authorities for non-compliance with safety standards.

- **Insurance Claims:** Increased insurance premiums or claims due to accidents.
- **Lost Productivity:** Reduced productivity and efficiency due to accidents or equipment damage.
- **Psychological Trauma:** Emotional distress and trauma experienced by personnel and their families.

COMMON CAUSES OF BOILER ACCIDENTS –

* **Poor Maintenance*:** Failure to perform regular maintenance, inspections, and repairs can lead to equipment failure and accidents.
* **Inadequate Training*:** Insufficient training of personnel can result in improper operation, leading to accidents.
* **Design or Manufacturing Flaws*:** Defects in boiler design or manufacturing can cause malfunctions and accidents.
* **Overpressure*:** Exceeding the recommended pressure limits can lead to boiler rupture or explosion.
* **Human Error*:** Mistakes made by operators, such as incorrect settings or procedures, can cause accidents.
* **Electrical Issues*:** Electrical faults or malfunctions can lead to boiler accidents.
* **Fuel or Combustion Issues*:** Problems with fuel supply, combustion, or ignition can cause boiler accidents.
* **Aging Equipment*:** Older boilers may be more prone to accidents due to wear and tear.
* **Low Water Levels*:** Operating a boiler with low water levels can cause overheating, damage, or explosion.
* **Corrosion*:** Corrosion of boiler components can weaken the structure, leading to failure and accidents.
* **Inadequate Safety Measures*:** Lack of proper safety devices, such as pressure relief valves or safety interlocks, can increase the risk of accidents.
* **Improper Installation*:** Incorrect installation of boilers or components can lead to accidents.
* **Material Failure*:** Failure of boiler materials, such as tubes or pipes, can cause accidents.

REPORT OF ACCIDENTS.

As per the Boiler Act, 1923 (5 of 1923),

- **Section 2 (a)** "Accident" means an Explosion of the Boiler, or Boiler Component, which is calculated to weaken the Strength or an uncontrolled release of Water or Steam therefrom, liable to cause Death or Injury to any Person or damage to Any Property.
- **As per Section 18 (1),** If any Accident occurs to the Boiler or Boiler Component, the Owner or Person In charge thereof shall within 24 hours of the Accident, Report the same in writing to the Inspector.

- Every such Report shall contain a true Description of the nature of the Accident & of the Injury, if any, caused thereby to the Boiler or to the Boiler Components or to any Person, and shall be in sufficient detail to enable the Inspector to judge the gravity of the Accident.
- **As per Section 18 (2),** Every Person shall be bound to answer truly to the Best of his knowledge & ability every question put to him in writing by the Inspector as to the cause, nature or the Extent of the Accident.
- **As per Section 18 (3),** without Prejudice to the Provisions of sub-section (1), where any Death has resulted due to any Accident, an Enquiry may be conducted by such Person & in such manner as may be prescribed by the Central Government.

CONTENT - This Case Study covers following Boiler Accidents.

Sr. No.	Name of Plant	Address	Accident Date
1.	M/S A. A. ENERGY	WADSA, DIST – GADCHIROLI	27/10/2022
2.	GAS TURBINE POWER STATION, MSPGCL.	URAN, DIST – RAIGAD (M.S.)	09/10/2022
3.	M/S T C TERRYTEX	DERA BASSI, DIST – MOHALI, PUNJAB	06/11/2023
4.	M/s ANSHUL SNACKS AND BEVERAGES PVT. LTD	BELA INDUSTRIAL AREA, DIST. MUZAFFARPUR [BIHAR]	26/12/2021
5.	M/S SHRINIDHI AGRO PROCESSING & COLD STORAGE	A/P SAVALI, TALUKA – MIRAJ, DIST. – SANGLI (M.S.)	03/12/2023
6.	3x660 MW KORADI TPS, MSPGCL	KORADI, DIST – NAGPUR (M.S.)	31/03/2019
7.	M/s MULA SAHAKARI SAKHAR KARKHANA.	A/P SONAI, TALUKA – NEWASA, DIST – AHMEDNAGAR.	25/12/2022

1. M/S A A ENERGY, WADSA (GADCHIROLI)-

- Bi-Drum A F B C Boiler with convection Bank Tubes, In-bed Tubes, Superheater, Water Cooled Furnace, Economizer.
- Capacity - 46 TPH,
- Working Pressure - 79.05 Kg/cm2,
- FSH Temp - 490 +/-5 Deg,
- Make – ISGEC John Thompson,
- Fuel – Rice Husk/ Coal.

