TECHNICAL LITERATURE

महाराष्ट्र शासन

सत्यमेव जयते

BOILER USER

BOILER INDIA 2022

BOILER™ INDIA 2022

14 | 15 | 16 SEPTEMBER

CIDCO Exihibition & Convention Centre

MUMBAI | INDIA

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Shri. Eknath Shinde
Hon. Chief Minister
Maharashtra State

अप्राप्यं नाम नेहास्ति धीरस्य व्यवसायिनः।

"There is nothing unattainable to the one who has courage and who works hard."

Maharashtra has always been the most industrious state and has maintained this position since long. Maharashtra is looked up as the leader in the agricultural sector, Industrial production, trade, transport system and education. The state capital is the commercial capital of India and is emerging as a global financial hub. Maharashtra is a pioneer in small scale industries and boasts of the largest number of special export promotion zones. Maharashtra has a large base of skilled and industrial labour. GOM has already decided to spend more than Four Lakh crores in the next three years on agriculture, health, human resource, transport and industry. Industries find Maharashtra an ideal destination for its knowledge based and manufacturing sectors.

Boilers are a very important part of the Industrial development. Maharashtra being more vigilant and sensitive in nature for safe and healthy practices look forward to the development ensuring adequate safety. With this preview and context, this present network and progress driven platform of Boiler India, 2022 has been made available. This futuristic opportunity presented needs to be utilized by one and all.

Wishing the best to the convention!!!

Jai Hind!!!

Jai Maharashtra!!!

Shri. Devendra Fadnavis
Hon. Deputy Chief Minister,
Maharashtra State

कल्पयति येन वृत्तिं येन च लोके प्रशस्यते सद्भिः।
स गुणस्तेन च गुणिना रक्ष्यः संवर्धनीयश्च॥

"The skill that sustains livelihood and which is praised by all should be fostered and protected for your own development."

Maharashtra is the economic power of the country and with the present post covid scenario it is expected to grow in larger proportions. The growth in the GSDP is expected to be at 18% against the 12% achieved this FY 21-22. Industrial sector shoulders as much as 46% of this responsibility. In line with the strong initiative's made by the Central government for the increase in the "Ease of Doing Business", Maharashtra is keen and devoted on this front. The Government of Maharashtra has chalk marked an 18% increase in the budget to enable the growth in both the urban and the rural development.

With the global competition in investment attraction, facilitation has been increased by the Government of Maharashtra. It has become imperative to provide seamless facilitation and world-class infrastructure to the industry and this unique convention is an important step in this direction. The work taken by the Department of Labour and Directorate of Steam Boilers to provide single platform for the Manufacturers and end users is a measure to boost the Industrial reach and develop an ease of accessibility towards the growth that Government of Maharashtra has sworn to. The growth is bifold with the manufacturers exposed to wider products and the Users getting a wide bouquet of products to choose from.

Looking forwarded to the success of the event and hence the State and Nation as a whole.

Dr. Suresh (Bhau) Dagadu Khade
Hon. Minister, Labour
Maharashtra State

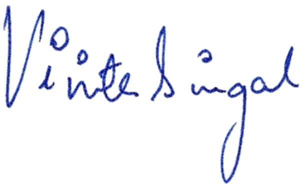
अभ्यासादेव कौशलम्।

"It is work that makes a man workman."

Maharashtra's industrial growth has gone hand in hand with the Human resource development of the State. Maharashtra is very progressive on front of professional education with a very strong base for highly intellectual and skilled manpower. Development of the society requires an all-around growth of manpower with given situation of dropout of school Students before reaching to high school, owing to different reasons, Maharashtra has developed full functional skill development society with a rigid framework instituted ensuring growth in the skill set. Directorate of Steam Boilers in this direction has contributed immensely by providing technical and skilled Boiler Attendants, Boiler Operation Engineers and super skilled Welders to the Boiler Industry.

Boilers are a very important and economical utility used in a wide variety of applications across the industry. The Directorate of Steam Boilers is setup as the primary institute entrusted with the responsibility against failures and hence any loss to the society or rather the nation as a whole. Using resourcefulness, the department is promoting the skill development to a higher level and most importantly to the under privileged strata of the society too. This present consortium is again another ingenuity of the department, leading to bring together all the different facades of the business together. Wishing good to the Boiler India 2022 initiative and great success.

Smt. Vinita Vaid Singal (IAS)
Principal Secretary, Labour
Maharashtra State



Department of Labour Maharashtra as always is a trend setter for the Nation. Maharashtra's industrial landscape has shown continuous upward movement. The onus of the above not only falls on the Stakeholders, management and the workers but also on the approach of the bureaucracy. Maharashtra has a very strong vision for the safety of the work force and this reflects in the failure figures with regards to the amount of establishments.

Boilers have a very big contribution towards the development of the industry and the society as a whole. Every facet of the industry utilizes the steam power be it the basic electricity production, pharma, FMCG sector, Glass manufacturing, to the service hospitality sector. The extremely powerful Boilers installations required more strict laws to ensure safety. Directorate of Steam Boilers, Maharashtra is not only a enforcing agency but also a developer of the holistic approach. With the immense success of the past endeavour in 2020, "Boiler India 2022" promises to be scaled up to multifold. The concentration on bringing such a big industry consisting of global market leaders, prime suppliers, dealers, accomplished academicians, experienced technocrats and service providers in this convention benefits the commercial capital of India.

Looking forward to the wonderful interaction during this convention.

Dhawal P. Antapurkar
Director of Steam Boilers,
Maharashtra State, Mumbai

यथा होकेन चक्रेण न रथस्य गतिर्भवेत्। एवं परुषकारेण विना दैवं न सिद्धयति ।।

"Just like a Chariot cannot Move with one Wheel, we cannot attain our Destiny without Hard work and Effort"

Steam Boiler have an ancient origin and have been widely used since. The utilization of boilers is on a very wide scale.

Boiler inspections in India have completed 152 years. Two serious accidents in 1869 led the foundation of present form of the Directorate The directorate has taken up the job of ensuring safety at a multi fold level. Boiler safety starts from the primary stage of construction, raw material selections, strict inspections of all manufacturing stages, correct erection, commissioning and use with appropriate and mandatory manpower deployment in the complete life cycle of the boiler.

It gives me immense pleasure to bring forth this new edition of "Boiler India 2022". The remarkable success of the event in March 2020 motivated us to go global, post the covid scenario. This year event promises to bring together the sophisticated and state of the art technologies in both the producer and the user ends. Looking forward to a fruitful interaction between all the stake holders in building of a safe work environment, stronger Industry and stronger Nation.

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SELECTION OF BOILERS & EXPLORING USE OF ALTERNATE FUELS

By Mr. Vivek Shinde, Forbes Marshall Pvt. Ltd.

Name: Vivek Shinde
Organisation: Forbes Marshall
Designation: Group Head
Education: MBA - Marketing and BE-Mechanical (Symbiosis Institute of Management and University of Pune)

Vivek Shinde leads the Boiler Business at Forbes Marshall. Over the last twenty years at Forbes Marshall, he has he has played multiple roles at Forbes Marshall in various capacities. He has played a key role in setting up new Joint Venture between Forbes Marshall India and Vyncke Engergietechniek Belgium in 2008. His major contribution has been in orienting the customer buying behaviour from a commodity purchase approach to a highly engineered purchase product approach.

In 2011 he played the role of the Divisional Manager heading the flagship SBU - Steam System Business in Forbes Marshall. Vivek has spear-headed the task force in rolling out Operations for Steam System Business in key international markets. He also plays a role in the strategic marketing and communication, product development and strategy for entry to new markets.

Basic theory of combustion

Fuels are composed of the following

- Fixed Carbon
- Volatiles
- Moisture
- Ash

Family of fuels

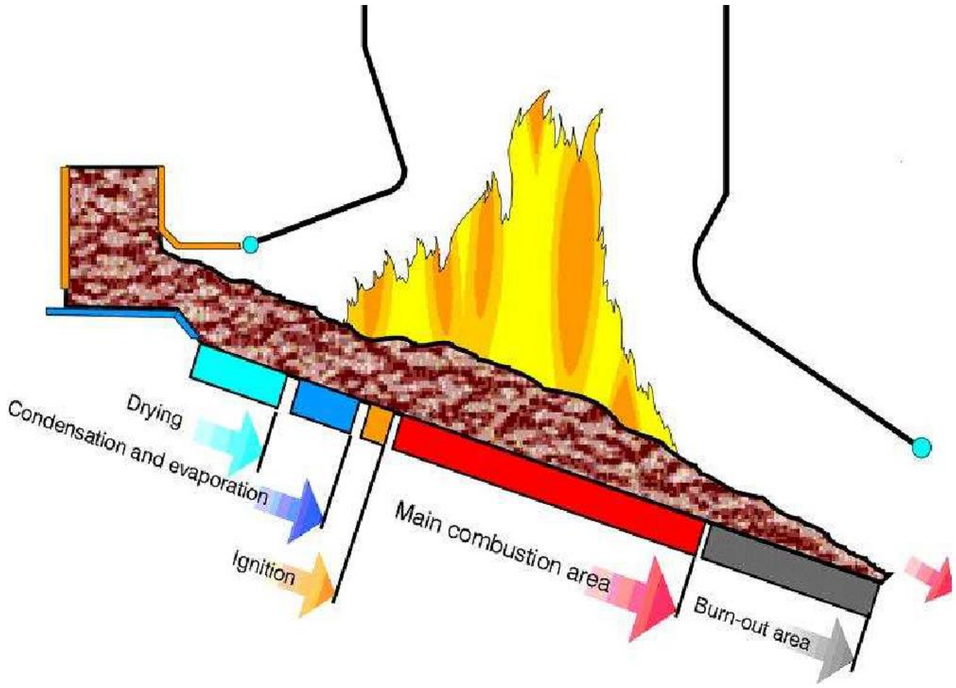
Biomass Family

Parameter	Wood	Bagasse	Rice Husk	Groundnut Shell
Fixed Carbon	14	12	15	23
Volatile Matter	54	38.8	54.68	71.2
Moisture	30	45	9.96	3.5
Ash	2	4.2	20.36	2.3
Approx GCV	3000	2800	3200	4200

Fossil Fuel Family

Parameter	Indonesian Coal	Indian Coal	Kutch Lignite
Fixed Carbon %	41.3	37.69	28.33
Volatile Matter %	35	24.41	20.67
Moisture %	19.4	7.5	36
Ash %	4.33	30.4	15
Average GCV (Kcal/kg)	5580	4000	2900

Combustion Cycle



Properties of the Fuel & their Effects

- Fixed Carbon & Hydrogen increase the Calorific Value of the Fuel.
- Moisture reduces the calorific value of the fuel.
- Volatile Matter decreases the reactive time for combustion and heat release rates.
- Ash is combustion Insulator

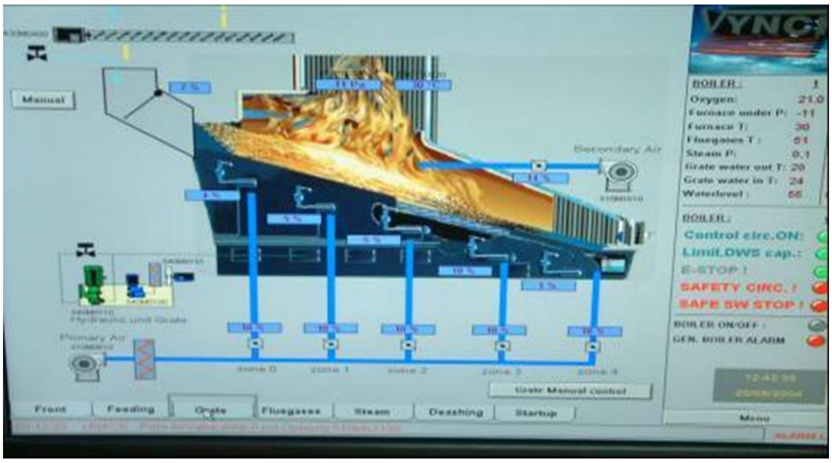
Summary of properties

- Does High Calorific Value mean Quick Combustion and Quick Heat Release rates? **No…**
- Higher Volatiles - Quick Combustion and Quick Heat Release rates.
- Higher Volatiles in fuel also have an advantage of lower Unburnts left in Ash during combustion process.
- Volatiles constitute the flame and fixed carbon are the glowing embers seen during combustion process.
- Fixed Carbon takes higher temperatures and longer time to burn.
- Size and Porosity of the Fuel - Highly porous fuels have lower energy per unit volume and require larger volume and surface for combustion.
- Active Surface Area of Fuel for Combustion - The fuel should be sized to provide the most optimum active surface area for combustion. Ideal fuel sizing is 5mm to 20 mm based on the combustion technology used.
- Fuels < 5 mm result in very high un-burnt as the fuel becomes very light and the combustion process fail to offer the desired residence time.
- Fuel > 20 mm results in incomplete combustion on account of lower Active Surface Area.
- Higher the moisture, higher is the heat lost from combustion process.

Types of Combustion

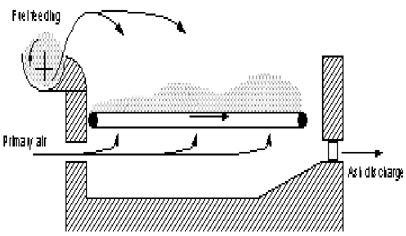
Progressive Combustion

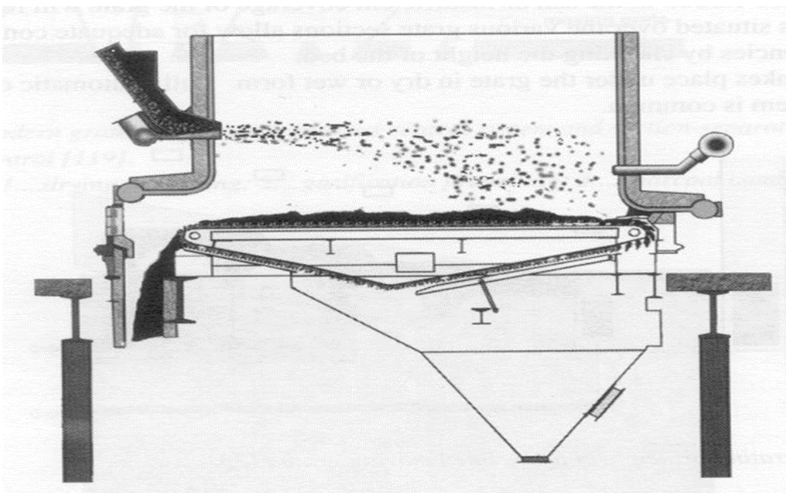
The type of combustion where there is progressive movement of the fuel and the grate and there is relative movement between grate and the fuel move during the process of combustion



Semi-Progressive Combustion

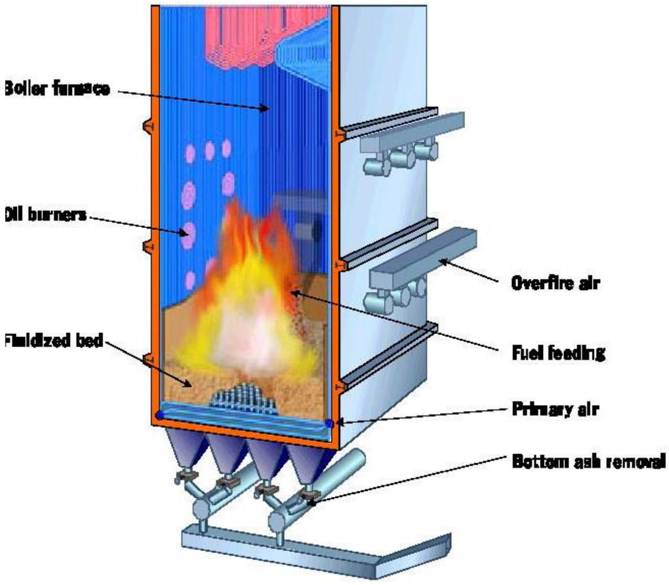
The type of combustion where there is progressive movement of the grate but there is no movement of the fuel on the grate i.e., no relative movement between grate and the fuel move during the process of combustion





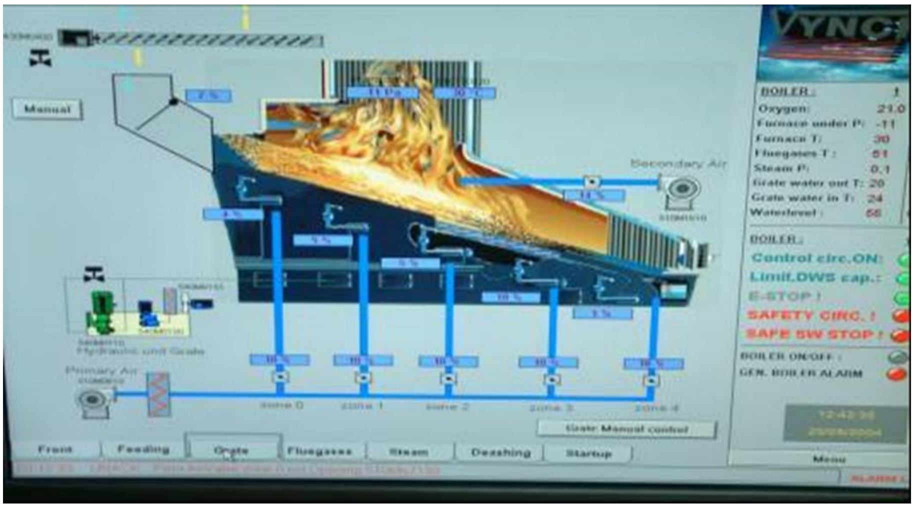
FBC

The type of combustion where there is NO progressive movement of the grate and of the fuel on the grate. and no relative movement between grate and the fuel move during the process of combustion.



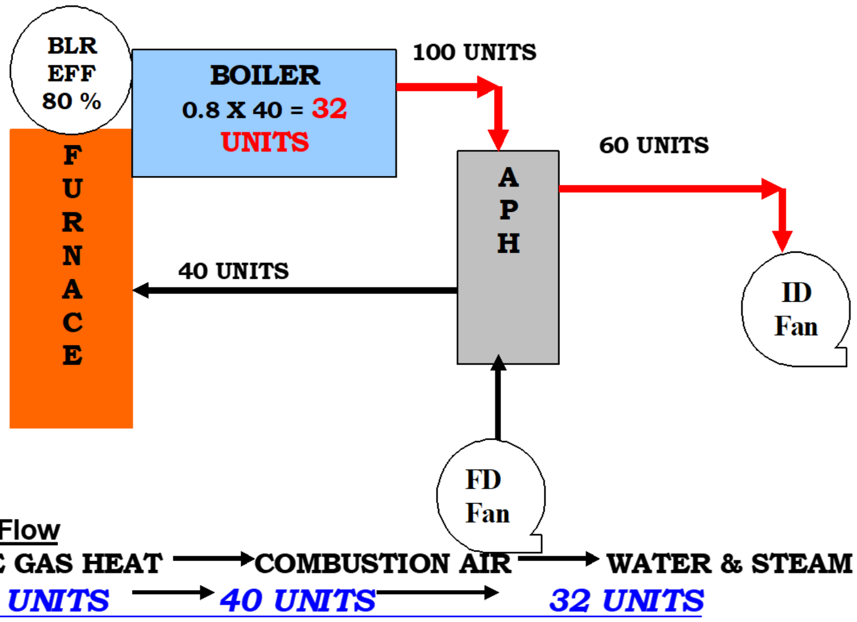
Air to Fuel Ratio Control

- Fully Automatic Fuel Control up to 30% of the load on the boiler.
- Fully Automatic Primary Air Control per Zone (4 fully automatic motorized Dampers)
- Fully Automatic Secondary Air Control (2 fully automatic motorized dampers)
- Tertiary Air Control (1 Damper)



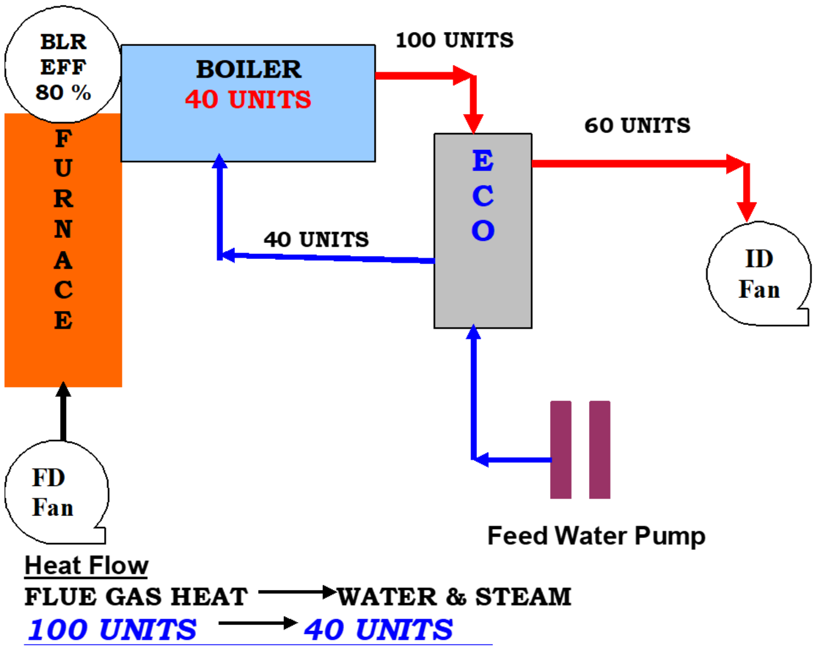
Heat Recovery Unit – APH

CIRCUIT WITH APH



Heat Recovery Unit – Economiser

CIRCUIT WITH ECONOMISER



OPPORTUNITIES OF CO-GENERATION IN PROCESS INDUSTRY

By Mr. Yohan Engineer
IB Turbo Pvt. Ltd.