OBSERVATIONS –

- Desuperheater pipe in between Primary super heater outlet header and Secondary super heater inlet header got ruptured.
- Secondary Superheater coils found distorted and misaligned and full of hard deposits. Secondary Superheater coils and Primary superheater coils are dislocated from their position.
- Secondary Superheater Outlet Header observed sagged by @ 125 mm, supporting saddles of the header were observed broken at few places.

- Attemperator spray line was also found detached and severely bent.
- De-superheater spray station control valve reported non-operational since last 11 months and that the spray was controlled manually.
- Temperature indicating thermowell before and after De-superheater nozzle were observed damaged.
- Supports of Primary super heater outlet header and Secondary super heater inlet header are observed dislocated and damaged.

PHOTOGRAPHS OF THE DAMAGED COMPONENTS –

Photographs of –

- Ruptured pipe showing thick lip burst,
- Spray pipe detachment and bending, • Inside surfaces of ruptured pipe, • Swelling of ruptured pipe,
- Distortion and misalignment of Secondary and Primary super heater coils.

ROOT CAUSE ANALYSIS –

- After analyzing the data it has been observed that the main steam temperature at Secondary outlet had reached 575° C and fluctuating in the range of 562° to 575° C. Moreover 125° C fluctuation in temperature observed within 7 minutes after studying in detail. This is be due to manual control of spray.
- The rupture occurred as the tensile strength at elevated temperature equaled the hoop stress from internal steam pressure.

- High metal temperature resulted into high carbon content in weld heat affected zones (HAZ) and led to material degradation.
- Long term overheating for last 11 months and short-term overheating on dated 26-10-2022 from 11:00 a.m to 04:00 a.m on dated 27-10-2022 is the root cause of failure.
- In short, the stress rupture is the root cause of failure of de-superheater header, which resulted to the accident.

RECOMMENDATIONS –

- The main steam temperature at boiler outlet is to be maintained strictly at all times as per the boiler manufacturers design data and parameters.
- The thermal analysis of the boiler is to be carried out and as per observation, the design of the superheater should be modified accordingly.
- The material of construction of PSH Outlet Header, SSH Inlet header and attemperator header should be upgraded to SA 335 P11 material.
- SSH Outlet Header to be replaced.
- In-situ metallography and plastica replica is to be carried out at Main Steam Pipe Line and Steam Turbine Casing.
- The attemperator control system to be made operational.
- In case of failure/malfunction of the attemperator control system, the boiler must be shut down immediately.
- The boiler should be operated by Boiler Operation Engineers at all times.

2. GAS TURBINE POWER STATION, URAN, DIST – RAIGAD (M.S.)

- Boiler Type - Forced circulation waste heat boiler.
- HP boiler: 208.69 tons per hour.
- LP boiler: 49.21 tons per hour.
- HP: 93 bar.
- LP: 11 bar.
- HP: 500 °C
- LP: 200 °C
- Make - M/s. STABO GMBHAT SIEGEN, West Germany.
- Year - 1991,
- Fuel -Flue gas.

OBSERVATIONS –

- Boiler was lagged, however in the vicinity of incident insulation was damaged and expansion bellow was also damaged.

- High pressure boiler circulation pump-1 was found severely damaged/ broken. HPBCP1`s electrical motor, coupling along with shaft observed thrown away at a distance approximately three meters.
- HPBCP1`s casing was pushed back from its foundation by braking foundation bolts due to back thrust and resulted into flashing of hot water and saturated steam in surrounding.
- High pressure boiler circulation pump-2 also found Shifted from its position. Suction and discharge piping of high-pressure boiler circulation pump-1 and 2 was observed slightly distorted.
- Structure of boiler adjacent to the High-pressure boiler circulation pump was damaged.