Name: Yohan Engineer
Organisation: IB Turbo Pvt. Ltd.
Designation: President (Operations)
Education: PhD - Turbine Optimisation using AI (Aston University, Birmingham, U.K.)

Yohan’s profile is in new product and efficiency improvement. With over 10 years of experience, Yohan has 4 research publications in Axial Turbines & Cycle - design and optimisation.

Pressure Reducing Turbines for Incidental Power Generation

There are 2 types of steam turbines in operation within industrial plants- Power plants and Industrial CHP. Power plants suffer from poor cycle efficiency and the resultant power cost is between Rs 5-7/unit for power plants in the 3-15 MW range. Whereas Power is the only output from the Power Plant Combined Heat and Power plants have higher exergetic efficiency.

The Steam required for the Process is generated by a Boiler and passed through a Steam Turbine to generate Electricity and the heat is subsequently used by the process. These include Textile Mills, Paper Mills, Rice, Solvent, refineries, chemical plants, Sugar and Distilleries and are gaining increasing prominence today. When properly configured and designed, the Turbine can meet 100% of the Electrical needs of some plants. IBL offer their Magnum Single Drum boiler and Multiple impulse & reaction turbines for CHP applications and have over 330 installations. These plants are usually between 12 Ton/Hr to 100 Ton/Hr, with a working Pressure of 51 Kg/cm^2 and 69 Kg/cm^2 and power from 800 KW up to 10 MW.

Despite their superior economics, back pressure turbines suffer from the following limitations:

- Additional Investment – 4-5 times that of a low-pressure Boiler
- First time boiler users consider it as a “risk” and do not have appetite for it.
- Operational issues at Part load – below 60%
- Unsuitable for processes with large fluctuation in steam flow
- Standalone machines require continuous load management

This leads to some industries opting for lo pressure Boilers for their plant steam consumption.

Steam tables elaborate that Producing steam at the highest pressure ensures maximum dryness. Producing steam at a higher pressure does not require additional enthalpy, and fuel consumption.

Pressure	Saturation Steam Temp.	Steam Enthalpy	% Increase compared to 10 Bar
3	143.7	654.1	-
10	179.4	663.0	-
17	203.4	667.1	0.6 %
21	213.8	668.2	0.78 %

Steam should also be consumed at the Lowest Pressure. The Temperature of Condensate depends on the temperature of steam, which depends on the pressure of steam. E.g., Condensate from 3 Bar steam will have a lower Enthalpy than condensate from 7 Bar Steam. This can be concluded as - Consuming Steam at Lower Pressures results in reduced fuel consumption.

Pressure	Steam Temp.	Steam Enthalpy
3	143.7	654.1
7	170.4	661.3

Pressure	Condensate Temp.	Condensate Enthalpy
3	143.7	144.5
7	170.4	172.3

Pressure	Enthalpy given to process
3	654.1 - 144.5 = 509.6
7	661.3 - 172.3 = 489.0

For the conversion of steam from high pressure to low pressure, it is important to understand the importance of Entropy. Entropy is a thermodynamic quantity representing the unavailability of a system's thermal energy for conversion into mechanical work, often interpreted as the degree of disorder or randomness in the system. The entropy of an object is a measure of the amount of energy which is unavailable to do work.

For Example - you can't unscramble an egg

The T-s Diagram or Mollier chart demonstrates the change in Enthalpy and Entropy during pressure reduction

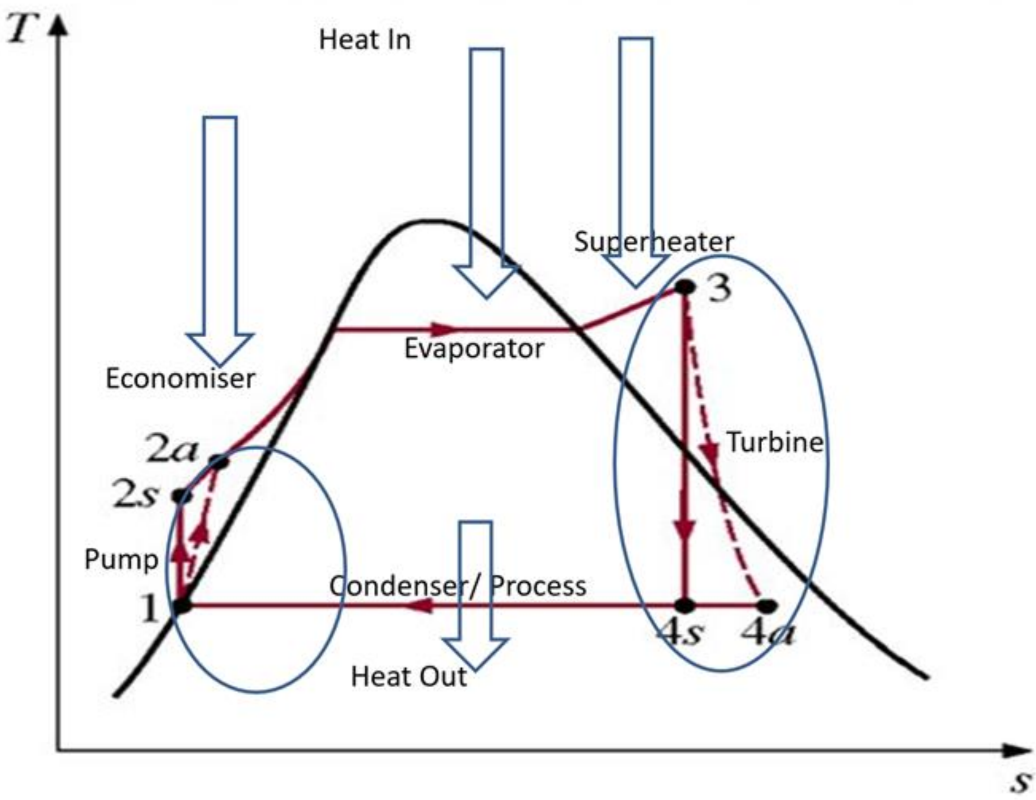


Figure below demonstrates the increase in Entropy during pressure reduction. Green line represents ideal expansion with no increase in Entropy. Red line expresses inefficient expansion with maximum increase in Entropy.

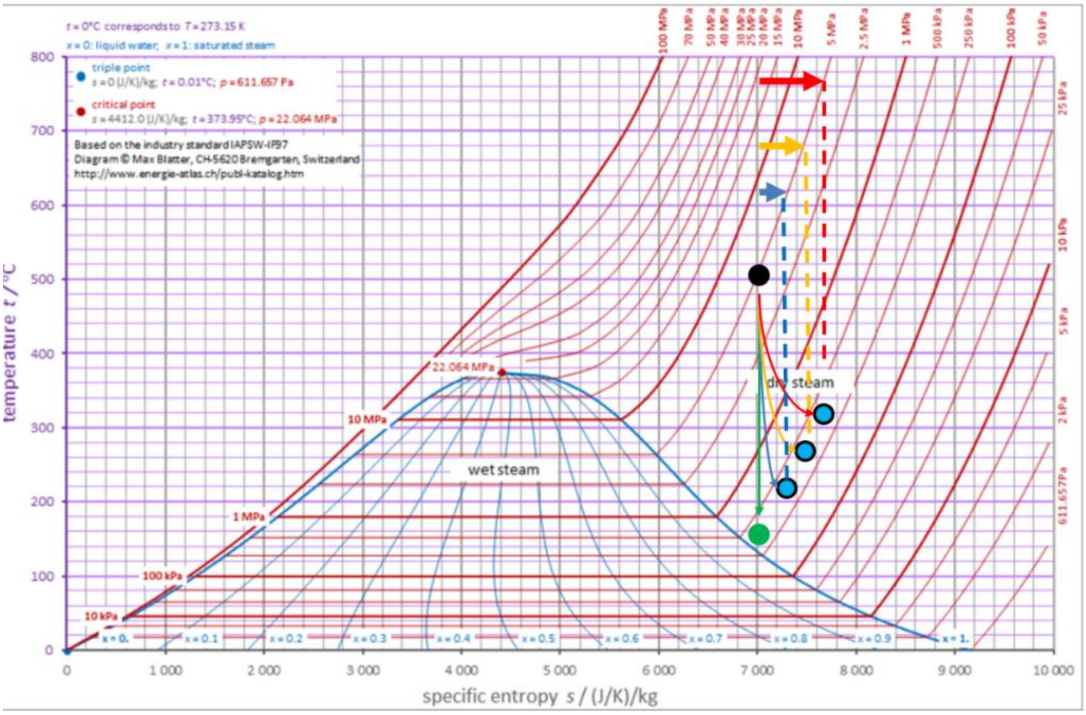
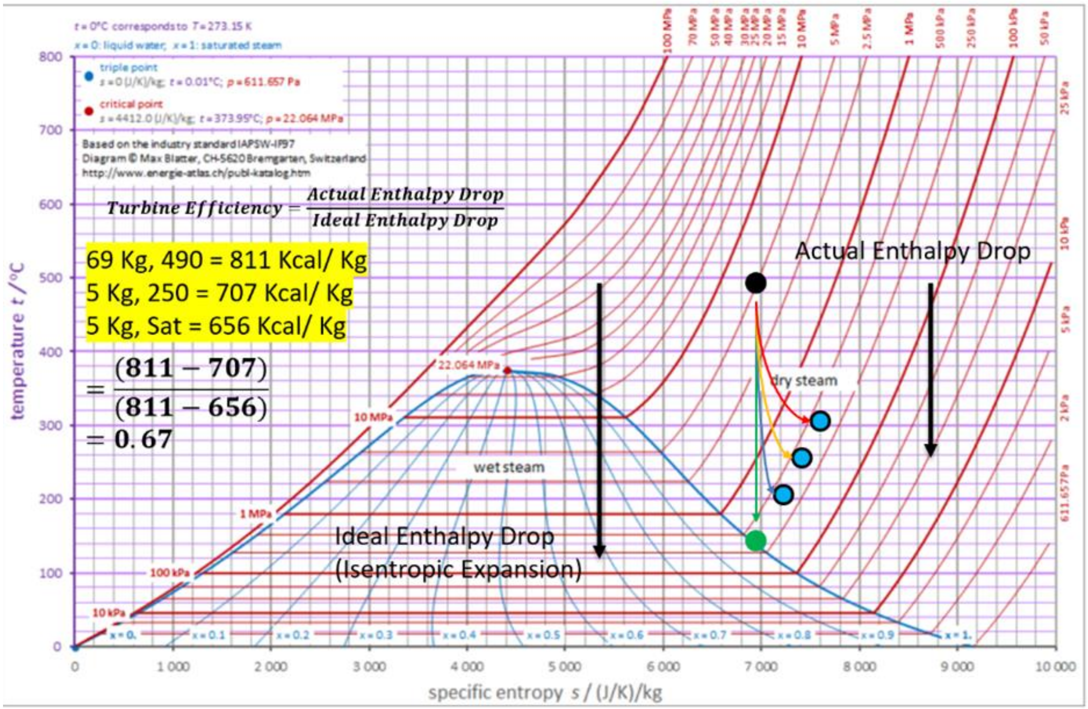


Figure below represents the decrease in Enthalpy. Green line represents ideal expansion with complete conversion of Enthalpy. Red line expresses complete conversion of Enthalpy

An Actual case with 63% expander efficiency is also shown.



Traditionally, process industries undertake pressure reduction using Pressure Reducing Valves (PRVs). IB Turbo’s PRT represents a novel way of recovering this lost energy.

A PRT is a special Purpose Turbine designed to reduce Pressure, while generating power at the same time.

	Pressure	Temperature	Entropy
	Kg/cm2a	Deg C	KJ/ K
From Boiler	10	184	6.5635
Using PRV	2	157	7.114
Using PRT	2	133.6	6.723

Entropy increases in the system using PRV = 7.11 - 6.56 = 0.55 KJ/K

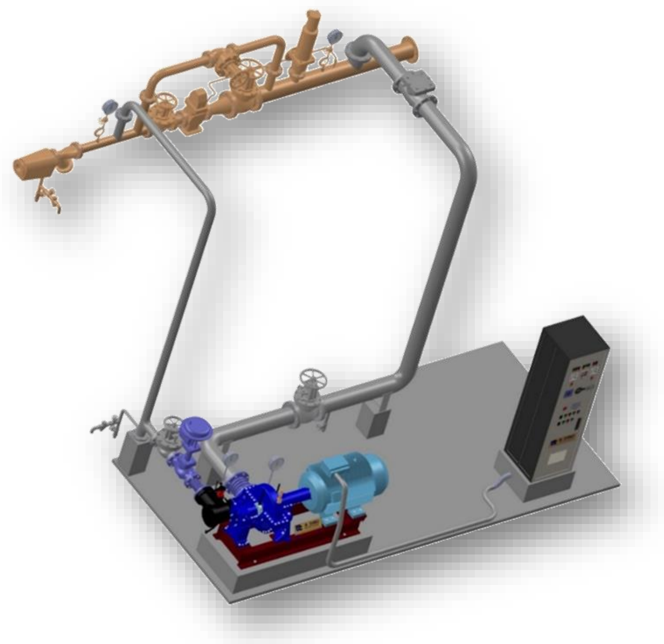
Entropy increases in the system using PRT = 7.11 - 6.73 = 0.38 KJ/K.

This means, the losses in the system are far less when we use a PRT. These losses are converted into electric Power Generation

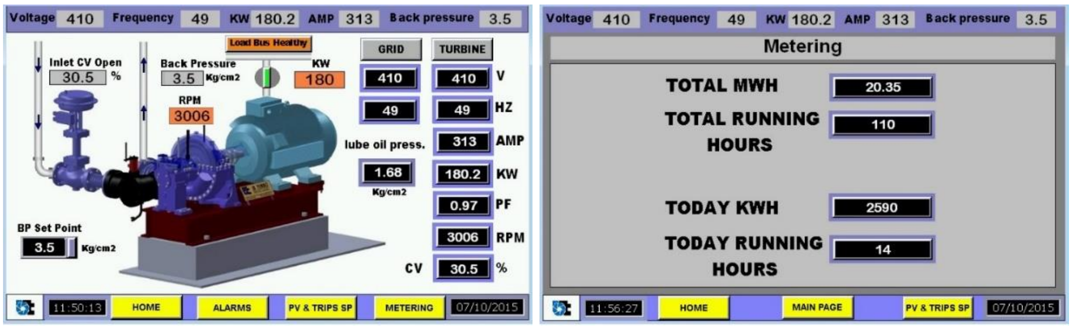
Process steam demand is maintained by control valve using a user defined back pressure set point.

Grid Voltage and Frequency are perfectly maintained by Induction Generator.

The PRT is installed in Parallel to the Standby PRDS station.



All user operation is handled via a 7" / 10" touch screen HMI display. The user-friendly display displays Turbine and Grid Synchronizing data in a clear, easily understandable format. The position of Steam flow control valve is also indicated on the display. The metering page quantifies daily & shift wise power generation, savings and return on investment.



To achieve highest possible efficiency for multiple plant configurations, IB Turbo has a range of Turbine Frames to provide the highest possible Power generation from the Customer's steam conditions.

- PRT – 4 (3-8 TPH Flow)
- PRT – 6 (8-15 TPH Flow)
- PRT – 6SS (API 611 compliant)
- PRT – 8 (15-30 TPH Flow)
- HBPRT-8

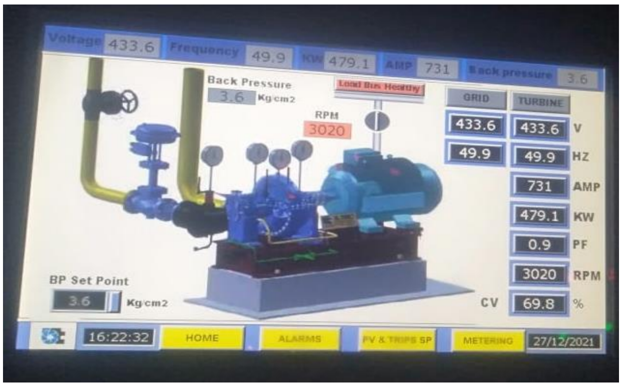
Referring to the limitations of High-pressure Cogen systems, PRTs have the following advantages:

- Additional Investment – 4-5 times that of a low-pressure Boiler
  Only 1.2x additional investment required
- First time boiler users consider it as a "risk" and do not have appetite for it.
  Good learning curve for process steam boiler users
- Operational issues at Part load – below 60%
  Can be operated as low as 30% flow
- Unsuitable for processes with large fluctuation in steam flow
  Induction Generator adjusts power generation based on process steam flow. Therefore, we call it "incidental power generation"
- Standalone machines require continuous load management to balance process steam demand
  PRT's control system varies the power generation for a fixed process set point.

Case study - Om Shree Papertek Hyderabad - 250 TPD Kraft paper Plant. Steam is mainly used for drying and pulping applications. This plant has a 17 Bar 20 TPH Industrial Boilers Ltd (IBL) make Boiler. PRT -8 frame with 450 KW Induction generator supplied in 2019.

Daily Power Generation is more than 9000 Units per day. Lifetime Power generation is 8947 MWh, considering power cost of Rs 7/unit this translates into savings of Rs 6.63 Cr over 3 years. Payback was achieved in less than 6 months. In brief, the Boiler house is converted from a liability to a profit centre.

In brief, the Boiler house is converted from a liability to a profit centre.



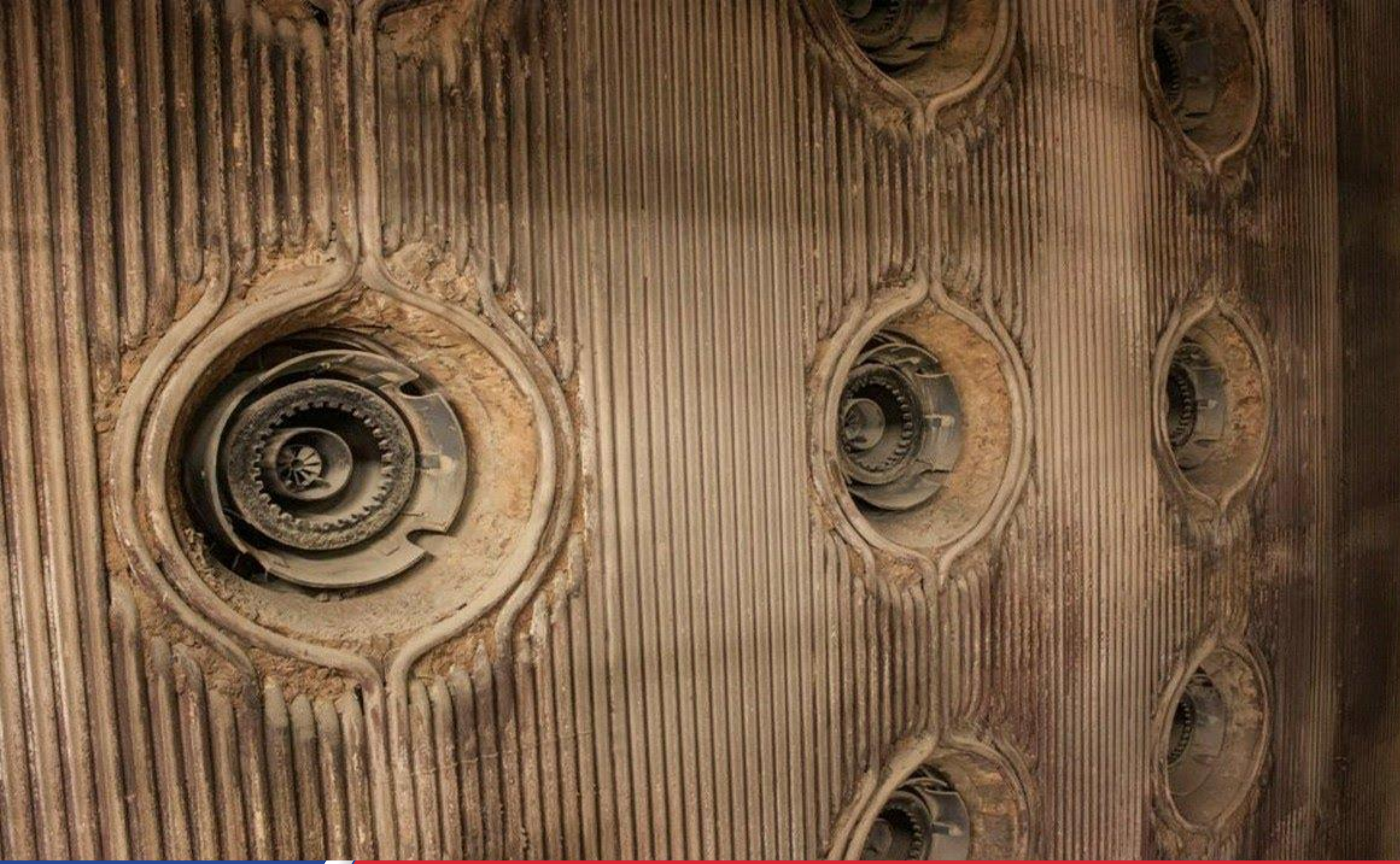
IBL has supplied 250 Low Pressure Boiler + PRT Turbine sets

Usually, they are in the range of

- 6 Ton/Hr up to 20 Ton/Hr
- Boiler Pressure of 10 Kg/cm^2 and 21 Kg/cm^2
- Power from 100 KW up to 800 KW
- Process Steam Pressure of 2 Kg/cm^2 and up to 6 Kg/cm^2

Table below elaborates the superior economics of PRTs compared to Solar PV modules

	PRT Turbine	Solar Photovoltaic
Maximum Power Generation time	24 Hr.	5 Hr.
Weather Effect	No effect	Affected by Fog, Rain and Winter time
Average Annual Generation from installed Capacity	75 %	15 %
Power generated by 100 KW system in a Year	650,000 KW	130,000 KW
Value of Power Generated @ Rs. 8.00 per KW	Rs. 52 Lacs	Rs. 10.40 Lacs
Investment for 100 KW	Rs. 51 Lacs	Rs. 60 Lacs
Maintenance Cost	Low	High
Return on Investment @ Rs.8 per KW	1 year	8 -10 years
Accelerated Income Tax depreciation applicable	80%	80%



OPTIMISATION OF BOILER EFFICIENCY & TROUBLE SHOOTING OF BOILERS

By Mr. K. K. Parthiban
Venus Energy Audit System

Name: K.K. Parthiban
Organisation: Venus Energy Audit System
Designation: Boiler Specialist & Director
Education: B. Tech in Mechanical engineering (IIT Madras), M.E in Thermal Power engineering (RECT Trichy)

K.K. Parthiban Served in BHEL, Cethar vessels Limited and in Veesons Energy systems in various disciplines such as Design, erection & commissioning of Boilers. He has over 40 years of experience in the boiler field and has the expertise in design, construction, operations and trouble shooting.