PHOTOGRAPHS OF DAMAGED COMPONENTS –

Photographs of –

- HP BCP damaged condition.
- HP BCP Electrical Motor Condition.
- HP BCP Casing Condition.
- HP BCP Suction & Discharge Pipe Condition.

ROOT CAUSE ANALYSIS –

- When a liquid flowing in a pipe is abruptly stopped by closing of a valve the velocity of the water column behind is retarded and its momentum gets dissipated due to the conversion of kinetic energy into elastic energy. A series of positive and negative waves are produced which travels back and forth in the pipe till they are damped out by friction this phenomenon is called as water hammer.

- In case of valve suddenly opened, expansions of water upstream of valve occurs and a wave of negative pressure travels up. The wave is reflected back up to the valve, again producing a wave of positive pressure which finally gets reflected.
- It becomes very clear that the process of closure or opening of valve causes additional pressures. The more rapid the closure, the more rapid is change in momentum, and hence, greater is the additional pressure developed. This additional pressure may be so high as to cause the failure of the studs of the impeller casing. (Weakest part in the circuit).
- After carrying out the detailed analysis drastic change of state of fluid from liquid to vapour and vice versa have caused large volume expansion fallowed by contraction and the system has undergone repetitive tensile and compressive stress pattern which has been subjected to cavitation.
- Cavitation involves the formation of water vapours that damage the metal components when they collapse back to liquid state. The collapse of bubbles and energy released creates the pressure jet that can strike a nearby weakest surface, potentially damaging it.
- **In this case of HPBCP-1, the drastic pressure rise has caused heavy condensate induced water hammer and steam flow driven water hammer along with cavitation which resulted in to voids, bubbling heavy shock waves and eventually failure of High-pressure water circulating pump.**

RECOMMENDATIONS –

- Periodic overhauling of High-Pressure by-pass control valve is to be carried out, to ensure proper working of High-Pressure by-pass control valve.
- In case of tripping of Steam Turbine and with improper/malfunctioning 0f High Pressure by-pass control valve, the BOILER SHOULD BE TRIPPED Immediately.
- Existing High-Pressure Boiler Water Circulations Pumps to be replaced with new pumps of appropriate design pressure considering static pressure and with reference to the boiler design working pressure.
- Stress analysis of Suction and discharge piping of Boiler Water Circulations Pumps to be carried out.
- To prevent steam cavitation in High Pressure Boiler Water Circulations Pumps and to prevent water carry over to super-heater, the drum level set points should be suitably set.

3. M/S T C TERRYTEX, DERA BASSI, MOHALI (PUNJAB) –

- Single Drum AFBC water tube boiler, with in-bed tubes, super heater, water cooled membrane panel furnace and economizer.
- Capacity -26 Tons/Hour.
- Working Pressure - 86 Kg/Sq. Cm.
- Heating Surface - 78 Kg/Sq. Cm.
- M. S. Temp. - 500° ± 5°C.

- Make - Industrial Boilers Ltd. Vapi. 2021.
- Fuel -80% Rice Husk 20% Rice Straw.

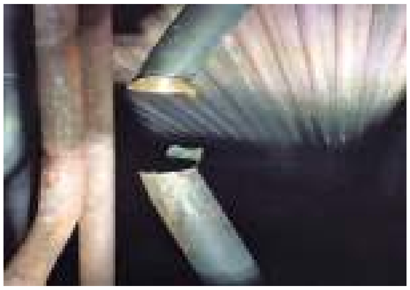
OBSERVATIONS –

- All 10 No. Riser Pipes showed sign of Overheating, i.e. Moderate Swelling at the External Surfaces of the Pipes & 5 to 10 mm. deviation in the Diameter at Top & Bottom of Riser Pipes.
- Un-burnt paddy straw was found in the super heater zone, at the Screen Tube Branch Welds and in the PSH zone.
- Economizer Water outlet Temp. is found to have risen above the Saturation temperature, indicating Steaming inside the Economizer.