During his career he has worked as a part time consultant for Thermax limited (Pune), Nestler limited (Mumbai), Thermal systems (Hyderabad), ISGEC John Thomson (New Delhi) and Enmas Andritz (Chennai). He also offers consultation to boiler users directly for boiler procurement, Trouble shooting, and Energy conservation.

His professionally consults on design verification services for new boilers for process & power plants. His company- Venus Energy Audit System provides construction audit, shut down audit and operational audit of boilers & power plant.

His IBR approved manufacturing company Sri Devi Boiler Spares and Equipment at Bangalore supplies pressure parts spares for boilers. His another company Sri Devi Engg supplies non pressure part spares from Pollachi.

Abstract

CFBC technology is a matured combustion technology preferred for wide range of fuels & for locations where fuel quality is inconsistent. CFBC boiler availability has been disturbing at many installations. In this article, we have reviewed the subject of erosion in CFBC boilers for the benefit of the boiler design, erection and operating engineers.

Coal ash chemistry & its fusion temperature

Coal is excavated along with various non-coal material, termed as mineral matter. The mineral matter gets oxidized on combustion. It is customary to analyse the chemical constituents of the ash as listed in table 1.

The fusion temperature of the ash should be above 1200°C. There are coals with low ash fusion temperature of around 1000°C. Such coals require attention to combustion temperature in furnace. There are standard procedures to test the ash fusion temperature of coal ash. One such procedure is outlined in ASTM D 1857 / ISO 540. However, for practical purpose the coal ash can be tested in a lab furnace to know its suitability to fire in the boiler and to understand the limiting combustion temperature. Ash content of a coal is mostly tested at plant lab. This ash can be placed at 1200°C to know if it is agglomerating or not. In case the ash melts at lower temperature, the ash would become hard particle and would affect the erosion of the furnace wall panel. Such erosion will be a gross erosion of the wall tubes.

TABLE 1: COMPARISON OF ASH CHARACTERISTICS of SOME COALS							
		US coal	South Africa	Russian	Poland	Indonesian coals	
As received fuel moisture	% wt	8	8	8	8	13.9	20.5
Sulfur in coal	% wt	0.71	0.52	0.33	0.50	1.1	0.3
ash percent in fuel	% wt	17.51	14.33	11.12	14.77	8.2	4.8
GCV as fired	Kcal/kg	6214.1	5923.3	6437.34	6409.0	5532.00	4514.00
Ash Chemical composition							
Silica	SiO2	49.46	54.90	57.39	49.75	52.10	38.50
Alumina	Al2O3	26.76	29.80	20.35	25.31	26.82	16.43
Titanium oxide	TiO2	1.49	1.35	0.86	1.24	1.16	1.00
Ferric oxide	Fe2O3	3.71	5.05	5.67	8.59	10.52	9.42
Calcium oxide	CaO	7.27	2.20	5.72	4.22	1.80	9.44
Magnesium oxide	MgO	1.85	1.05	2.16	1.85	1.38	4.03
Sodium oxide	Na2O	0.50	0.24	1.26	1.15	0.65	4.73
Pottassium oxide	K2O	0.78	3.55	1.93	2.44	2.80	1.07
Sulfur trioxide	SO3	5.74	0.72	3.35	4.78	1.47	14.31
Phosphorous oxide	P2O5	1.38	0.12	1.00	0.54	0.50	0.37
Manganese oxide	MnO2	0.07	0.05	0.06	0.13	0.00	
trace metals	XX	0.97	0.97	0.25	0.00	0.80	0.70
Ash fusion temperature (reducing atmosphere)							
Initial deformation temp	Deg C	1345	>1500	1249	1210	1310	1120
Hemi spherical temp	Deg C	1375	>1500	1288	1330	1359	1140
Flow temperature	Deg C	1415	>1500	1340	1430	1470	1190
Ash nature- empirical parameters compared							
Base to acid ratio		0.18	0.14	0.21	0.24	0.21	0.51
Silica ratio		0.79	0.87	0.81	0.77	0.79	0.63
Slagging index		0.13	0.07	0.07	0.12	0.24	0.15
Fouling index		0.18	0.36	0.54	0.66	0.53	2.79
Iron loading	kg/Mbtu	5.81	6.79	5.44	11.00	8.69	5.59
Sodium content	%	0.5	0.24	1.26	1.15	0.65	4.73
Total alkali content	%	1.014	2.579	2.532	2.758	2.495	5.435
Ash fusion temp-V1<0.2 high	0.2	High	High	Low	Low	Low	Low
Deposit removal-V2>0.8 Easy	0.8	Tough	Easy	Easy	Tough	Tough	Tough
Slagging nature-V3<0.6 Low	0.6	Low	Low	Low	Low	Low	Low
Fouling nature V4<0.2 No	0.2	No	Yes	Yes	Yes	Yes	Yes
Iron loading, V5>0.3 high	0.3	high	high	high	high	high	high
Alkali per 10^6 kcal		0.286	0.624	0.437	0.636	0.371	0.580
Fe2O3 Per 10^6 Kcal		1.045	1.222	0.980	1.980	1.565	1.006
Quartz: Sio2/Al2O3		1.85	1.84	2.82	1.97	1.94	2.34
Qc,Quartz content 0.01*ash*(SiO2-1.5Al2O3)		1.63	1.46	2.99	1.74	0.98	0.67
Pc,Pyrite content 1.2*(S-0.3)		0.49	0.27	0.03	0.24	0.96	0.00
Abrasion Index Qc + 0.5*Pc + 0.2*Ac		5.38	4.46	5.23	4.81	3.10	1.63

Operating temperature of the CFBC furnace

The operating temperature of the CFBC furnace is dependent on how much evaporating and superheating surfaces are placed in the furnace. In addition, the furnace heat absorption is a function of the fines content in the circulating bed ash / material. Heat transfer in upper furnace is dependent on the amount fines in the upper furnace. The fines content is influenced by many factors. They are:

- Ash content in coal: When the ash content is less than 8%, there can be less fine particle addition from ash. This may not match the depletion from the furnace. This would result in less upper furnace inventory and thus leads to higher combustion temperature. Upper furnace inventory is known by the difference in furnace pressures between kick off zone and cyclone inlet. This is usually in the range of 80 -125 mmWC. Photo 1 shows the case with sufficient solids in the upper furnace.

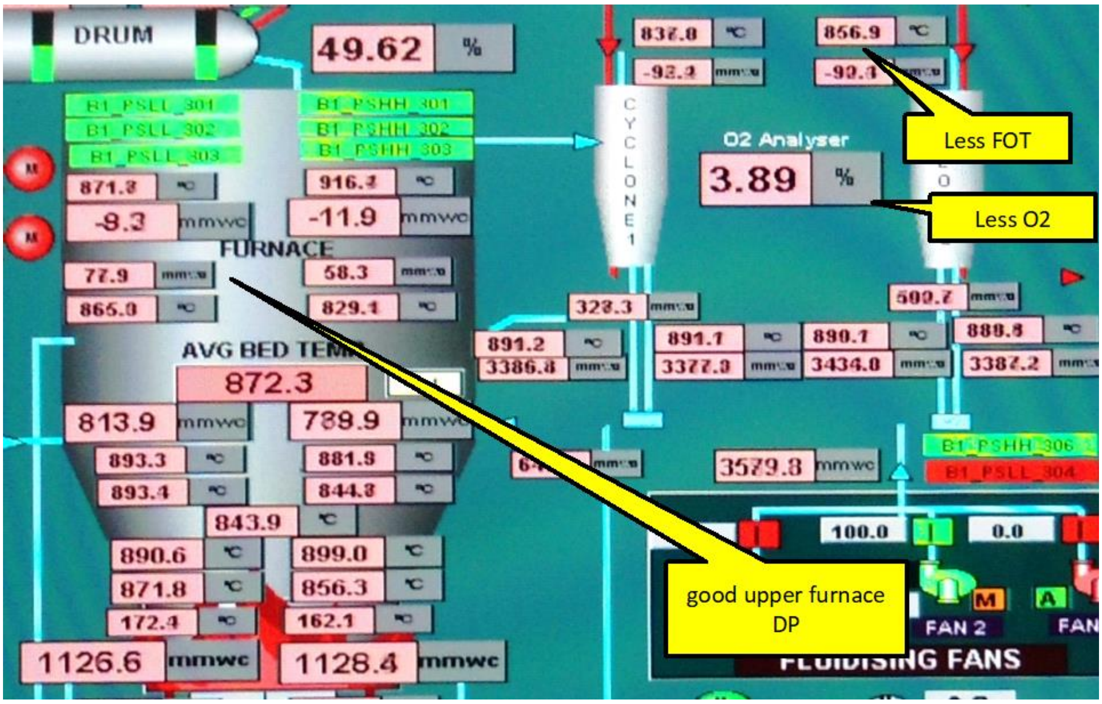


Photo 1: The above shows the upper bed DP of 78 mmWC. The average bed temperature is 872°C. The oxygen in flue gas is under control.

Photo 2 shows the case where the upper furnace DP is 17 mmWC. Less upper furnace DP leads to high FOT and demands high oxygen % to keep the temperature under control. Operation with high EA increases the erosion rate.

Photo 2: The upper furnace DP is hardly 17 mmWC. The cyclone outlet temperature is 936 & 945°C even with O2 at 6.34%. The cyclone had not been performing well or the solids input from fuel had been less. It is net retention effect of addition, depletion of fine solids to furnace.

- Feed coal particle size distribution: Depending on the top size of coal particles from coal handling plant, fines percentage will be present in the feed coal. High ash coals would have hard ash particles which do not break down in furnace. Less fines in the input coal would lead to high combustion temperature. Loop seal temperature & furnace exit gas temperatures run high. See photo 3 showing the wide temperature profile & high oxygen % due to use of high size particles as specified by the boiler maker.

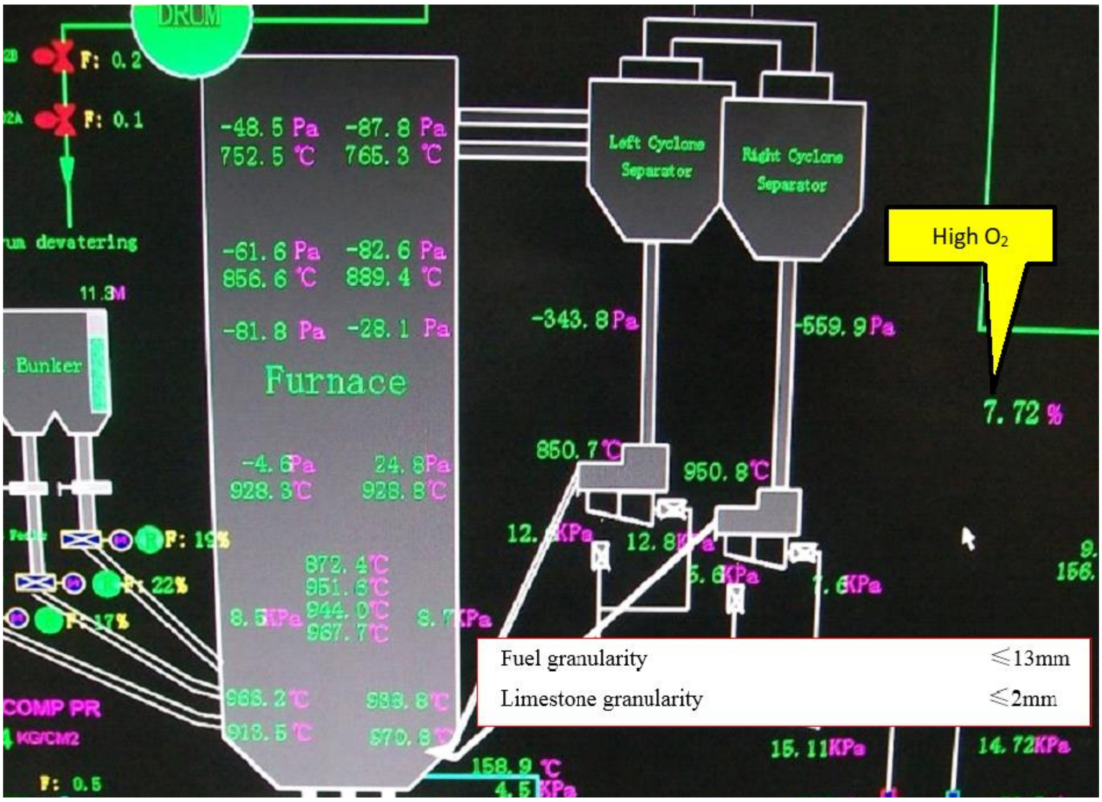


Photo 3: The above is a case of wrong specification of fuel. The supplier had specified coal particle size as 13 mm. The upper furnace DP has been only 60 Pa. This is too less. The oxygen level is 7.72%. The loop seal temperatures differ by 100°C. Furnace bottom to top temperatures show 200°C difference. Altogether the boiler was not working as CFBC.

- Percentage sorbent (limestone) addition: For sulphur containing fuels, limestone is used for SOx capture. The fineness and composition and the percentage addition would decide the combustion temperature.
- Cyclone collection efficiency / cut off particle size- the design of cyclone is critical for low ash coals. When the fines leave the furnace, the combustion temperature would raise. Fly ash particle sieve analysis proves the efficiency of cyclone. Radial and volute entry configurations have been used by boiler maker. Volute entry with proper velocity would have the best collection efficiency. Boilers with less ash input needs an efficient cyclone. In one case, the cyclone profile was changed by us to improve the collection efficiency. Figures 1 & 2 show two cases with poor cyclone design.

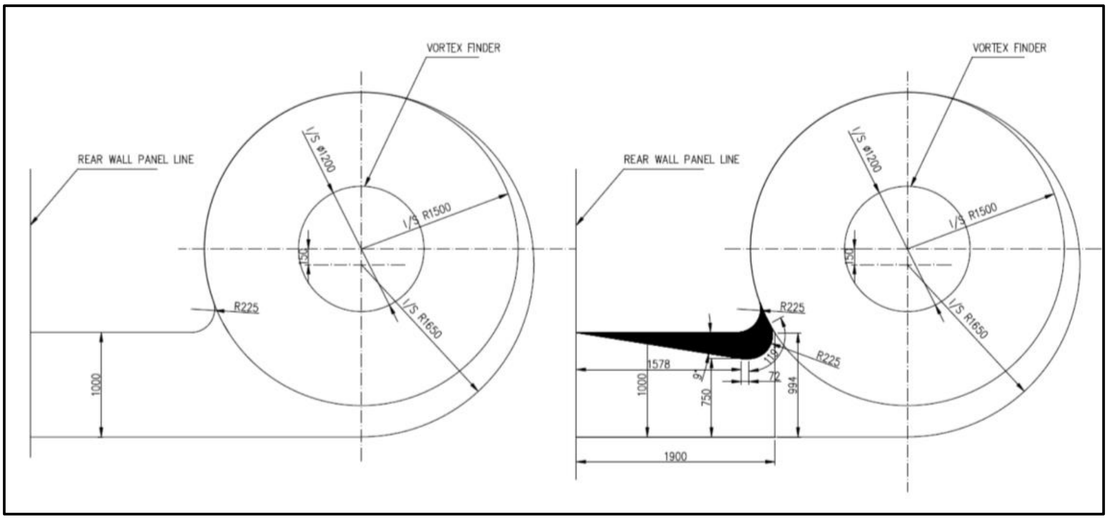


Figure 1: The above photo shows the modification of the radial entry cyclone with volute entry. The +90 micron particles in ESP fly ash came down from 25% to 9% after this modification. Otherwise, the loss of fines from the furnace was high and furnace exit temperature had been +950°C. The exit temperature came down to 875°C after the modification.

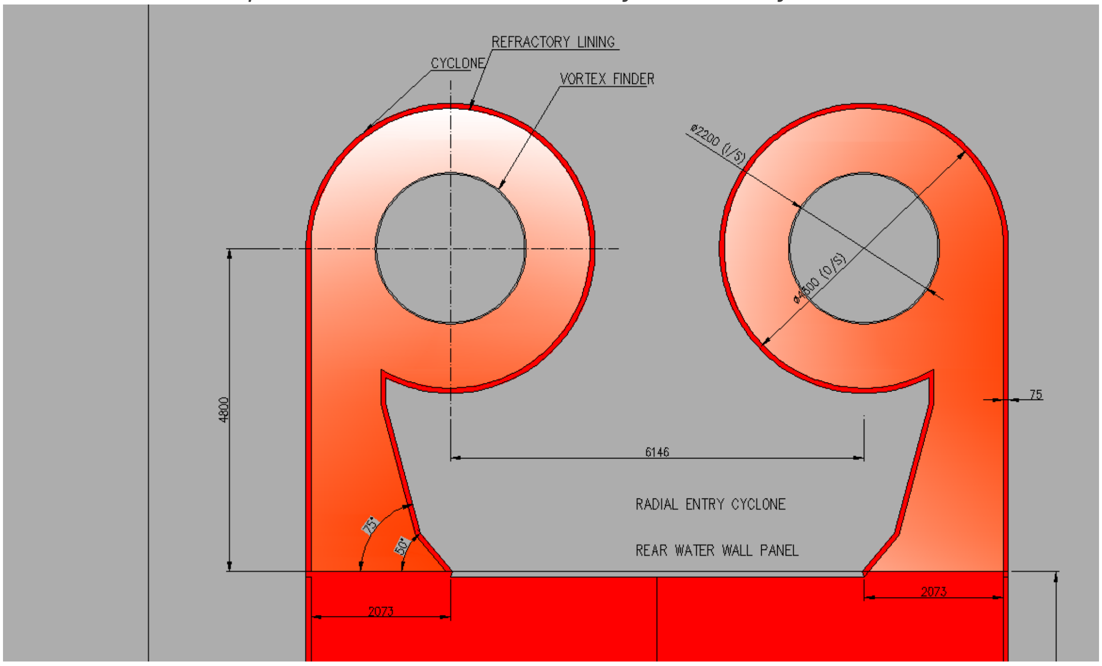


Figure 2: The cyclone configuration shown is a radial entry cyclone which resulted in a poor collection efficiency. This demanded the cofiring of high ash Chilean coal along with the design Indonesian coal. Otherwise, the bed inventory retention was very poor.

We recommend the fly ash is regularly monitored by sieve analysis. See a sample report.

Fly ash sieve analysis report						
Date & Time	Sieve Size					
	Unit-1			Unit-2		
	>90micron	>75micron	<75micron	>90micron	>75micron	<75micron
6.8.2014	12.5	8.5	79	-	-	-
7.8.2014	12.5	8.5	79	1.5	5	93.5
8.8.2014	7	6	87	2	3.5	94.5
9.8.2014	11	8	81	1.5	4	94.5
10.8.2014	10.5	8.5	81	2.5	5	92.5

- Ash removal rate from furnace / loop seal – inadvertent excess draining of bed material leads to high combustion temperature. A brief period with high furnace temperature can turn the ash to fuse and become harder.

Make up bed material

Make up of bed material will be required for low ash coals and in case, where the cyclone collection efficiency is not designed as per low ash input from coal. In case the bed material contains minerals that fuse at low temperatures, then the bed ash becomes harder. The hardness of the bed ash will increase the rate of erosion.

Recommended make up bed material size	
Microns	*% pass thro*
<600	100
<400	90
<300	50
<250	10

Make up bed material should have fusion temperature above 1200°C. The particle size range for start-up can be 0.5 to 2.35 mm. However, for make-up purpose, the bed material should be < 600 microns. See recommendation in table here.

Bed ash reclamation and external recycling system

CFBC boilers fired with low ash coals are sometimes equipped with bed ash reclamation system. Such a system should have a magnet system to separate iron from the ash. This depends on the coal. If the coal contains pyrite, such a system is required. There have been cases where the 3mm sq. screen size had been selected. The screen opening size can be 1.5mm sq. only. Photo 4 shows a bed material ash reclamation system with magnetic separator.

Photo 4: Drum type magnetic separator is used at plant to separate iron from bed ash. This will help to avoid rise in iron in solids inventory in the furnace. This is applicable for pyrite containing coals.

Bed ash parameters to check

Whatever be the coal fired or bed material used or sorbent used, ultimately there are some bed ash parameters to be monitored to prevent erosion damage to the furnace wall tubes / wingwall evaporator / wingwall SH panels. They are:

- Bed ash bulk density: Bed ash bulk density is usually in the range of 1400-1450 kg/m^3 due to high fines being retained in the furnace. Yet when the ash contains high iron (usually comes in to the boiler as pyrite), the bulk density can reach 1650 kg/m^3. The erosion rate of the furnace wall tubes will be higher due to iron accumulation.
- Bed ash iron content: As explained above the iron that comes as pyrite tends to accumulate in the furnace. This increases the erosion rate of the furnace tubes. This will be a gross erosion. It is a must that iron particles are restricted to 10%. The iron particles are to be separated by a magnet.
- Bed ash sieve analysis: There had been a mistake in particle specification by some boiler makers. The coal handling plant should be selected without a pre-screen system in the case of low HGI coals. Different coals produce different fines percentage on crushing. For CFBC fines are preferred. In case of higher percentage of coarser

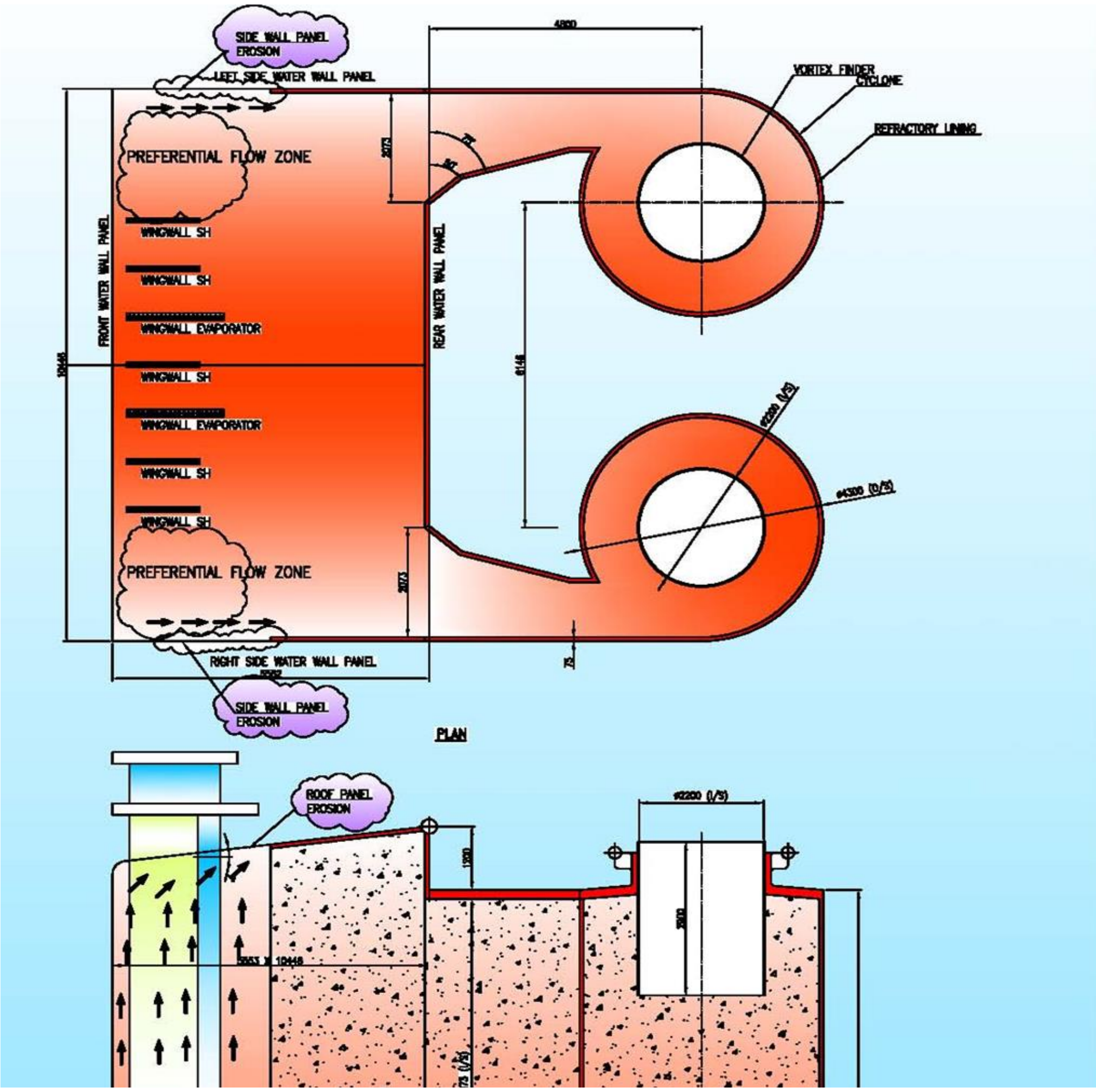
particles, say +3 mm, the bed expansion is limited. This leads to high bed temperature. In addition, coarser particles cause high erosion rate. It is general requirement that all particles are less than 6 mm with minus 1 mm in between 30% & 40%. By draining at controlled manner, the coarser particles can be taken out of the furnace inventory. Large size drain pipes tend to remove fines also from the bed. Gates should be throttled so that only coarser particles are taken out.

Loop seal malfunctioning

- Higher capacity boilers are fitted with two cyclones. In case a loop seal is plugged, the bed temperature would rise. This causes the bed material to become harder. The boiler may continue to generate rated steam with rise in furnace temperature. There are cases of fallen vortex finder and the boiler continued to operate.
- In the case of single cyclone, the transfer rate could be disturbed due to partial plugging. On full plugging of the loop seal, there will be uncontrollable bed temperature rise. This can be known only by proper and adequate instrumentation at the loop seal. Due to partial plugging, the bed temperature can rise. Plugging can occur due to any of the following reasons.
    - Nature of sorbent
    - Inadequate air flow at loop seal
    - Plugging of air nozzle
    - Failure of air nozzle and filling of loop seal windbox
    - Refractory spalled from above or at the loop seal itself and affecting material transfer

Inlet configuration to cyclone preferential erosion of side walls

- The gas inlet configuration to cyclones can cause erosion of the side walls. See figure 3. The gas flows along the side walls before entering in to the cyclones. The side wall panel gets eroded due to this effect. See photo 6 showing the side wall erosion.



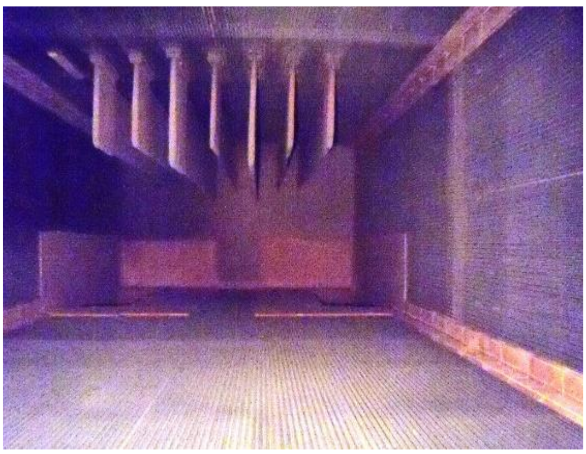


Figure 3: The above figure shows a boiler with two cyclone system. The erosion is seen in side wall panels, because the entry to cyclone is along the two side walls. Erosion was experienced at roof panel also in the cavity zone in front of cyclone entry

Photo 5: The photo shows the cavity on either side of the wingwall panels as viewed from furnace below. Photo shows the refractory lining at roof. The roof eroded at location shown. See photo 8 as well.

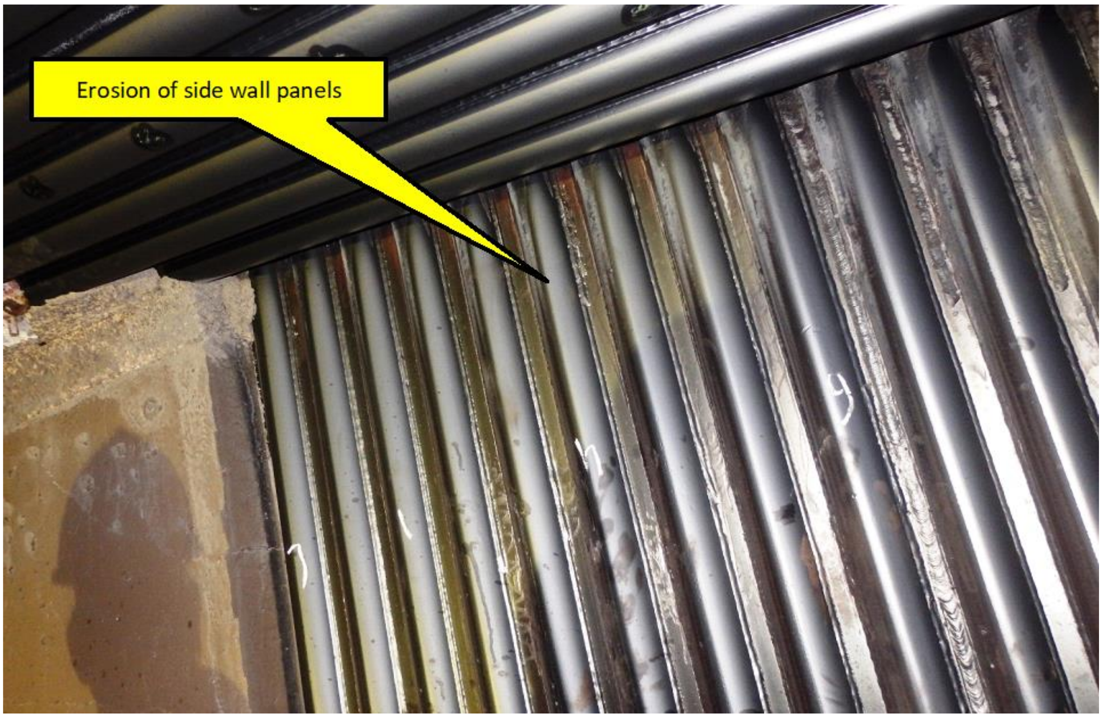


Photo 6: The above photo shows the erosion of side wall panels in the boiler with cyclone entry configuration as in figure 3.

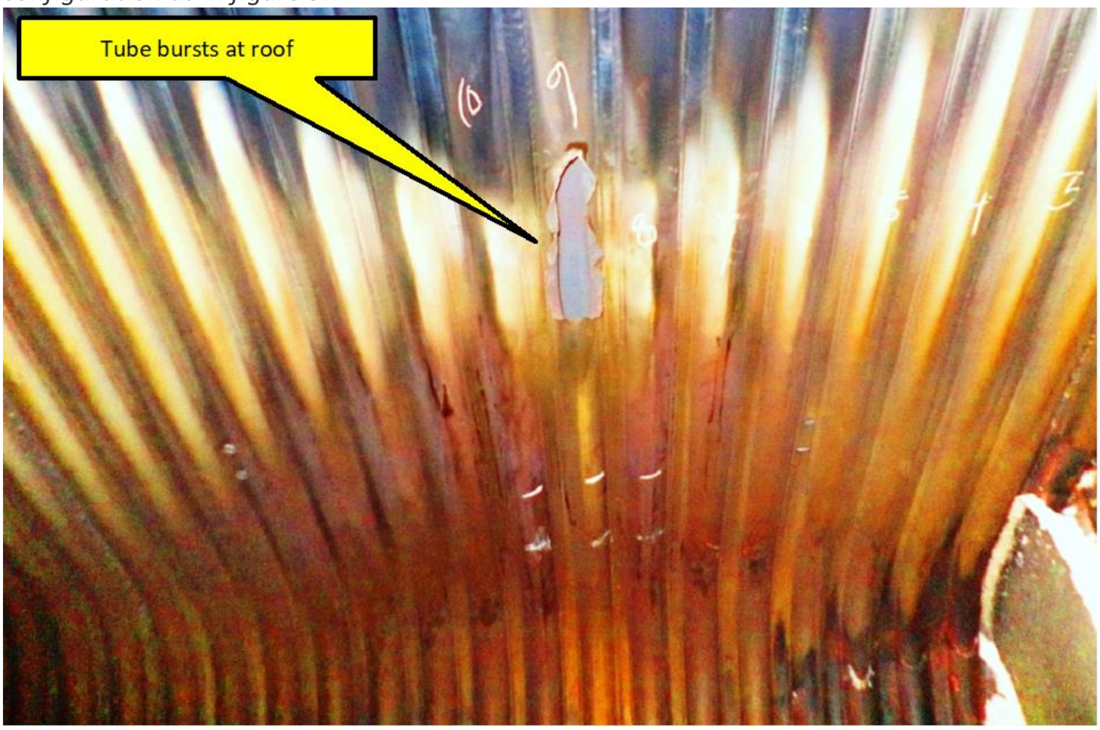


Photo 8: The above photo shows the eroded roof panel & the burst roof tube. The arrangement of wingwall SH / Evaporator had allowed preferential gas flow as shown in figure 3.

- The cyclone inlet wall angle can be altered as in figure 4. Some manufacturers are yet to adopt this feature.
- In figure 5, the cyclone entry is at the centre. This may cause the material to drop out along the side walls, depending on the % width open at rear wall. Not all the bed inventory enters cyclones. Some fall out of stream. This cause internal recirculation of solids. This is the reason some part of the side walls and rear wall panels are refractory lined.

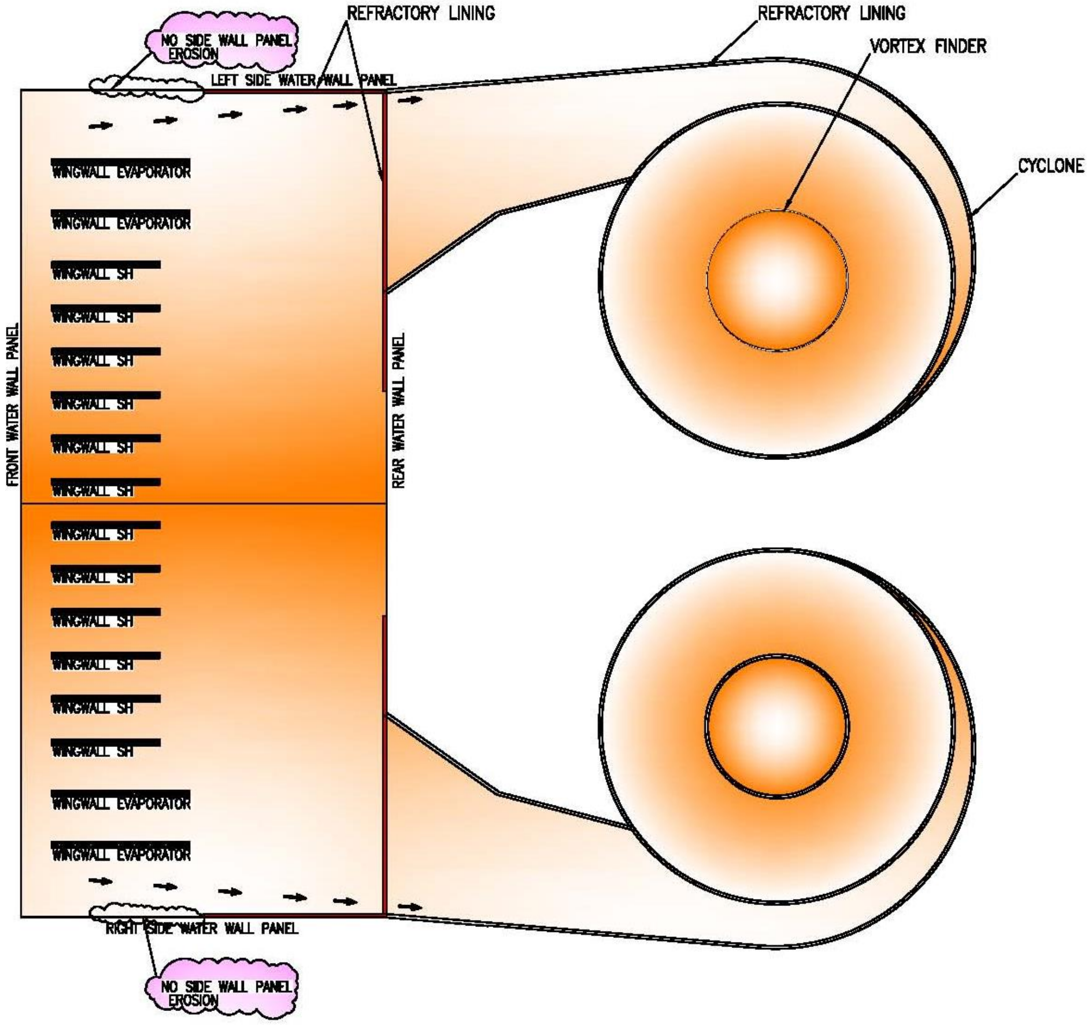


Figure 4: The above shows a boiler with two cyclone system. The erosion along the side wall is prevented by the design of the cyclone inlet wall plane. The gas entry to cyclone is volute. This cyclone was found to perform well. The +75 microns particles were the least in this unit.

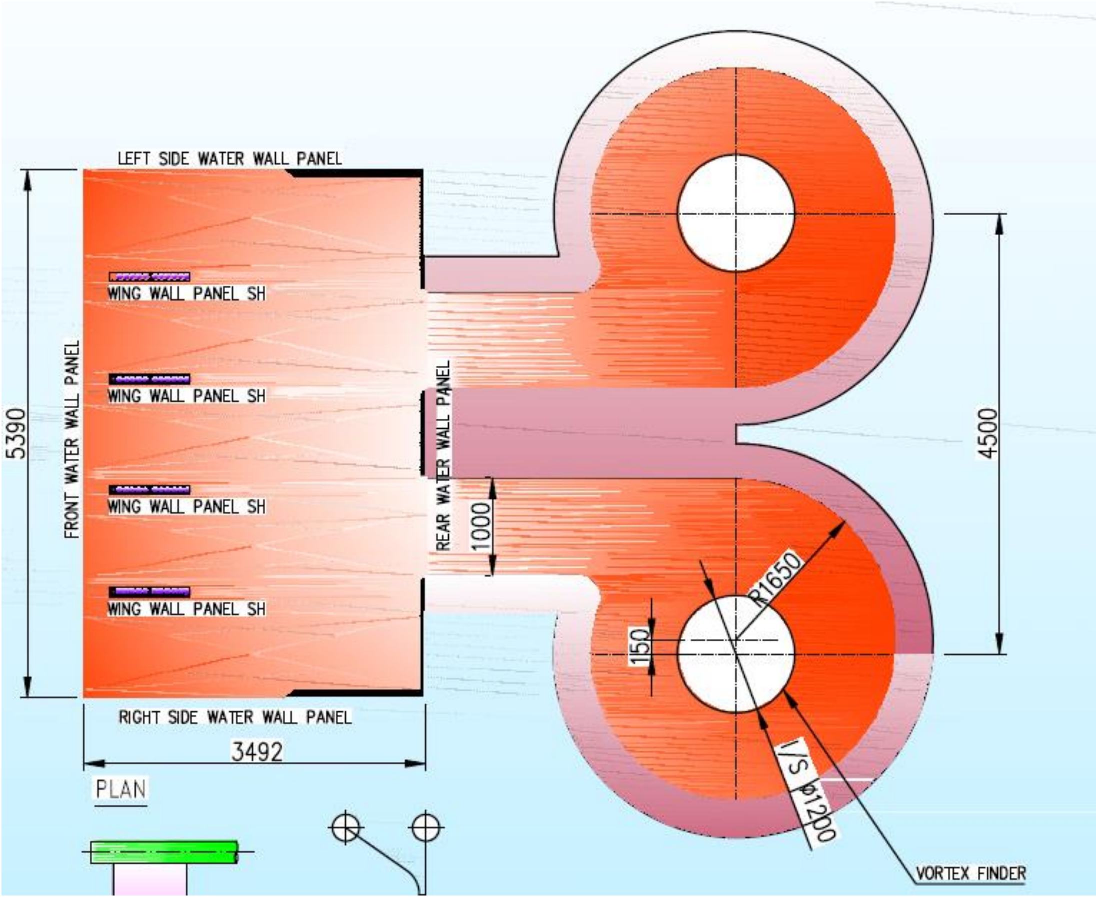


Figure 5: The left side figure shows central entry to cyclone. This prevents the erosion of side wall tubes. But this can increase the dust flow towards side corners. If the entry is wider, this problem would not be experienced.