PHOTOGRAPHS OF DAMAGED COMPONENTS –

Photographs of –

- Ruptured Riser Pipe.
- Top Portion of Riser Pipe.
- Bottom Portion of Riser Pipe.
- Unburnt Paddy Straw in Convective SH zone (Paralli)
- Burnt ESP Internals.
- Damaged ESP Internals.






ROOT CAUSE ANALYSIS –

- The firing of excessive paddy straw (paralli) in the boiler caused fuel carryover in the furnace. This led to secondary combustion causing overheating (localized heating) of riser pipes.
- There was a lot of fluctuation in the boiler loads. This affects the designed steam/water circulation ratios of the boiler. When the boiler is operated on lower loads the boiler has very poor water circulation in its circuits. This leads to overheating of pressure parts.
- There was persistent Load fluctuations in the Boiler which resulted into uneven mixing of Two Fuels of different densities over considerable duration of time.
- In Short, the improper mixing of the Fuels Rice Husk & Rice Straw led to Excessive Carryover & caused Secondary Combustion inside the Furnace & resulted into Localized heating of Riser Pipes.

RECOMMENDATIONS –

- The boiler operating parameters are to be maintained strictly at all times as per the boiler manufacturers' design data and parameters.
- Proper fuel mixing apparatus to be put in place for proper mixing of fuels, until such an arrangement is made the firing of Paddy Straw (paralli) should be discontinued.
- The material of construction of riser pipes should be upgraded to alloy steel material and covered in refractory.
- Flame detector should be installed in the ESP with warning alarm.
- Boiler should not be operated below 80% Load & Temperature; Draught & Flow Recorders should be provided & maintained.

4. M/S ANSHUL SNACKS AND BEVERAGES PVT. LTD AT BELA INDUSTRIAL AREA, DIST. MUZAFFARPUR [BIHAR]

- BOILER MAKER: FORBES VYNCKE PVT. LTD.
- BOILER WORKING PRESSURE: 14.50 KG/CM2 SATURATED.
- Capacity – 3 TPH.
- TYPE OF BOILER: WET BACK SMOKE TUBE BOILER.
- YEAR OF MAKE: 2019.
- HEATING SURFACE AREA: 97.14 SQ. METERS.
- FUEL: SOLID

OBSERVATIONS -

- The total area was filled with debris from boiler and its auxiliaries and the boiler house structure and roof were completely damaged.
- The Shell detached from the Boiler was found lying @ 5 Meters on the right of the foundation. The Front & Rear ends of the Shell was found sheared around the Circumference.

➢ The Front-End Tube Sheet that was sheared from Boiler Shell has distorted & was found in the premises of another factory. The Fusible Plug was found attached to the Front-End Tube Sheet.

➢ The Rear End Tube Sheet was distorted & was found @15 to 20 Meters from the Boiler Foundation. The Entire Rear End Tube Sheet appears to have been flung straight damaging everything in its path.

➢ The Furnace of the Boiler was found in the premises of another factory.

➢ Smoke Tubes were found elongated, twisted, overheated & mingled condition.

PHOTOGRAPHS OF DAMAGED COMPONENTS.

Photographs of –

1. Damaged Boiler Shell.
2. Damaged Front End Tube Sheet.
3. Damaged Rear End Tube Sheet.
4. Damaged Furnace of the Boiler.
5. Damaged Smoke Tubes.

ROOT CAUSE ANALYSIS –

- Feeding excess fuel into the boiler or disturbing the draft system of boiler abruptly.
- The malpractice of boiler operators is to blank fire the boiler over the night.
- In the evenings when the plant is about to be shut down for the day, the operators fill up the boiler furnace with fuel and close all the dampers and draft systems and steam stop valve.
- This is done to maintain temperature/pressure in the boiler throughout the night, (ambient temperature on 26.12.2020 was Min. 10 °C Max 24 °C) so that, the next morning the boiler pressure can be easily raised without much effort to meet the plant requirements.
- When the boiler is blank fired the whole night, the fuel in the furnace burns slowly with insufficient air hence causing incomplete combustion of the fuel which leads to a dangerous buildup of Carbon Monoxide in the boiler.
- **The next morning when the boiler doors are opened there is a sudden rush of fresh air inside the boiler furnace which ignites the subdued flame. This has resulted in an explosion inside the boiler.**

RECOMMENDATIONS –

- Prior to any fuel firing or after a Boiler trip, a furnace purge cycle is mandatory to clear residual combustible mixture or volatile gases entrapped in the Boiler.
- Instruments for accurate measurement of CO, CO2 & Oxygen in the flue gas needs to be installed on priority.
- Provision of Explosion door on the Gas side of the Boiler.
- Boiler Operators & Engineers should be trained to operate the Boiler as per SOPs highlighting the Dangers of such Malpractices.

5. M/s Srinidhi Agro processing & Cold Storage, A/P Savali, Taluka – Miraj, Dist. – Sangli (M.S.) -

- Horizontal multi-tubular fire box smoke tube Boiler used for Drying operation.
- Capacity -01 TPH.
- Heating Surface -27.33 Sq. Meter.
- Working Pressure -10.54 Kg/cm2.
- Manufacturer -M/s Thermax Ltd., Solapur.
- Fuel - Wood.

OBSERVATIONS –

- Boiler (Smoke Tube with front & rear TP) had been thrown away from foundation & landed @ 25-meter west side of the shed.
- Semi-circular furnace shell found separated & lying in Boiler house at left corner
- Main Shell half circular thrown away @ 300 meter at other Factory premises.
- Boiler broken into 5 pieces mainly & spread away to different locations.
- One Spring of Safety valve found outside the Boiler shed.
- The Roof of Boiler house found completely collapsed.
- The Boiler Structure Columns & Beams were found broken from its place & spread away.
- 70% wall found collapsed & bricks spread away @25-meter periphery of the shed.
- Feed pumps found thrown away towards Chimney & found in broken condition.
- Two guy ropes of Chimney found broken.
- Supply pipe of Feed Tank found broken & no water found inside.
- All ducting Fire bars found displaced from location.
- Main shell plate, Main Stop valve, one safety valve, Mobrey attachment with separated cable & Gauge glass found in damaged condition.

PHOTOGRAPHS OF DAMAGED COMPONENTS -

Photographs of –

1. Damaged Semi-circular Furnace Shell & the Main Shell.
2. Damaged Smoke Tube Boiler with Front & Rear Tube Plates.
3. Damaged Boiler Structure, Columns & Beams & Roof.




SEQUENCE OF EVENTS –

- ➢ As per regular practice and statements, the Boiler was started at 10:30 am on Dated 03-12-2023.
- ➢ Sufficient Fuel feeding was done before startup of the Boiler & Fuel ignition started at 10:30 am.
- ➢ Power Supply failure occurred at @ 11:00 am. Restoration of Power supply work
- ➢ commenced from 11:00 am & was in progress.
- ➢ Due to the Power supply failure, the Mobrey also stopped functioning.
- ➢ From 11:00 Hrs. to 12:51 Hrs. approx. 2 hours, Boiler was running with very low/ No water level, finally resulting in overheating of the furnace.
- ➢ Overheating marks on Shell have been noticed during inspection by the team.
- ➢ Due to Power supply failure, ID & FD fans and Boiler Feed pumps stopped.

ROOT CAUSE ANALYSIS –

Explosion was analyzed and examined on two main reasons, Flue gas side explosion and Pressure Parts explosion.