Arrangement of wingwall panels

The arrangement of the wingwall panels should be equally spaced. Too close a spacing can cause preferential internal recirculation of solids. Figure 3 shows the boiler, wherein uneven arrangement of wingwall panels have resulted in preferential gas flow and resulted in thinning down of the roof tubes. Photo 8 shows the roof tube failure in the above case. Figure 6 shows the thickness mapping when the erosion failure occurred at this boiler. Around 20 tubes from each side wall only shows up erosion. The thinning has taken place within 2 years of boiler operation.

TUBE NO	Lj	Li	Lh	Lg	Lf	Le	Ld	Lc	Lb	La	L	L1
1					5.0	4.9	5.0	4.9	4.8	5.2	5.2	4.9
2				4.0	4.5	4.4	4.0	*	*	3.5	3.9	4.9
3	3.9	3.8	3.7	3.5	3.7	3.4	2.2	*	*	2.6	3.3	4.4
4	4.0	4.5	3.7	3.7	3.2	2.9	1.6	*	*	2.1	2.9	3.9
5	4.0	3.9	3.7	3.5	3.4	2.9	2.4	*	*	1.5	2.1	3.1
6	3.9	3.8	3.7	3.5	3.3	2.9	2.7	*	*	1.8	1.5	3.3
7	3.9	3.7	3.4	3.2	3.2	2.1	2.1	*	*	2.0	1.4	3.2
8	3.9	3.9	3.4	3.5	3.1	3.0	2.4	*	*	2.8	1.2	2.7
9	4.7	4.5	3.6	4.0	3.3	2.8	2.7	*	*	2.1	1.4	2.2
10	4.3	4.2	4.3	3.9	3.9	3.3	3.7	*	*	1.5	1.8	1.5
11		4.3	4.0	4.3	3.3	3.5	3.2	*	*	2.9	1.6	2.8
12			4.4	4.0	4.1	3.2	3.7	*	*	2.4	2.2	3.4
13					4.1	4.0	3.6	*	*	2.4	2.0	1.4
14					4.4	3.9	3.7	*	*	2.6	2.2	1.2
15					4.2	3.7	3.2	*	*	2.7	2.7	3.3
16					4.2	4.2	3.9	3.8	3.2	2.8	2.8	3.3
17					4.4	4.0	4.0	4.0	3.4	3.1	3.1	3.5
18						4.0	4.2	3.7	3.7	3.1	3.2	3.7
19						4.0	4.0	3.9	3.6	3.5	3.2	3.6
20						4.4	4.2	4.0	3.8	3.5	3.5	3.7
21							4.3	4.5	3.8	4.0	3.9	4.3
22							4.6	4.3	4.3	3.9	3.9	3.9
23							4.5	4.1	4.1	3.8	3.6	3.2
24							4.2	4.3	3.9	4.0	3.9	4.2
112			4.9	4.9	4.9	4.9	4.9	4.4	4.6	4.4	4.2	4.5
113			4.9	4.9	4.9	4.8	4.7	4.4	4.2	3.3	3.4	4.1
114			4.6	4.6	4.5	4.5	4.2	4.1	3.8	3.6	3.3	3.8
115			4.9	4.6	4.5	4.7	4.5	4.1	3.4	3.7	3.3	3.8
116			4.9	4.8	4.6	4.5	4.2	4.0	3.8	3.3	2.9	3.5
117			4.7	4.7	4.4	4.6	4.1	3.6	3.2	2.9	2.4	3.1
118			4.8	4.5	4.3	4.5	3.9	3.8	3.6	3.2	2.8	3.1
119			4.8	4.8	4.3	4.5	3.8	3.7	3.4	2.8	2.5	2.7
120			4.6	4.8	4.3	4.3	3.8	3.5	3.4	2.9	2.6	2.4
121			4.6	4.5	4.3	4.6	4.1	2.4	2.2	2.7	2.3	2.4
122			4.9	4.5	4.2	4.2	3.6	3.1	2.9	2.3	1.9	2.9
123			4.4	4.4	3.9	4.1	3.5	2.9	2.6	2.1	1.8	2.2
124			4.3	4.1	3.7	3.9	3.3	2.8	2.4	1.9	1.5	2.0
125			4.3	4.1	3.6	3.8	3.0	2.6	2.1	*	2.3	1.9
126			4.2	4.2	3.4	3.7	3.0	2.7	2.4	*	*	1.9
127			4.4	3.7	3.6	3.8	2.8	2.3	2.0	*	*	*
128	4.3	4.2	4.1	3.6	3.4	3.5	2.7	2.2	2.0	*	*	1.7
129	4.2	4.1	3.9	3.6	2.9	3.2	2.5	2.0	*	*	*	1.5
130	4.1	4.0	3.9	3.6	3.0	3.2	2.5	2.2	*	2.0	1.8	1.9
131	4.1	4.0	3.9	3.6	2.9	3.2	2.6	2.0	1.5	2.4	*	1.9
132	4.2	3.9	3.9	3.6	2.8	3.1	2.4	2.1	1.6	2.0	1.5	1.5
133	4.3	4.0	3.9	3.6	3.3	3.5	2.8	2.3	1.9	1.7	1.5	2.2
134	4.1	4.0	3.9	3.9	3.0	3.2	2.8	2.4	2.2	1.9	1.6	3.5
135	4.4	4.1	4.1	3.7	3.4	3.6	3.2	3.0	2.6	2.4	2.5	3.9
136			4.5	4.4	4.1	3.9	3.9	3.7	3.4	3.5	3.4	4.6
137			4.9	4.8	4.8	4.9	4.5	4.6	4.9	4.5	4.9	4.8

<3.4 MM thk tubes

Figure 6: The top table shows the erosion pattern of the roof tubes (in front of the normal roof lining) in the wingwall SH / EVAP configuration shown in figure 3 & photo 8. Only 24 roof tubes on either side of the combustor & towards the cyclone entry had thinned down. Based on the pattern of erosion refractory protection zone was increased.

Narrow inlet configuration to cyclone-preferential erosion of side walls.

The gas inlet configuration shown in figure 7 is bit odd. There will be fall out of material in between the two gas flow paths at cyclone entry. This is because gas flow opening width is much less as compared to the width of the rear wall. The rear wall is subject to high recirculation of solids. The heat pick-up pattern also can be different due to this. As the gas flow is along the side wall panel, the entire side panels would need protective refractory lining.

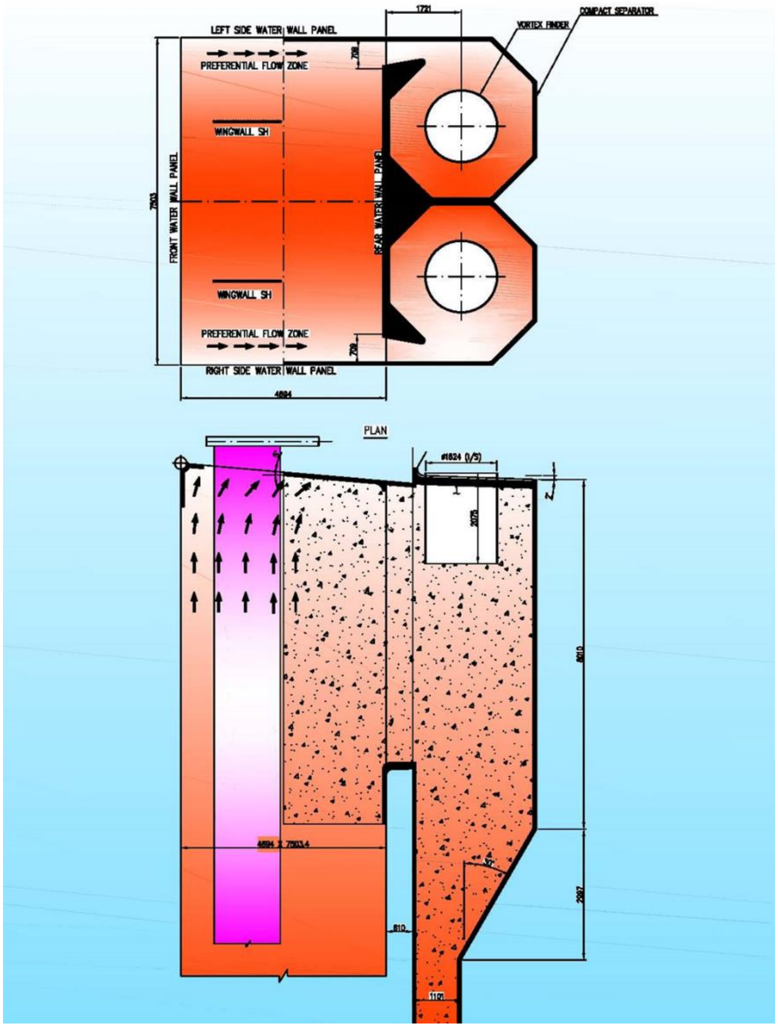


Figure 7: The top figure shows narrow entry to cyclone. The collection efficiency of this cyclone is good as the vortex is away from gas path. The internal recirculation of solids along the rear wall is expected to be more.

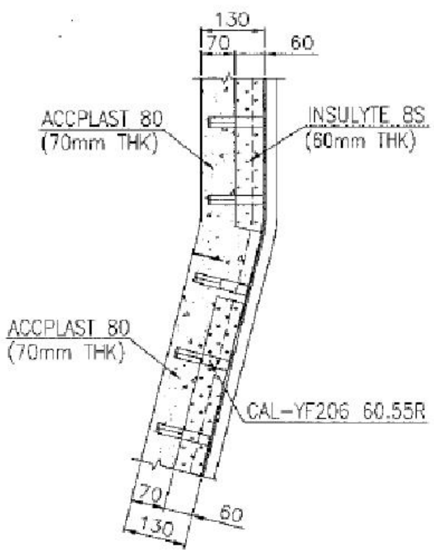
Improper refractory lining

Refractory lining defects fall in to following subcategories.

- Refractory design at lower furnace
    - The anchor design adopted with thick refractory lining had been subject to thermal spalling due to heating and cooling cycles. A tube leak is sufficient to create damage to the refractory. See photo 9.

Photo 9 & 10: The left side photo shows the V type anchor welded to panel tubes. The refractory spalls off easily since the refractory thickness should be at least 75 mm from tube crown. The right-side photo shows the stud's design. This design is superior. The refractory repair is simpler. Thin layer of plastic refractory is found to be adequate during maintenance.

    - There are cases of improper refractory design at lower part of furnace. Of all the designs adopted the use of LC castable with use of studs welded to tubes prove to be the best. See photo 10. However, around the fuel feed opening and other openings high alumina plastic refractory is desirable.
    - One manufacturer provides a multilayer design, which is the worst design of all from maintenance point of view. See figure 8 & photo 11.



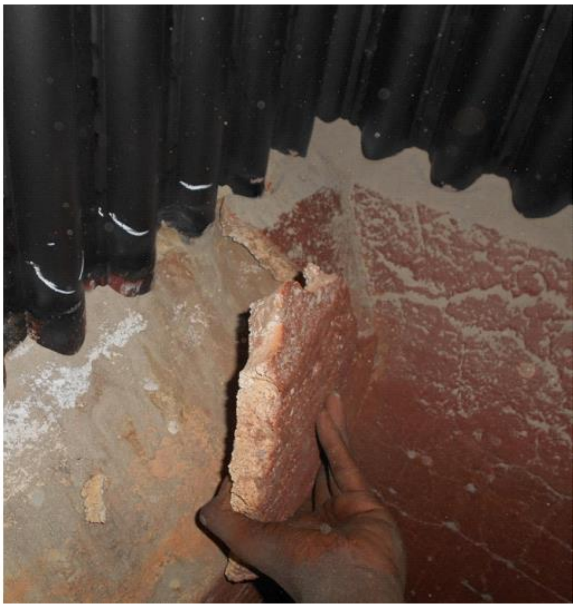


Figure 8 & Photo 11: The above refractory detail adopted by one manufacturer is the most complex refractory we have seen. The entire refractory had to be done all over again due to this poor design. The design is not suited for the quick thermal cycling / occasional high temperature excursions and large temperature swing during a tube leak. Tube leak is unavoidable. If it happens, the design should not demand total refractory rework. We find the stud design with 50 mm thick LC castable is found to be good. 10 mm thick plastic refractory overcoat is seen to be good enough during maintenance.

- Refractory spalling due to thick sections
    - Thick refractory sections in excess of 50 mm may be used for the various openings such as fuel feed points, SA ports, ash recycle openings and start up burners would spall and create havoc. The tubes get exposed locally and are subject to localized erosion. This is frequently seen during shut down inspection. See photo 12.
    - The spalled refractory blocks lead to erosion failure of air nozzles. This is quite a dangerous situation leading to hot bed material pouring in to windbox. See photo 13 & 14.

Photo 12-14: Thick refractory in CFBC furnace walls is prone for spalling because thermal expansion. The air nozzles get eroded when the spalled refractory fall in between the nozzles and obstruct the air path as they get stuck near / at air nozzle openings. Air nozzle failures cause combustible bed material seepage in to the windbox. This is a serious hazard starting from simple refractory defects. Bottom photo shows the accumulation of bed material inside the windbox.

- Improper refractory geometry at corners

- CFBC combustors are invariably of rectangular cross section. The upward gas flow is at the centre and the particle downflow is high along the wall. The erosion rate has to be monitored in CFBC boilers on every annual shut down. This is not the case with other combustion technologies. Generally, fins cannot be closed accurately at the corners. This also add to local fin-tube profile defects. See photos 15 & 16 showing corner tube erosion. Some manufacturers provide corner refractory. Some boiler makers do not provide this.

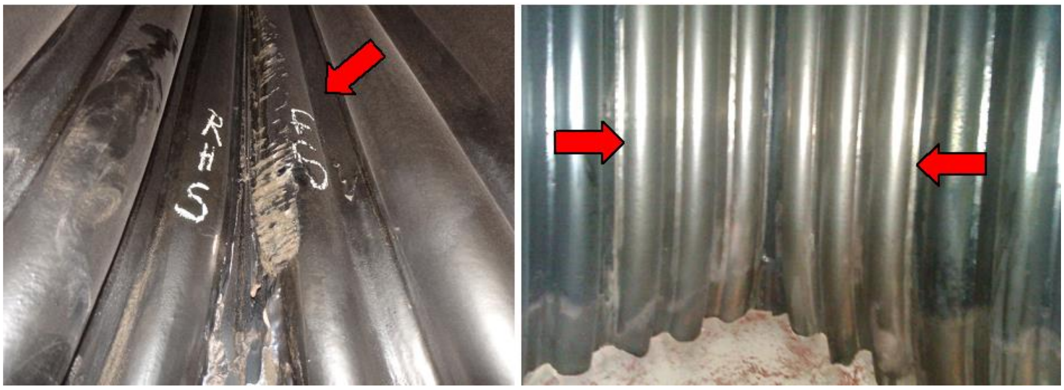


Photo 15 & 16: Both the photos above show erosion of corner tubes in CFBC boiler. The location depends on the load factor and the cyclone outlet configuration. In addition, the corners of CFBC boilers generally have defects on fin closures. By applying the corner refractory, the corner tubes can be protected. See figure 9 below.

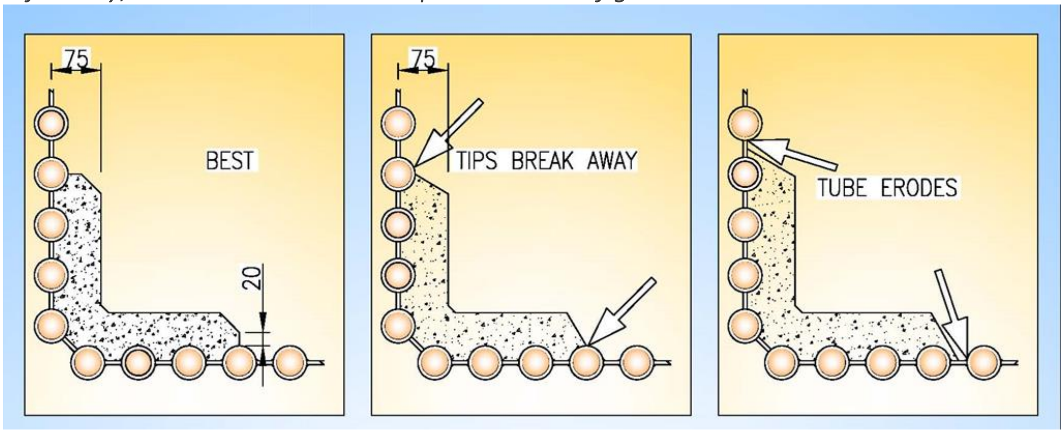


Figure 9: The above figures show the good & bad corner refractory details. Neither the designer or applicator do justice to this detail. Same manufacturer is seen to have supplied boilers with different refractory contours at corners.

- The cyclone entry geometry causes preferential erosion along the front wall corners. Low load operation enhances this effect. This also demands furnace corner refractory.
- Where the furnace corner refractory is provided, improper geometry is adopted by some boiler makers. The good and bad corner refractory details are illustrated in figure 9.

- Refractory ends cannot be finished with thin edges. Thin edges simply break away and create zig zag paths for material flow. Localized craters are created on the tubes in this area. See photos 17 & 18.

Photo 17 & 18: While the CFBC boiler demands a corner refractory detail for protection from erosion, improper design, improper application cause localized erosion. Localized deep cuts are seen in places of improper refractory tipping. Metal filling is to be done to stop the growth of the cut.

- Improper refractory geometry at kick off bend zone
  - Kick off zone is a design detail added in CFBC combustor during the development & scale up process. Some designs do not have this. Instead, alternate arrangements are provided. As the particles travel down at good speed, the refractory applies a brake. The dissipation of kinetic energy causes in erosion of both refractory & tubes nearby. When the refractory is in excess, the refractory erodes. Due to installation mistakes in refractory contour, the tubes can erode. See photos 19 & 20 showing the erosion of refractory and tube. Figures 10 -12 show the refractory profile requirement at kick off zone. It is recommended to have 90% alumina plastic refractory at the kick off zone (around 500 mm height) to slow down the erosion rate of refractory.

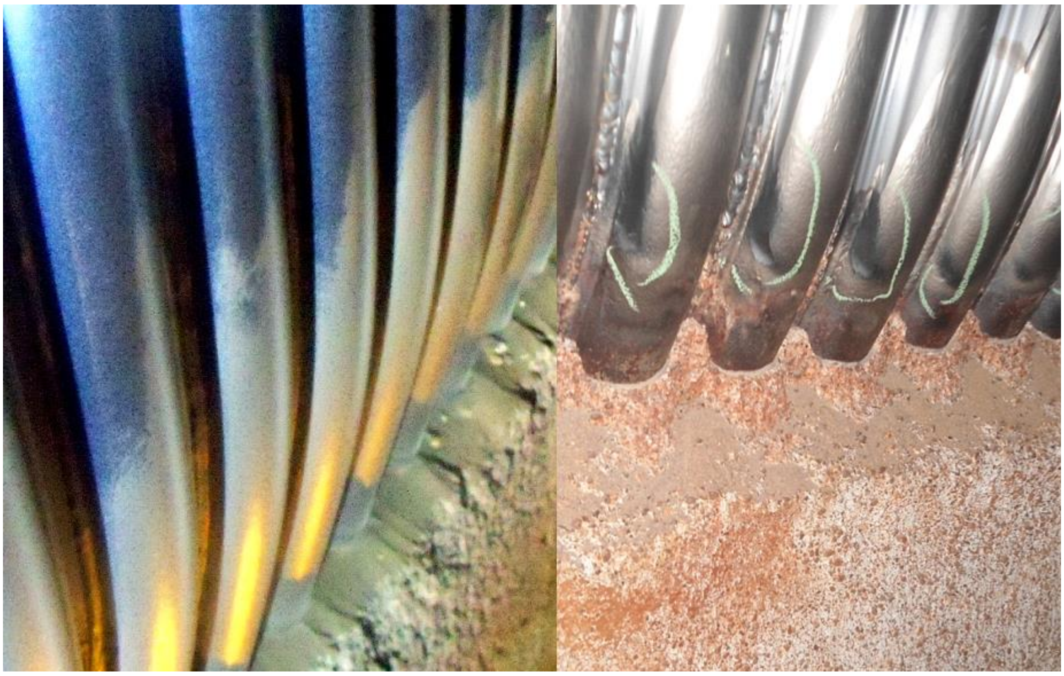


Photo 19 & 20: The above photo shows the erosion of excess refractory constructed at kick off zone. As the projecting refractory acts a brake for falling material, the tubes above get polished / eroded.