1. EVALUATING FLUE GAS SIDE EXPLOSION AS MAIN CAUSE OF ACCIDENT:

- During combustion from 10:30 am the reaction of Oxygen & Carbon resulted in
- formation of Carbon dioxide.
- Due to sufficient fuel, reaction of CO2 & Carbon in the fuel resulted in the formation of Carbon Mono oxide.
- Stoppage of fans created O2 deficient atmosphere, Carbon took oxygen from
- generated CO2 accelerating the formation of Carbon Mono oxide, leading to unsafe explosive atmosphere.
- As the fans were stopped, flue gases with high concentration of highly inflammable Carbon Monoxide got accumulated in the furnace.
- Ignition due to fire sparks in the furnace or auto-ignition of highly inflammable gas due to Furnace shell attaining the auto ignition temp of Carbon mono oxide led to Severe Gas side explosion Causing severe damages to the pressure part components.
- Above theory is however not supported by the findings at the site. Had the explosion taken in the Flue gas side the complete assembly of Boiler should have been thrown away to a short distance like the smoke tube bundle.
- Flue gas explosion should have caused some distortion in the fire boxes of the Boiler, they were however found in undistorted condition even after this severe explosion. Retarders in the smoke tubes found in position.
- The Dust collector was found in undistorted and undamaged condition.

In view of above attributing the cause of accident to gas side explosion is ruled out.

2. EVALUATING EXPLOSION OF PRESSURE PARTS DUE TO INSTANTANEOUS PRESSURE RISE:

- Boiler operating pressure could not be ascertained at the time of Power failure as no logbook was maintained and no witness could talk about the Boiler pressure.
- However, it can be very well assumed that the pressure might have reached the process requirement pressure as the Plant was started.
- During combustion from 10:30 am the Process plant and the Boiler came to a complete halt due to power failure at 11:00 hrs.
- Due to sufficient fuel and due to natural draught, the fuel in the furnace continued to burn even after stoppage of ID & FD fans. The feed pumps stopped working due to power failure causing low water in boiler. This led to severe overheating of furnace and Boiler.

- The overheating of the shell was to the extent that Manhole Gasket of shell was completely burnt and the wire mesh inside the gasket was also completely burnt. It is very evident from the site condition that there was very low or no water in the Boiler at the time of explosion.
- The Boiler was with active fire and low water condition for almost one and half hour.
- The electrician came the site for restoration of power at 11:30 hrs., ands as he was in the final stage of restoration of Power, explosion occurred in the Boiler House. It could not be established from the statements as to whether explosion occurred at the instance of Power restoration or the explosion occurred before restoration of POWER.
- The Fireman who died in the accident was the only person present in the Boiler house at the time of explosion. As soon as he realized that there is severe overheating of Boiler, he might have tried to pump in water by either opening the feed water valve or the outlet valve of feed water tank. (It is pertinent to mention here that the feed tank outlet valve was observed to be in closed or partially open and jam condition.)
- As soon as water was fed inside the severely overheated Boiler [either due to restoration of Power or because of feed valve opening by the operator or due to feed tank outlet valve opening by the operator causing water to enter the boiler due to the positive head of feed tank] this led to instantaneous steaming inside the Boiler resulting in severe pressurization causing explosion.
- The aforesaid theory is substantiated by the relevant observations at site.

SUMMARY OF TEST REPORT.

- According to test report of pressure parts of subject boiler submitted by M/s TCR Engineering "Though the temperature has not exceeded the design metal temperature however, spheroidization of perlite is indicated in the report which leads to conclude that overheating above the working temperature of the pressure parts has taken place."
- Failure Analysis Report No. TRC/EMD/LT-IB, dated 22-07-2024 submitted by M/s CPRI, Nagpur indicates minor growth of grain size towards steam side of shell plate due to temperature excursion which confirms overheating of boiler pressure parts.

CONCLUSION –

- All above points indicate severe overheating and over-pressurisation due to instantaneous evaporation leading to explosion of Boiler.
- The cause of accident is attributed to the poor safety awareness, slackness of management, insufficient knowledge amongst staff and operation of boiler without Qualified Boiler Attendant in immediate attendance of Boiler has led to the explosion of Boiler.

RECOMMENDATIONS –

- Boiler shall be operated with valid certificate in force at all point of time.
- Boiler to be operated by Qualified Boiler Attendants/Boiler operation Engineer as per the Heating surface area of Boiler.