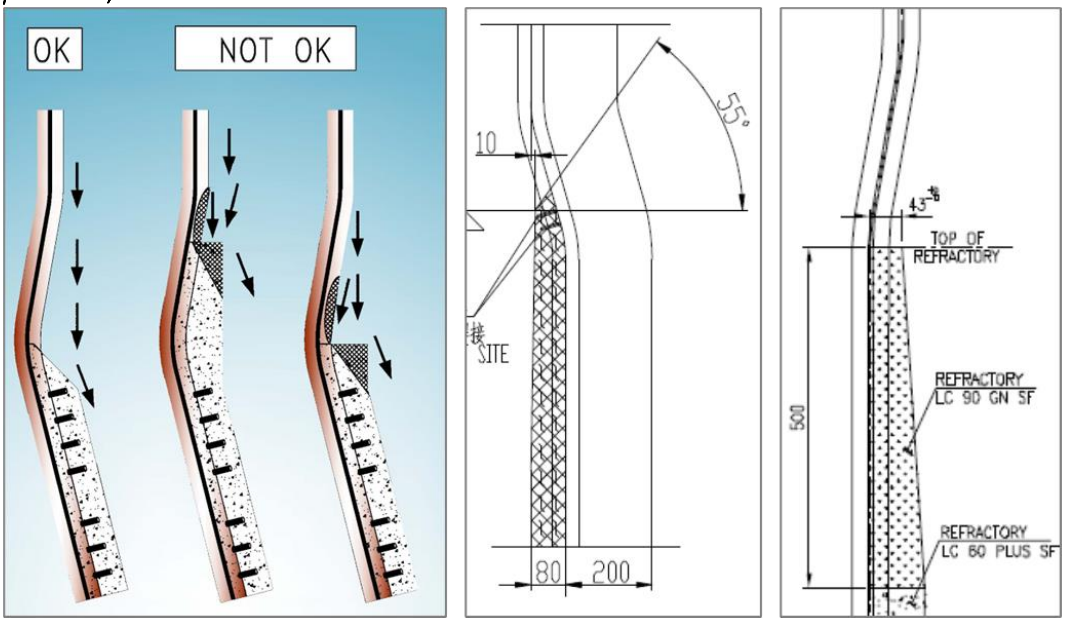


Figure 10-12: The above are the details of other boiler makers. If there is excess refractory, the waterwall at kick off zone erodes faster. The accuracy of construction is very important. The flow of solids should be free & unobstructed.

- Improper anchor design / Excess refractory at wingwall evaporator / superheater at bottom

- Except for the vertical part of the wingwall panels, the rest of the panel is covered with LC refractory or plastic refractory. This should be a thin refractory with adequate studs. Any other details would fail. See photo 21 & 22 showing improper protection. Figure 13 shows the improper engineering of wingwall SH / Evaporator bottom tube protection system. When the studs are inadequate or when the refractory thickness is excess, spalling is encountered. Then the bottom most tube of the wingwall evaporator / SH fails by erosion. If the refractory thickness is more than 40 mm there is vulnerability of spalling. See photo 23 showing the spalling of refractory due to excess refractory. Figure 14 shows the correct refractory detail to be followed.

Photo 21 & 22: The above photos show poor practices by some boiler makers. Left side photo shows the inappropriate protection system. Right side photo shows the absence of studs to hold the refractory at the bends.

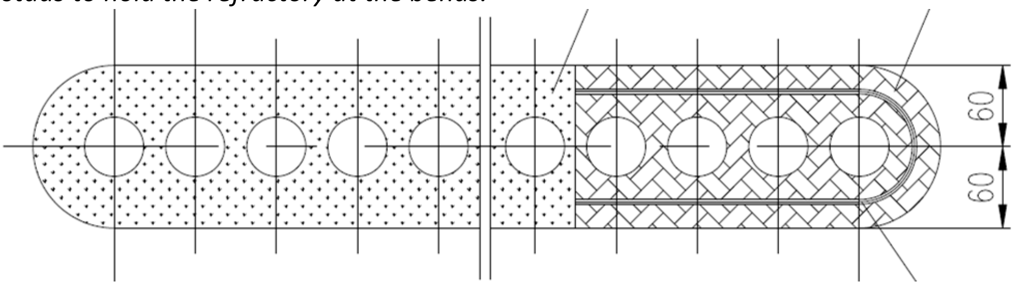


Figure 13: The above drawing shows the improper anchor design to hold the refractory. A steel used for anchor should not have large thermal expansion. If so the refractory would certainly break away.

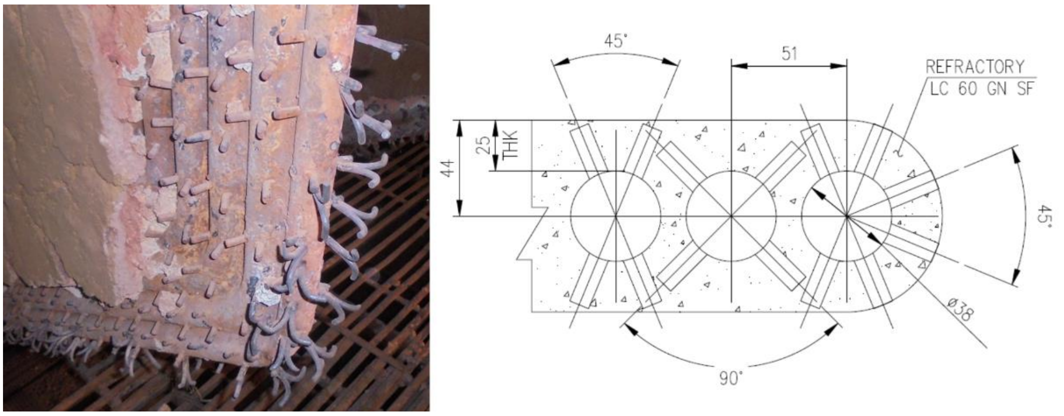


Photo 23 & Figure 14: Photo shows the refractory spalling due to excess refractory. The figure shows the refractory desirable for erosion protection of the outer most tube of wingwall evaporator / SH bottom / bend section. Long anchors are not required at all.

Improper panel manufacture – erosion due to manufacturing defects

- Not every manufacturer is clear on this. Unlike the PF boiler / AFBC boiler / stoker fired boilers / gas or oil-fired boilers, CFBC furnace panels demand stringent quality levels during manufacture & during field work. Manually welded panels is not acceptable. Only panels made by automatic welding machines are to be used. Panels coming under refractory lining can be made by manual welding process. Figure 15 states the important quality requirements during the production & construction stage.

Manufacturing and erection notes for CFBC furnace panels:

1. Panel should be manufactured using automatic SAW machine or Automatic MIG welding machine.
2. All tube and fin buttwelds are to be flush ground smooth only on fire side.
3. After completing the fin to fin butt weld from outside, inside seal run to be done before grinding smooth.
4. No knots are permitted in the tube – fin welding. Weld should be uniform.
5. Tubes should be parallel and well aligned.
6. Panel shall be free of bow and twist.
7. Panels should be erected to plumb.
8. Diagonal distance of panels shall not deviate by more than 5 mm.

Figure 15: The above notes are the important ones for CFBC panel manufacture and erection at field. Note no 3 and 7 are specific to field work.

- Several defects such as out of alignment tubes & fins, excess welding at fins, non-removal of tube & fin butt weld beads, bowing of panels cause preferential erosion. These are explained in this article.

Improper erection of furnace wall panels

Not all erection engineers or erection contractors are clear on quality requirements of the furnace panel assembly. Furnace wall panels are sent in parts due to transport and erection constraints. Field work demands stringent quality levels. Some of the serious defects and the effects are listed here.

- Failure to remove the tube & fin buttweld beads lead to localized erosion patterns which ultimately lead to tube failure at the fin-tube weldments. This is illustrated in figure 16-18. Photo 24-27 show real life examples.

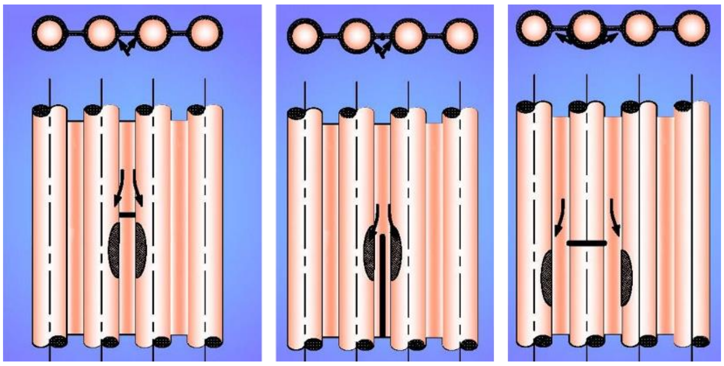


Figure 16-18: The above figures illustrate the flow of solids in CFBC furnace around the fin / tube butt weld projection. Tube leakages occur at the fin-tube weldment area only.

Photo 24: The left side photo shows the haphazard erosion pattern experienced at tube butt / fin butt weld zone.

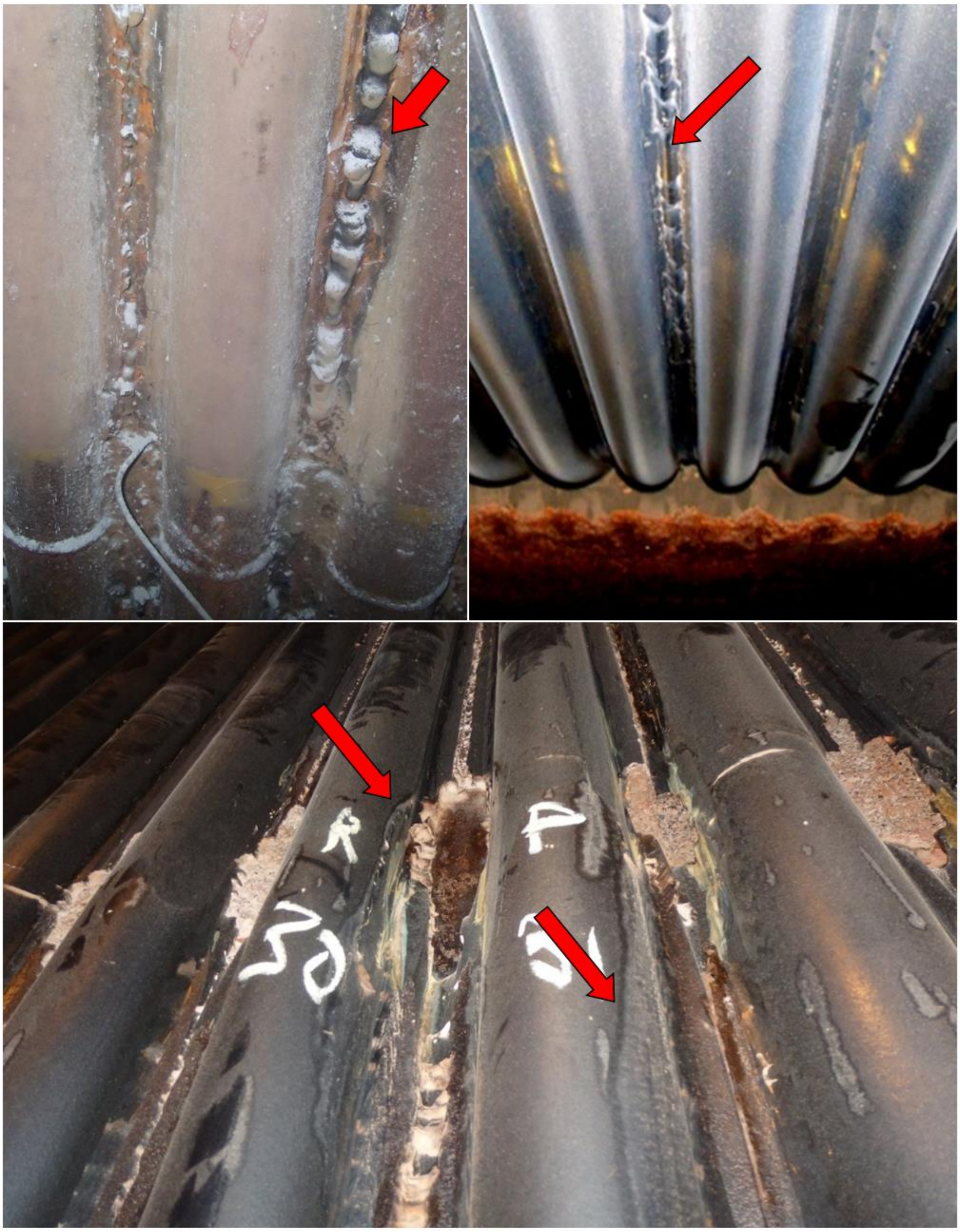


Photo 25 to 27: The top photos show the no finish / poor finishing of fins leading to erosion of the tubes at the fin to tube weld zone. Many of the construction engineers or inspection engineers are not aware of this requirement. The main reason for this discrepancy is that no scaffolding is carried out to finish the welds on the fire side. Scaffolding or floating platform materials must be envisaged in the procurement stage itself.

- Fin filler plates are to be properly placed in plane. The welds should be of full penetration welds and the excess beads are to be ground off. Portable pencil grinders / carbide cutting tools are to be used to remove the weld beads on the fire side. Photos 24 & 27 show the detrimental effect of the defects.
- Panel fins which are slit for alignment purpose are to be sealed with full penetration welds. The beads are to be ground flush afterwards. Generally during construction, the panel-to-panel weldments are carried out from outside the furnace. CFBC boiler demands scaffolding inside in order to carryout full penetration welds and to flush grind all the tube to tube butt weldments, fin to fin butt weldments, fin closures at field joints.
- The furnace wall panels have to be absolutely vertical in both Y-Z planes. Failure to maintain verticality leads to gross erosion of panels. Photo 28 shows the erosion of tubes near the field weld, where vertical alignment is compromised. Figure 19 shows the mechanism. See photo 29 showing the localized panel erosion due to the presence of bow in the panel. On one wall, just one panel may alone get eroded in a peculiar manner when verticality is compromised. See photo 30 & 31 showing the patch erosion due to the out of verticality defect. Figure 20 illustrates the mechanism.

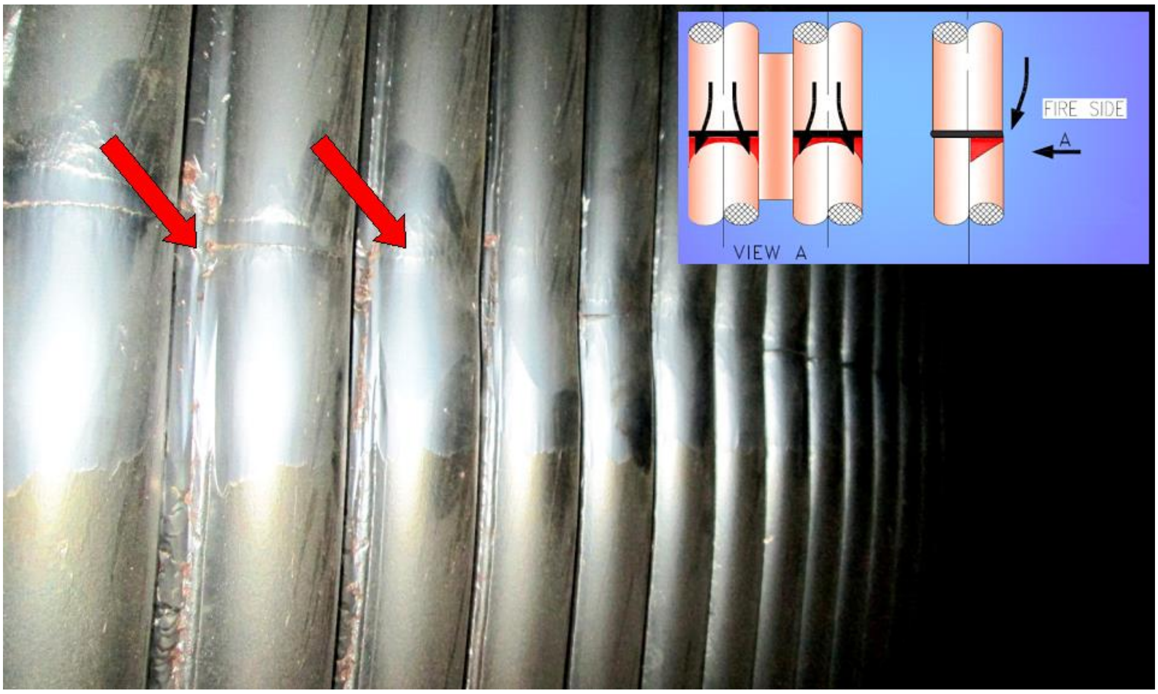


Photo 28; Figure 19: The top photo & figure show the erosion due to misalignment of tube at field joint. The tubes are eroded as the bottom panel tubes got displaced towards the fire side. Hence the solids moving down along the panel chop off the projected surface.

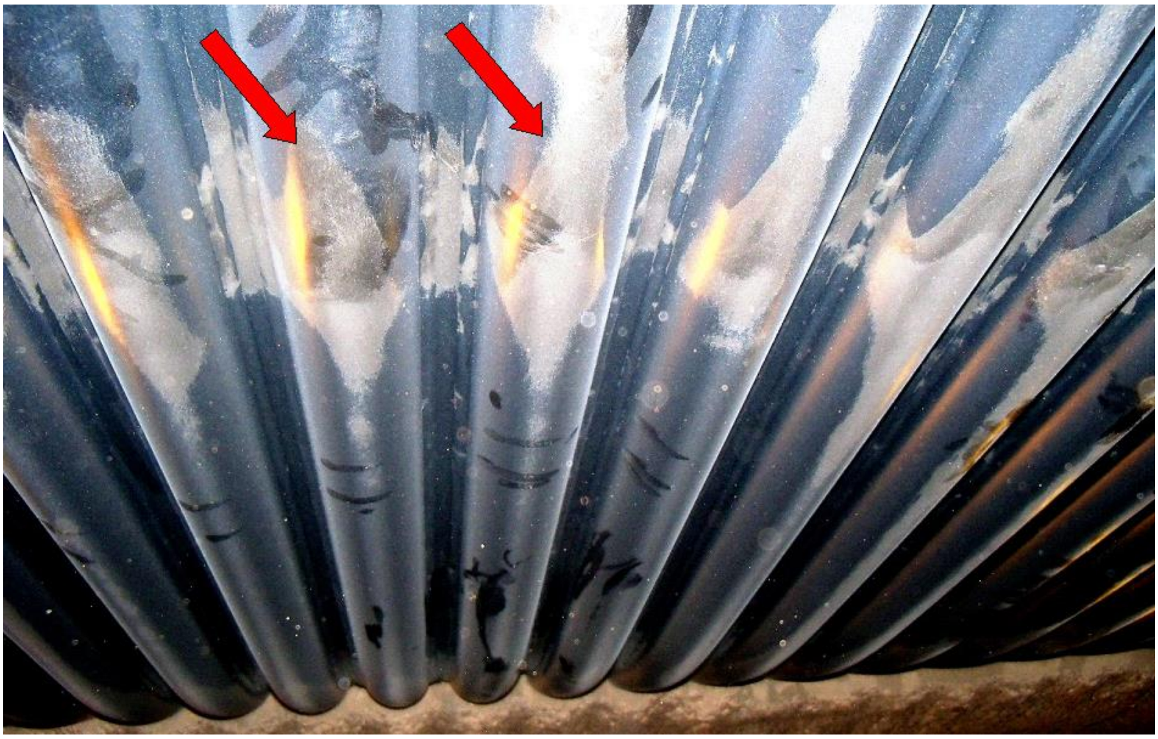


Photo 29: The photo shows the erosion of tubes when there is bow present in the panel. Improper handling and failure to ensure panel verticality resulted in the erosion of tubes at the bow zone.