- The boiler operating parameters are to be maintained strictly at all times as per the boiler manufacturer's design data and parameters.
- In case of power outage, the Fire inside the furnace must be immediately put off, withdrawn and extinguished.
- Proper Boiler water level should be maintained to avoid overheating.
- All mounting and fitting particularly safety valves shall be properly serviced/overhauled.
- In case of eventualities like power failure, alternate arrangement for supplying feed water to the boiler should be available at site.
- Before starting the boiler after a hot shut down, the boiler gas passes must be purged.

6. 3X660 MW KORADI TPS (UNIT -9), KORADI, DIST. – NAGPUR –

- Boiler Type - Supercritical, One through circulation.
- Boiler Make - L & T, M H I
- Boiler Capacity - 2151 Tons/hr. 660 MW.
- Year of Manufacture - 2013
- Main Steam Pressure at S.H.Outlet - 254.4 Kg/cm2
- Main Steam Temperature at S.H.Outlet - 5690 C.
- Fuel - Coal.

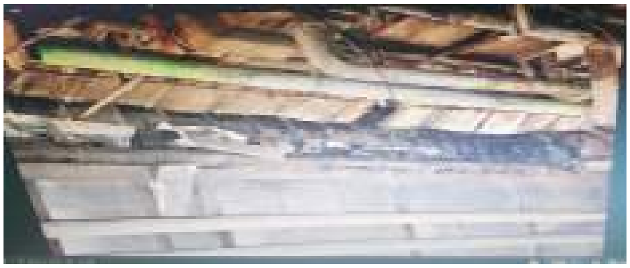
OBSERVATIONS -

- Seal plates of front, rear and R.H.S. found detached and bent.
- Seal trough was damaged and plates of seal trough found bent.
- Insulation at R.H.S. front and rear water wall found damaged.
- Buck stay near corner No.8 found bent
- 2 Nos. of panel holding hangers at corner No.5 and corner No.6 at 11 metres found distorted.
- Buck stay below seal trough at front water wall found bent at centre.
- Seal trough at about 20 Mtrs. along with of front water wall header, 13 Mtrs. along with of R.H.S. water wall header & 20 Mtrs. along length of rear water wall header found heavily distorted and damaged. Approx. 50 Nos. seal plates of about 1200 mm x 990 mm found detached from scalloped bar which are attached to furnace water wall tubes.
- S.S. wire mesh of seal trough attached through clits welded to furnace water wall tubes found detached and severely damaged.
- Front and rear water wall distorted at about 130 mm to 500 mm towards boiler and chimney respectively.

PHOTOGRAPHS OF DAMAGED COMPONENTS –

Photographs of –

- Damage of Rear side Water wall panel.
- Rear Side Seal Trough Bulging.
- Damage of S. S. Mesh at Seal Trough.
- Damage of Bottom Ash Hopper Seal Plate (Detached & Bent).
- Damage of Front, Rear & RHS Seal Plates.
- Damaged Rear side Hopper Seal Plate.



ROOT CAUSE ANALYSIS –

- The clinker accumulation at LHS side might be due to fused slag deposited clinkering whereas the heavy clinker fallen down at RHS front high elevation might be due to high temperature bonded deposit clinkering as the imported coal blended with LOCM might be having furnace clinkering indices attributed towards tendency of severe clinker formation.
- Fused slag deposited clinkering are associated with molten or sticky particles and are primarily dependent on coal composition & adjacent temp. The volatile matter % of imported coal is more and thus it proportionally increases flame length.
- The nature and amount of fused slag deposited clinkering formed on tube surfaces are mainly dependent on ash characteristics.
- High temperature bonded deposited clinkering is troublesome & they often obstruct the flue gas passes & subsequently leads to the detachment from their position at higher level to bottom ash hopper, which is the main root cause of accident occurred at RHS side of boiler.
- High temperature bonded deposited clinkering is troublesome & they often obstruct the flue gas passes & subsequently leads to the detachment from their position at higher level to bottom ash hopper, which is the main root cause of accident occurred at RHS side of boiler.
- On the basis of observations, statements, data analysis & photographs it can be concluded that the imported blended Coal playing the vital role in the formation of ash fused slag deposited clinker and high temperature bonded deposited clinker which has been observed at LHS & RHS respectively.
- In this case, falling heavy high temperature bonded deposited clinker from high elevation to the bottom ash hopper leading to furnace pressurisation and resulting into explosion of furnace and escaping out of flue gases from the seal trough at this point of critical juncture.
- After carrying out thorough investigation from all above-mentioned documents, it is concluded that at such rarest of rare occasion of falling down high temperature bonded deposit just after removal of clinker at LHS, that too when allied normalisation of work was in process.

RECOMMENDATIONS –

- Guidelines approved by Ministry of Commerce and Industry; Department of Industrial Policy & Promotion (Boiler Section) are recommended to follow strictly for prevention of such type of accident.
- Inspection of High Temp bonded deposits & its safe removal is to be carried out before commencement of Offline Fused Slag Deposit removal at Furnace.
- Usage of Coal of high ash quality imported, blended or washed should be studied for its effect in the boiler system and ash handling system. Record of slagging indices are required to be displayed in control room.
- When coal having high slagging indices are in use, then bottom ash evacuation & soot blowing frequency is required to be increased.

7. M/S MULA SSK LTD., AT – SONAI, DIST – AHMEDNAGAR.

- Type of Boiler – Bi-Drum, Water Tube.
- Boiler Capacity – 80 TPH.
- Heating Surface – 4911 Sq. Mtr.
- Working Pressure – 77 Kg/Sq.Cm.
- Final Steam Temp – 5000 C.
- Make – M/s Walchandnagar Industries.

OBSERVATIONS -

- The down comer piping in right hand side from water drum to front header failed at three different isolated locations.
- All the point of failures are outside of ash hopper. No reduction in thickness observed, no bulging due to overheating observed.
- The down comer piping which failed were subjected to only heating by convection and not in direct contact with flue gases, ash, or heat by radiation.
- The second point of failure is 900 LR elbow ahead of this pipe.
- Right hand side down comer pipe below the water drum failed abruptly,
- The portion of sheared off pipe shifted @ 8 meter away from the point of the failure, thereby causing damages to surrounding structure, platforms, and pressure parts in vicinity.
- RHS water wall panel found severely distorted in rear @ 42-45 No's tubes in length @ 10,000 mm severely distorted of @80-100 mm.
- 3 No's tubes located outside of furnace in rear side found punctured as secondary damages.
- Several piping's i.e., drain and soot blower piping damaged due to accident.
- Right hand side down comer stub with water drum found bulged.

ROOT CAUSE ANALYSIS –

- A failed portion of 450 elbow in right hand side indicates metallurgical degradation, failed portion of pipe indicates initial stage of degradation.
- Right hand side down comer stub with water drum found bulged. No significant deviation in the thickness observed. However, hardness found marginally high and slight degradation in metallurgy observed.
- In right hand side another down comer stub of 250NB with water drum developed the sub-surface discontinuity. The said down comer piping is near to water wall panel. Also, LHS DC piping supplying water to front header; joint of 45o elbow with down comer pipe found cracked and clearly visible in DP test.

- All the down comer piping within the ash hopper and outside ash hopper were subjected to thickness measurements and DP testing of all butt joints. Hardness at various locations and same were found satisfactory except for failed down comer piping hardness found marginally high.
- All the down comer piping's within ash hopper are exposed to heat mainly by conduction by surrounding ash.
- The in-situ tests carried indicates significant metallurgical degradation.
- **Erosive wear, which is one of the main causes of Material Degradation is caused by the contact of Erodent particles on the Surface of the Material.**

RECOMMENDATIONS –

- Cover the downcomer piping within ash hopper with refractory.
- 100 % in-situ metallography of all pipe fittings.
- Periodical NDT for downcomer piping within ash hopper.
- Restrict boiler output to rated output.

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