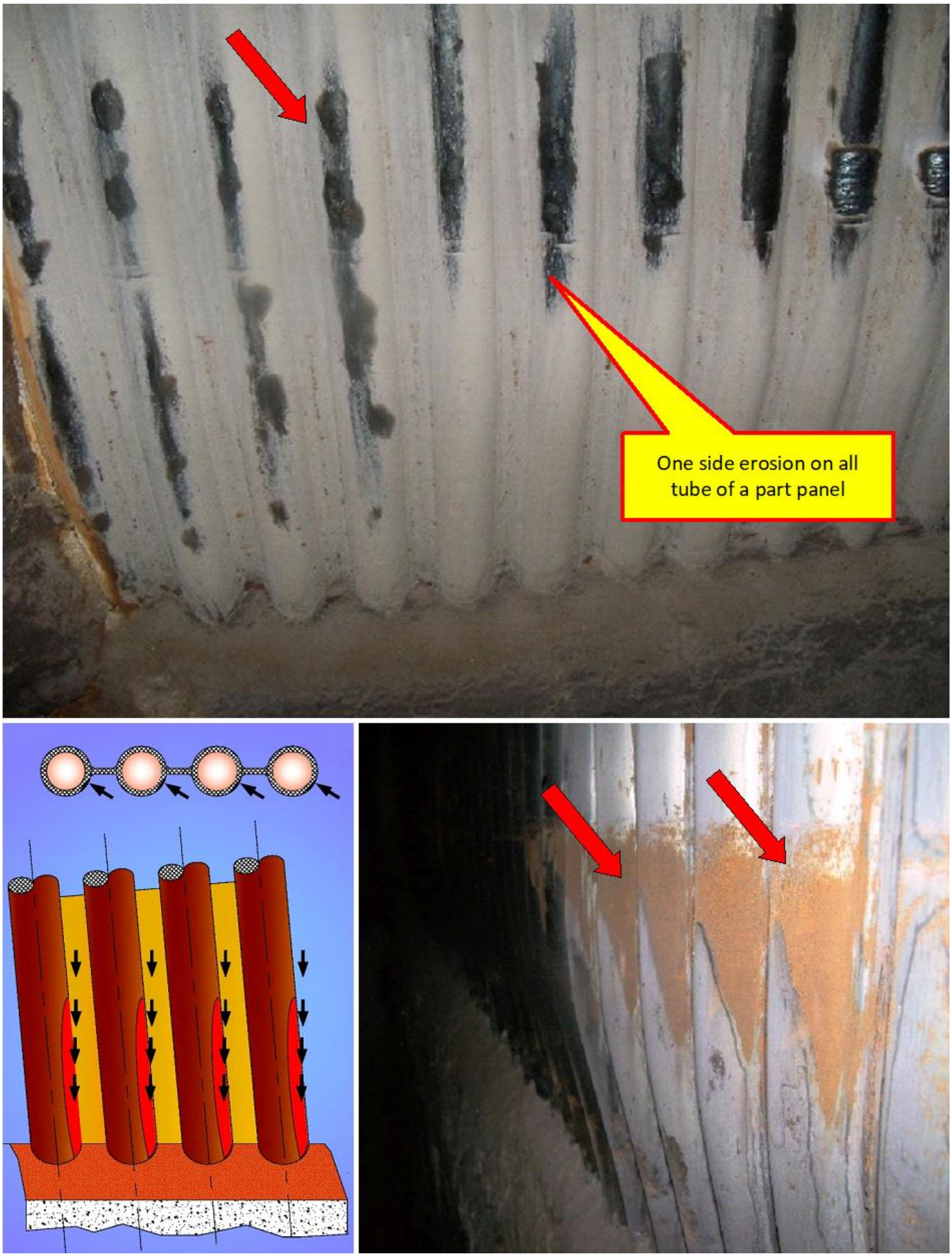


Photo 30 & 31; Figure 20: The top photo shows the erosion of tubes when a panel is inclined / out of verticality. Bottom photo shows the case of out of verticality of bottom panel at the field joint. In the figure the erosion mechanism is illustrated.

- No scrap can be left on the fire side anywhere. Or else local failure will be encountered. Even a thermocouple inserted in the furnace will be subject to erosion. Not only the thermocouple would be cut, but also the panel tubes nearby will be eroded off. Photo 32 shows the panel tube erosion near the thermocouple insertion point. Figure 21 illustrates the mechanism. Retractable thermocouples are recommended below the wingwall SH for start-up flue gas temperature control purpose.

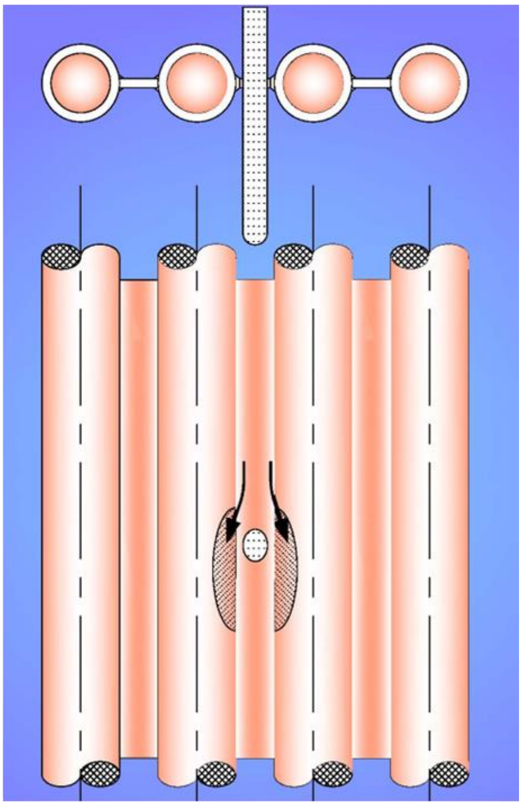


Photo 32; Figure 21: The top photo shows the erosion of tubes when there is an instrument tapping penetration in the panel. A thermocouple at mid of furnace is not required for CFBC furnace.

- Pressure tapping are permitted in the CFBC combustor. Again, the tapping should be in flush with the fin.
- Periodical replacement of panels may be required in CFBC boilers. The replacements may be warranted within a period of 5 years depending on the coal ash particle abrasiveness and other construction defects. Usually, the replacement will be a length of 5 m from the bottom tapered panels. Such replacement panels are also to be fabricated using mechanized panel manufacturing machine with auto SAW or auto MIG technology. A compromise results in frequent outages. See photos 33-35 driving the point.

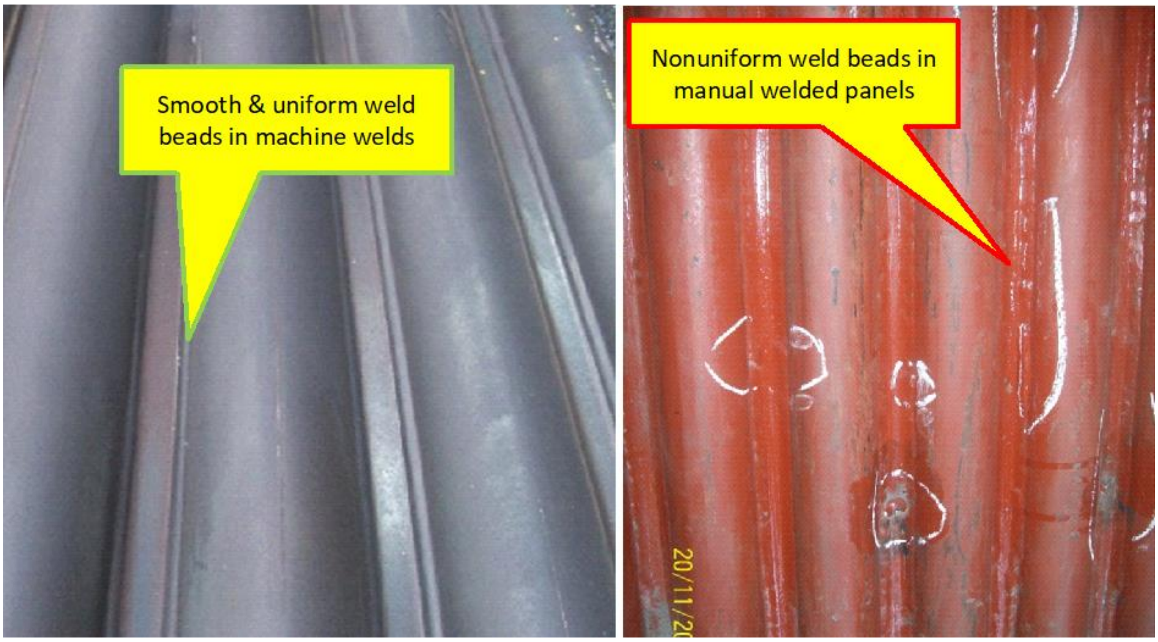


Photo 33 & 34: The difference between panels made by manual process and automat can be seen here. The nonuniform weld beads would cause localised erosion problem.

Photo 35: Photo shows the out of alignment of manually welded panel below the original machine welded panels. Boilers owners have to procure the spare panels only from parties who would deliver the panels duly welded in mechanized welding machine. Panel replacement team should be clear about the quality requirements at field.

Improper metal spray

- Metal spray technology had been developed for reconditioning worn out components in several industries. This has been extended to CFBC boilers. Some boiler makers apply this technology for furnace wall panels that come above the kick off zone. This is the place where the panels have a shorter life. This is because the velocity & particle density is maximum here. See figure 22, showing the flow of solids in CFBC furnace. Photo 36 shows the erosion effect on the kick off zone refractory.

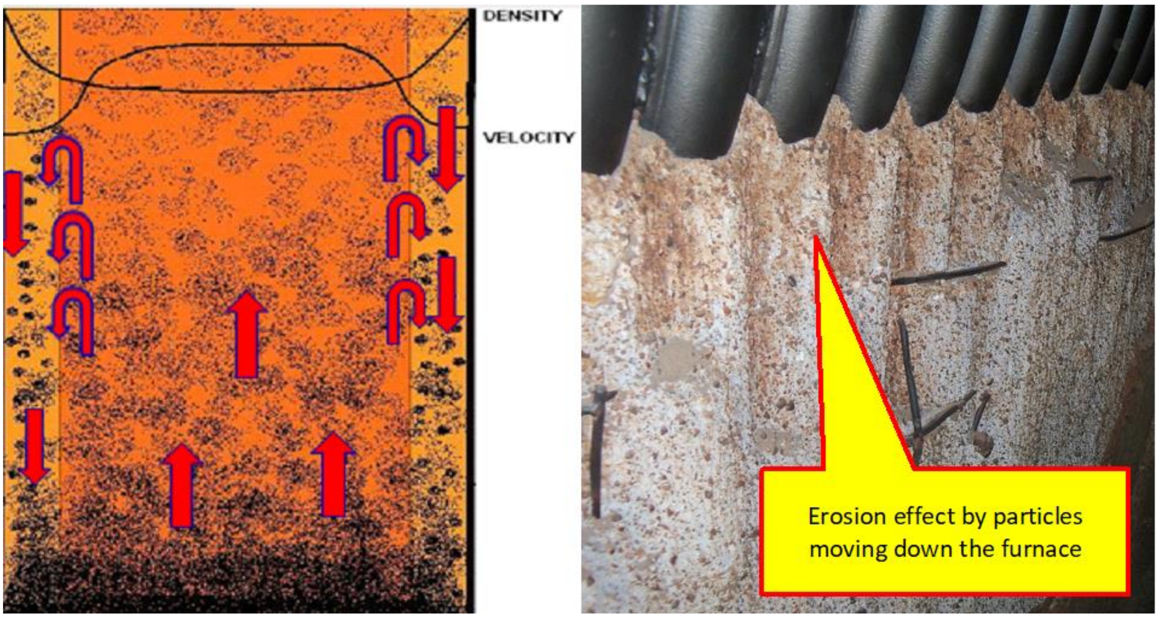


Figure 22; Photo 36: Figure shows the motion of solids in CFBC furnace. The density of solids is high near the wall & highest along the corners. The gas velocity along the wall is lesser. Some particles combine forming clusters. They flow in the passage created between the tubes along the fins. This can be inferred by the erosion pattern of the refractory at kick off zone. It is therefore calls for replacement of the furnace wall panels to a length of 5 m above the refractory over a period.

- HVOF spray with wear resistant materials to a thickness of 100-150 microns have been tried by many. Field application had been a disaster. This is because HVOF spray cannot applied properly by manual process at field conditions. Improper angle & distance and non-uniform layer thickness have led to miserable failure. Even panels with first supply with HVOF spray had failed in 3 years' time. See photo 37 -39 showing actual experience from two different plants.

Photo 37 to 39: Metal spray itself develops a mechanism of erosion. Coating peels off causing an inverted V or V cut in the panels. These photos are from unit which had operated for 3 years before failures became frequent. The first supply from manufacturer had this quality issue. Any field application may not give a satisfactory result. It is sensible to use plain water wall panel.

- Users who have tried under field conditions revert back to regular furnace panels. This gives longer life as compared to metal sprayed panel.

Part load operation

Part load operation result in internal recirculation of solids within the furnace. The flow through the cyclone & loop seal would reduce. In case of two cyclone system, there can be high temperature at one loop seal due to short circuiting of gas from furnace to loop seal. This is noted by the difference in loop seal temperature. The material flow pattern is not predictable. Prolonged operation can cause issues. There are cases that one or two walls appear to be polished.

Deviation from design fuels

The design of furnace, cyclone & loop seal etc. are designed for a specified fuel. The gas quantity can largely differ when high moisture / low GCV fuels are fired. There are cases where the design moisture is 10% and as fired moisture is 30% - 38%. The flue gas velocity could be higher causing high erosion rate at target zone of the cyclone. Design fuels should be specified on air dried basis instead of as received basis. This is particularly applicable to Indonesian coals.

Malfunctioning of vortex finder

The vortex finder can be subject to distortion due to tube leaks. See photo 40 & 41. Vortex finder may be subject to distortion due to constraints in thermal expansion. This leads to differential gas flow between the cyclones. This leads to unbalanced gas flow within the furnace. It can result in short circuiting of flue gas through the loop seal. This can also show up difference in erosion pattern of the furnace wall panels. It is seen that the cyclones show up difference in erosion pattern.

Photo 40 & 41: Photos show the distortion of the vortex finder in two different boilers. Vortex finder gets distorted when there is a tube leak at roof tube or in upper furnace walls or even at the water-cooled cyclone. The sudden quenching of hot surface with water leads to unpredictable distortion. Continuing with distorted vortex finder alters the gas flow pattern at the furnace and cause preferential erosion.

Variation in gas flow between cyclones-cyclone construction

The cyclone can be made from steam cooled tubes or water-cooled tubes or it can be of refractory construction. The most important part of cyclone is the bull nose in the cyclones, in the case of refractory construction. Difference in opening dimensions / shape can cause differential gas flow. There will be difference in collection rates of ash between cyclones. This will cause internal recirculation of solids within the furnace. There will be uneven erosion of refractory. Photo 42 & 43 shows the erosion of vortex finder. The refractory erosion showed a large difference between two cyclones.

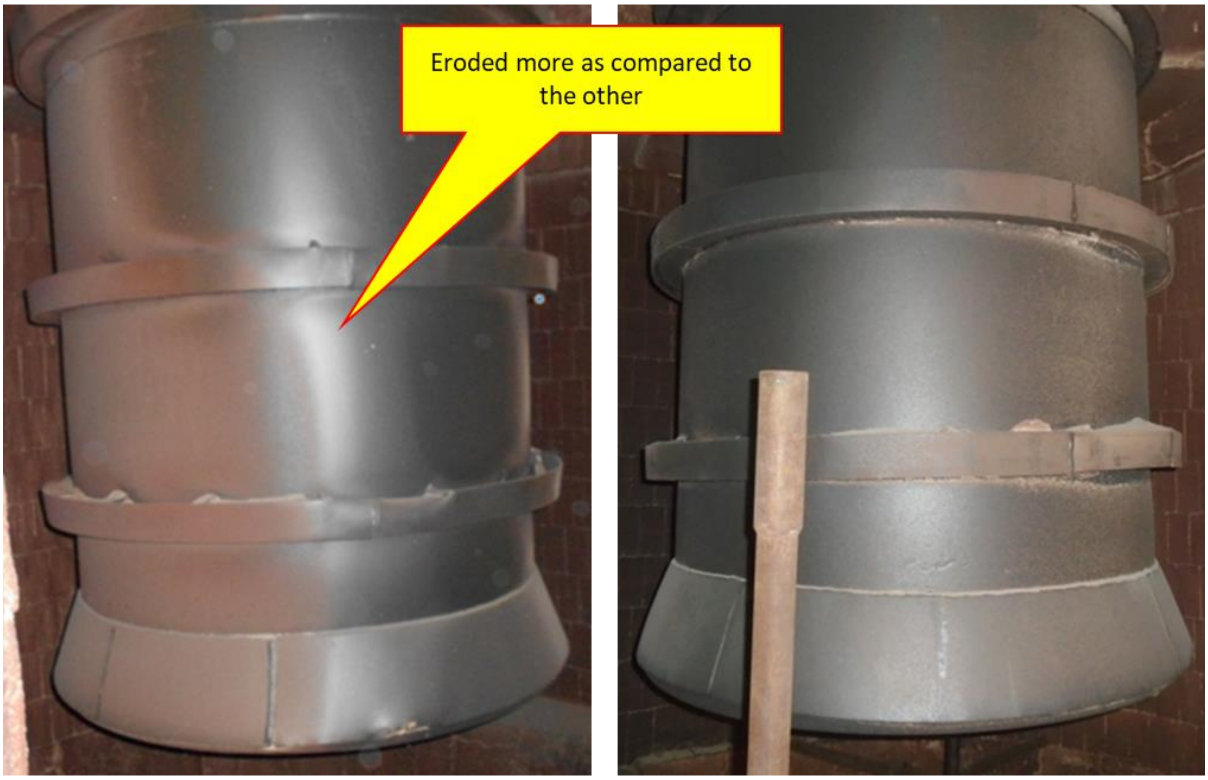


Photo 42 & 43: Photos show the difference in polishing between two vortex finders of same boiler. The collection at loop seal was found to be different. The refractory erosion was found to be different. Altogether there had been less upper furnace inventory in this boiler due to radial entry to cyclone. There had been difference in cyclone entry openings and shape. This is a case of refractory cyclone. When there is a difference in the cyclone and its entry formation, differential gas flow would be present.

Variation in gas flow between cyclones- inadequate upper furnace density / DP

When the upper furnace inventory is less the loop seals show difference in temperature. The collection rate would be different. This is due to inadequate resistance for the gas flow. Short circuiting of flue gas takes place as the flow of solids in downleg will be less.

Imbalance in fuel feeding

Number of fuel feed points are provided in the design to distribute the fuel equally, in the way air is well distributed by grid nozzles and SA ports. Some boiler engineers ignore this and choose to feed coal with large unbalance. This can cause preferential internal circulation of the solids.

Erosion of furnace tubes around SA ports

SA nozzles setting should be projected inside the furnace to a minimum length. In cases where the nozzles are left inside the refractory seal box, the refractory erodes / spalls over a period. Subsequently the tubes around the SA port opening begin to erode. See photo 44 & 45 and figure 23.

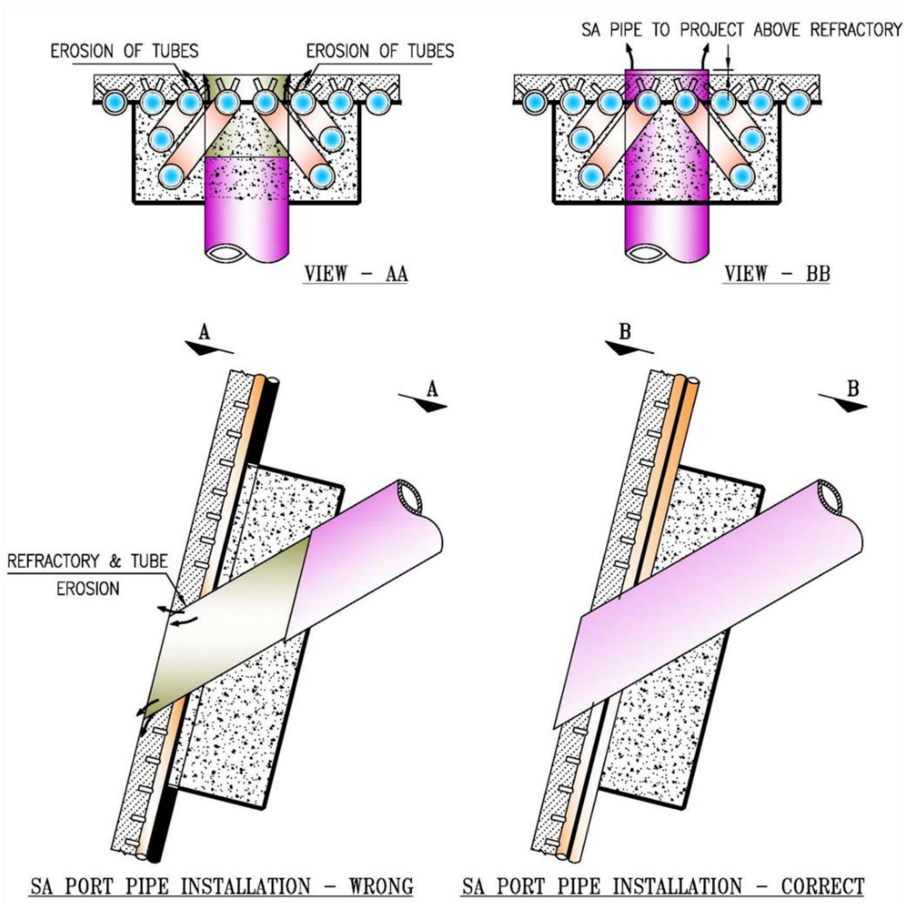


Photo 44 & 45; Figure 23: Photos show the erosion of tubes adjacent to SA port. Distortion of SA port pipe can happen due to wrong material selection of the port / if the minimum air is not maintained during operation. When there SA port pipe is not properly installed / if the refractory is not constructed properly, then also the tubes nearby the SA port would erode. In case SA port is not projected beyond the furnace tube, the refractory spalling can cause direct erosion of tubes.

Erosion protection for furnace wall panel above Wingwall SH / Evaporator openings

As discussed earlier, any protrusion in the furnace walls would be subject to erosion. For this reason, the wingwall SH and wingwall evaporator are covered with high alumina refractory at the penetrations. Now the refractory itself becomes a disturbing element causing the panel tube erosion. See figure 24 and photo 46 & 47 emphasizing the point. The erosion protection is chosen between weld overlay and HVOF spray.

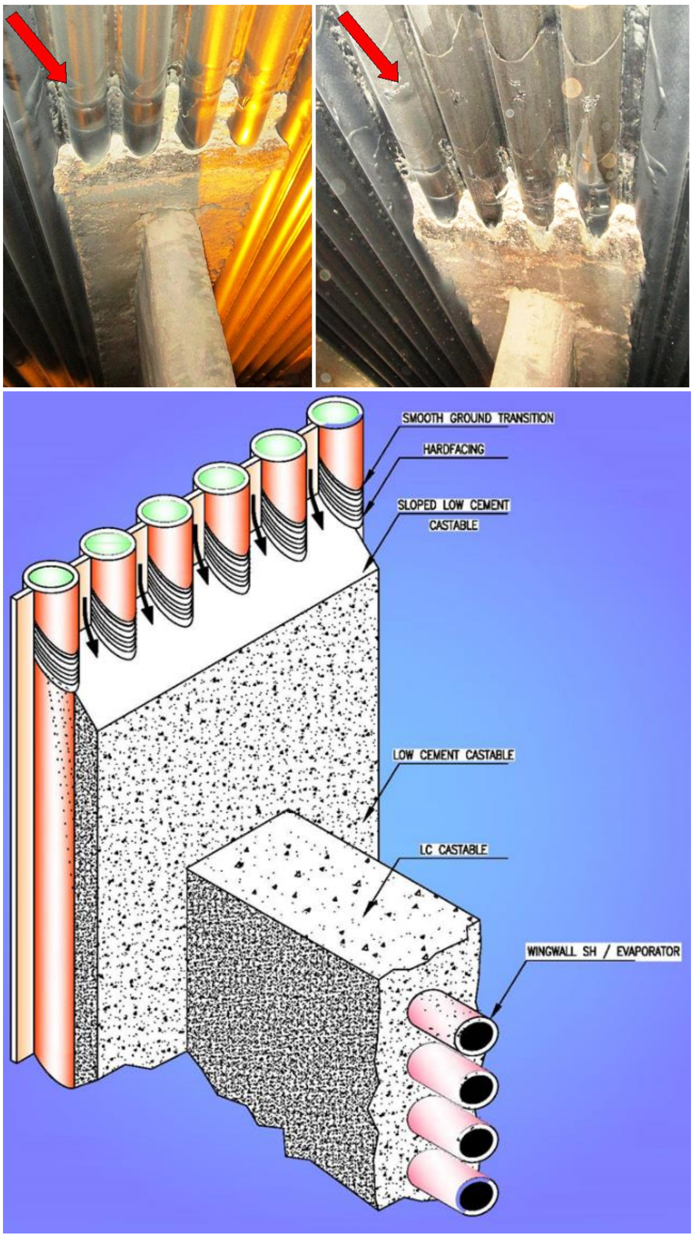


Photo 46 & 47; Figure 24:

- *Photos above show the possibility of moustache erosion along the refractory to tube interface. The figure illustrates the solid flow which cause localized erosion of tubes.*
- *Weld overlaying is adopted here. HVOF metal spray can be adopted only if proper working conditions are made available.*
- *Metal spray or weld overlay is required for 200 mm length. The overlay should be completed before applying the refractory since a 50-mm overlap is a must between refractory and the overlay.*
- *The sloped refractory face is important to reduce the erosion rate. The contouring of refractory along the tube is important as required for furnace corner refractory.*

- Weld overlay is seen to last longer. Only care is to be taken to have a smooth transition between bare tube and the overlaid portion.
- Metal spray or weld overlay is found required for 200 mm length. The overlay has to be completed before applying the refractory since a 50-mm overlapping is a must between refractory and the overlay.
- HVOF metal spray can be adopted only if proper working conditions are made available.
- The sloped refractory face is important to reduce the erosion rate.
- The contouring of refractory along the tube is important as required for furnace corner refractory.

Erosion protection of wingwall SH / Evaporator above the refractory

The wingwall SH or evaporators are protected from erosion at the bottom zone. This is specifically required as the wingwall SH / Evaporator tubes are oriented horizontally to the solids flow direction. Once the tubes are oriented vertically the erosion rate is greatly reduced. However, the transition zone between the refractory and the vertical tubes is susceptible to erosion. In this zone, metal spray or HVOF spray is applied. See photo 48 & 49. HVOF metal spray has its limitation with respect to dry heating during start up. Field repair is not successful unless it is executed with complete removal of previous coating. Weld overlay is found to be simpler. The transition zone is between weld overlay and the bare tube should be ground smooth. The refractory should be sloped at 45° to allow free flow of solids.

Photo 48: Photo shows the peeling of the HVOF spray over the wingwall evaporator panel. Field repair is not successful, unless it is executed with complete removal of previous coating.

Photo 49: Photo shows the repair of weld overlay zone in wing wall SH. The mistake here is that the refractory should be sloped at 45° to allow free flow of solids without much resistance.

Limestone chemistry

There are boilers which use petcoke. Petcoke contains high sulphur. In order to limit the SOx emission, limestone is fed along with petcoke. The quality of the limestone could vary from location to location to large extent. Petcoke does not contain ash. Hence the bed inventory is made of limestone in this case. The silica and alumina content decide the baking effect at loop seal downleg and the flowability in the loop seal outlet duct. The inerts available in limestone improve the flowability of solids. There are cases where the flowability of ash had been poor. This results in partial plugging / full plugging of loop seal. If this is not noticed, there can be high internal solids circulation within the furnace. This can increase the erosion rate depending on the inert content of limestone.

Conclusion

The CFBC technology is opted to reduce the unburnt carbon levels in fly ash so that the ash becomes usable at cement industry. The gain in efficiency is a matter of how much is the ash content and what is the GCV of fuel. CFBC boiler needs high head PA, SA and ID fans and hence the auxiliary power consumption is high. Yet a user knowingly opts for CFBC for the benefit of carbon loss. We have compiled our observations from design / operational / shut down auditing of several CFBC installations and presented here. Boiler manufacturers are required to give a good installation without the defects highlighted in this article.

REMOTE REAL TIME PERFORMANCE MONITORING USING LATEST SENSING & MEASURING DEVICES

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Thermax Ltd.

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Organisation: Thermax Ltd.
Designation: Head of Innovation
Education: B. Tech in Mechanical engineering (IIT- BHU), M. Tech in Energy system (IIT- Bombay)

Over 25 years of experience Mr. Jha is responsible for development of new products and introduction of new Technology.

Name: Rohit Khindri
Organisation: Thermax Ltd.
Designation: Head, IIoT - Heating Business
Education: B.E. Electrical Engineering (S.S.B.T College of Engineering and Technology, Jalgaon), Post Graduate Programme in the internet of things (IoT) (BITS Pilani)

Rohit has 15 years of experience in the development of new control systems & IIoT. His interests include AI, sensors technology, ML and AR/VR. His achievements include, 1 patent granted and 1 patent application, 2 highest Innovation award, Introduce IIoT in the Heating business of Thermax Ltd & led the IIoT development team

Name: Bharat Pathak
Organisation: Thermax Ltd.
Designation: Business Head - Heating Services
Education: B.E. Mechanical (University of Baroda), AMP Professional (IIM Bangalore)

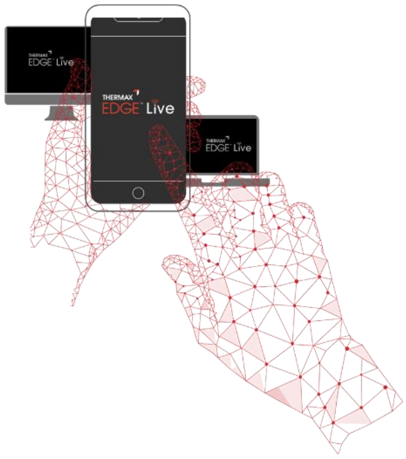
Leading the Global Service Business for Heating SBU Bharat has a total of 22 + years of experience in the field of Energy & Environment, Heat and Mass Transfer, Refrigeration and Air-Conditioning, & International Business. He was amongst the first ones to propagate, conceptualize, sell and successfully execute several waste heat recovery projects in industry, which includes recovery of exhaust gases of process equipment and gas engines, turbines, waste heat recovery in textiles sector and many others.

Thermax EDGETM Live

Real time performance monitoring using latest sensing and measuring device

What is EDGE™ Live?

EDGE™ Live is an Enterprise Asset Performance Enhancement Solution It integrates all your industrial assets across the globe and can perform data analytics at the click of a button. It is a powerful platform that allows you to tread your energy optimisation journey with great flexibility and versatility without compromising on quality. Edge Live is powered with Artificial Intelligence, Machine Learning and Thermax engineered algorithms.



Thermax's Three Tier Advantage

Synergy
Bringing experience and technology together

- Leveraging deep domain expertise in energy and the environment space
- A powerful digital platform providing an unparalleled user experience

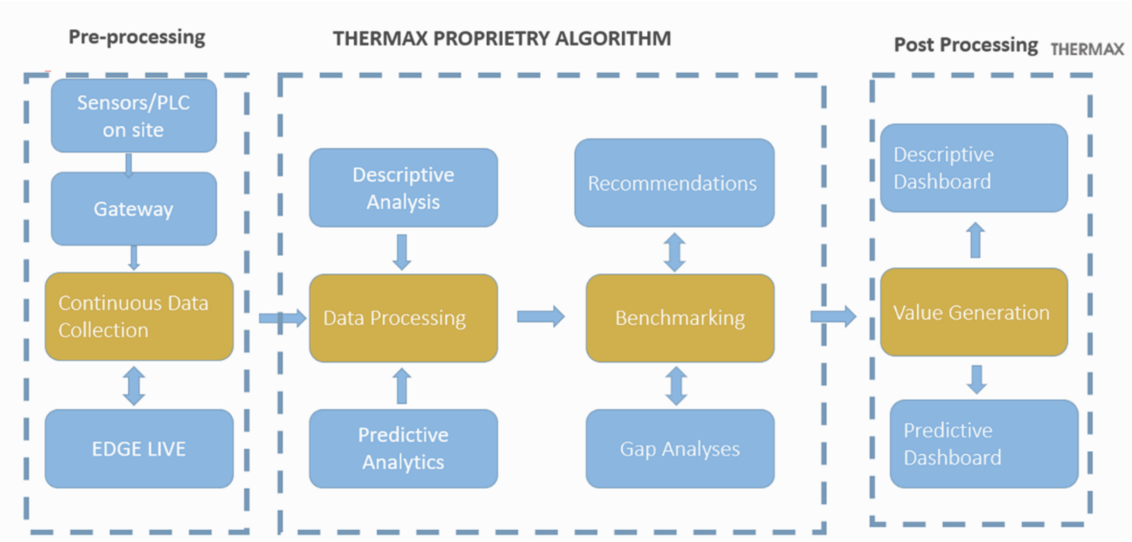
Service Excellence
Offering integrated and seamless support

- Support through well-equipped operations centre
- Consultative guidance by subject matter experts to enhance the health of the assets

Scalability
Connecting 50+ asset classes across multiple locations and businesses

- Compatible with your existing systems
- Asset agnostic infrastructure

Edge Live- How it works?



Components of Edge Live Solutions

Physical Components
- Sensors
- End Device / PLC
- IIoT Gateway

Virtual Components
- Cloud
- Analytics
- User Interface

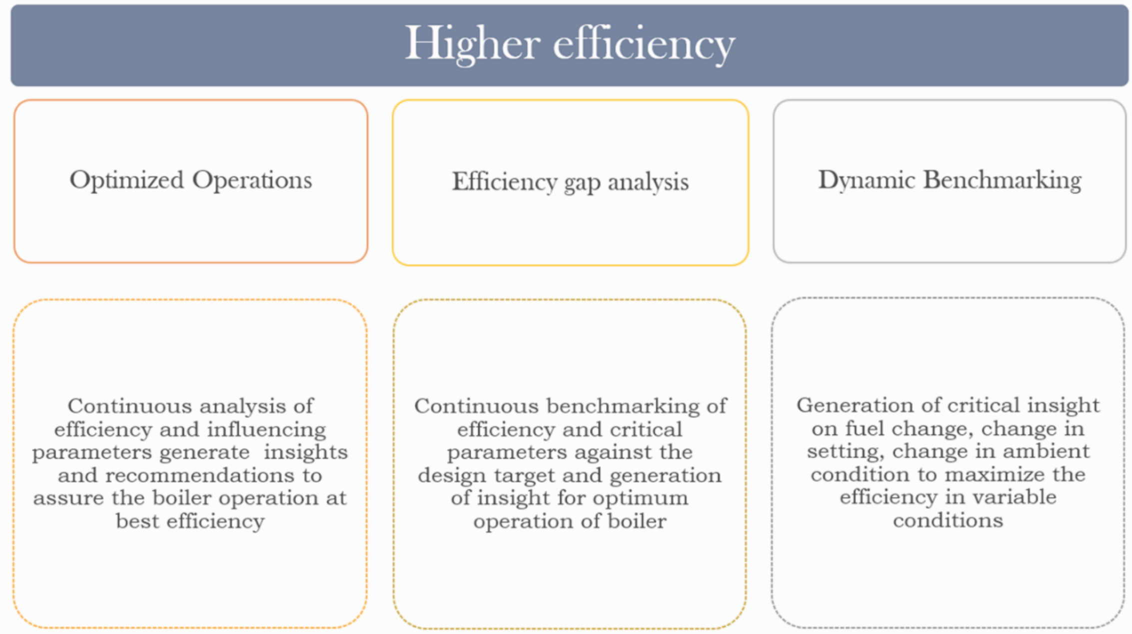
Edge Live- Product architecture

- Live & Historical data
- Correlation analysis
- Energy management system
- Maintenance management system
- Advanced control & control diagnostics
- Summary reports (Daily, Weekly & Monthly)

Enhance your business outcomes

EDGE™ Live is a user-friendly digital solution that helps you to maximise your business outcomes through:

Improved Plant Performance



Enhanced Uptime

Increased Availability

Early Anomaly Detection	Boiler Failure Prediction	Predictive Maintenance
Superfast algorithms for micro-trend analysis and alerts	Deep neural models for predicting failure long before they happen	Based on real condition instead of preventive or periodic maintenance

Enhanced Life

Wear & Tear Predictions	Robustness Improvement	Aggregate Analytics
Predictions of residual life and asset degradation	Catching misbehaving sensors and parts	Applying learnings from similar units for continuous improvement

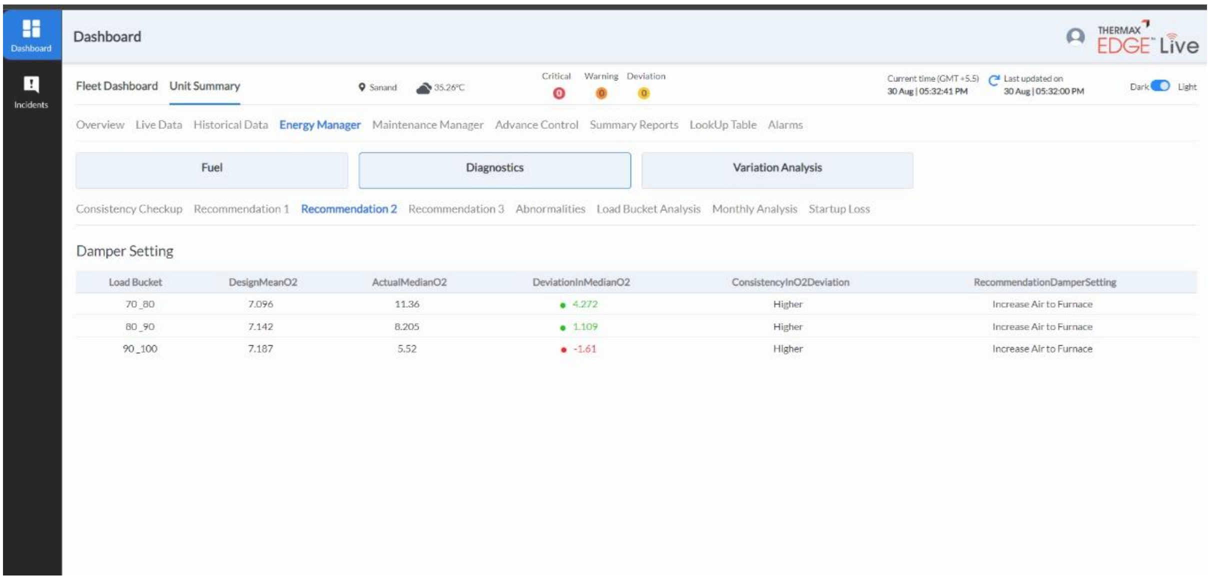
Enhance your business outcomes

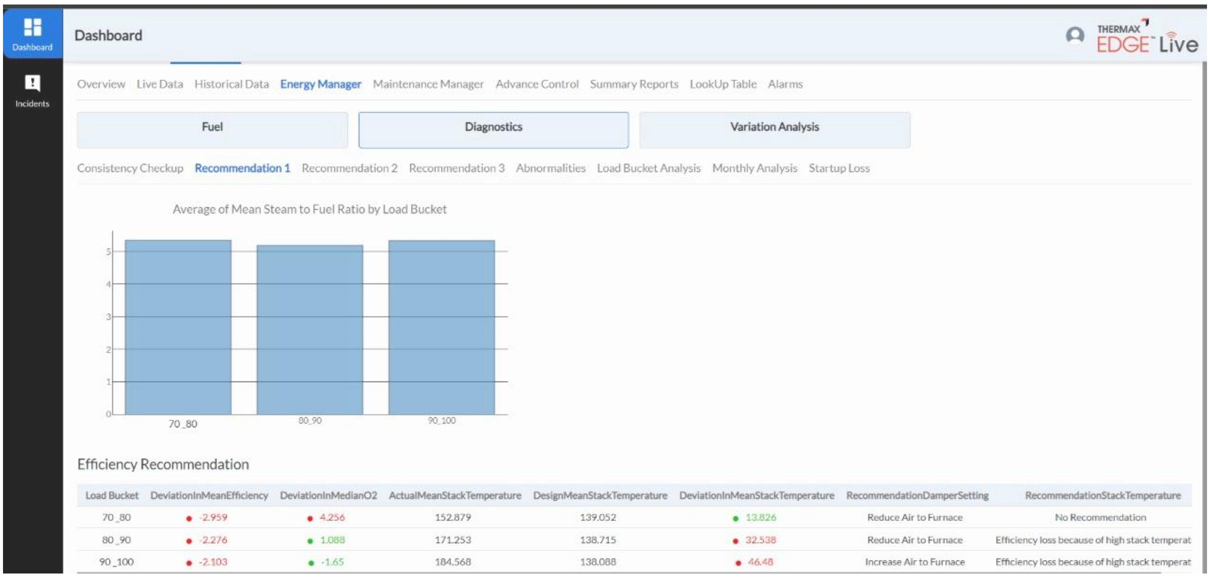
Knowledge Management - Enhanced knowledge sharing and collaboration

- Improve asset performance by leveraging timely alerts and reports
- Empower the workforce to leverage expert guidance
- Retain knowledge expertise
- User-friendly access at your fingertips

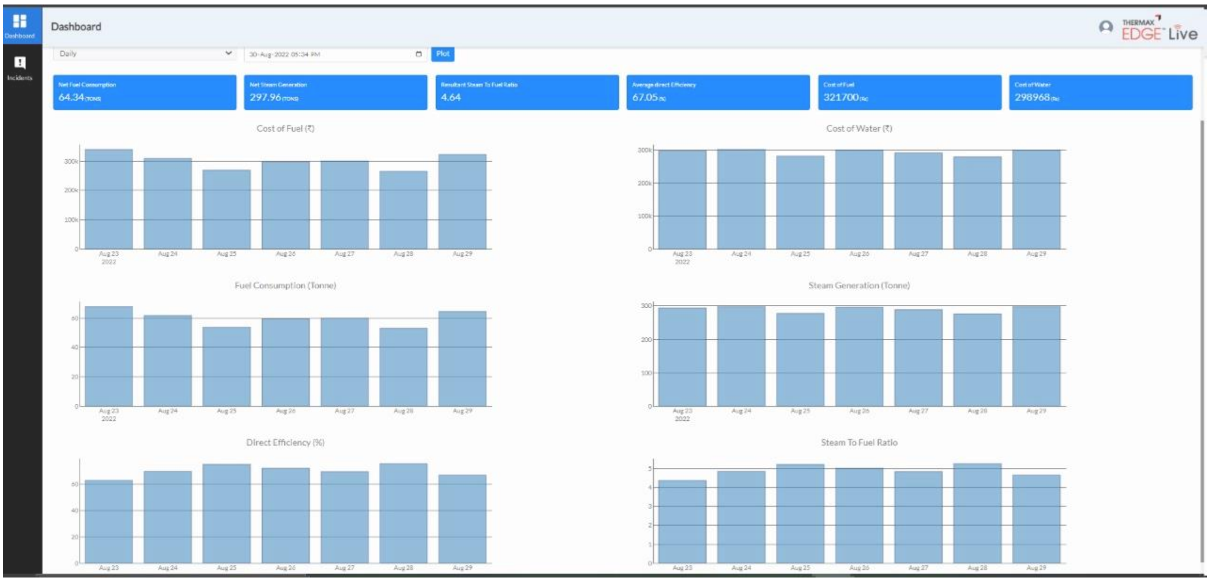
Dashboard

Recommendations





Reports


Dashboard
Incidents
Daily
Plot
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Net Steam Generation
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Resultant Steam To Fuel Ratio
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Average direct Efficiency
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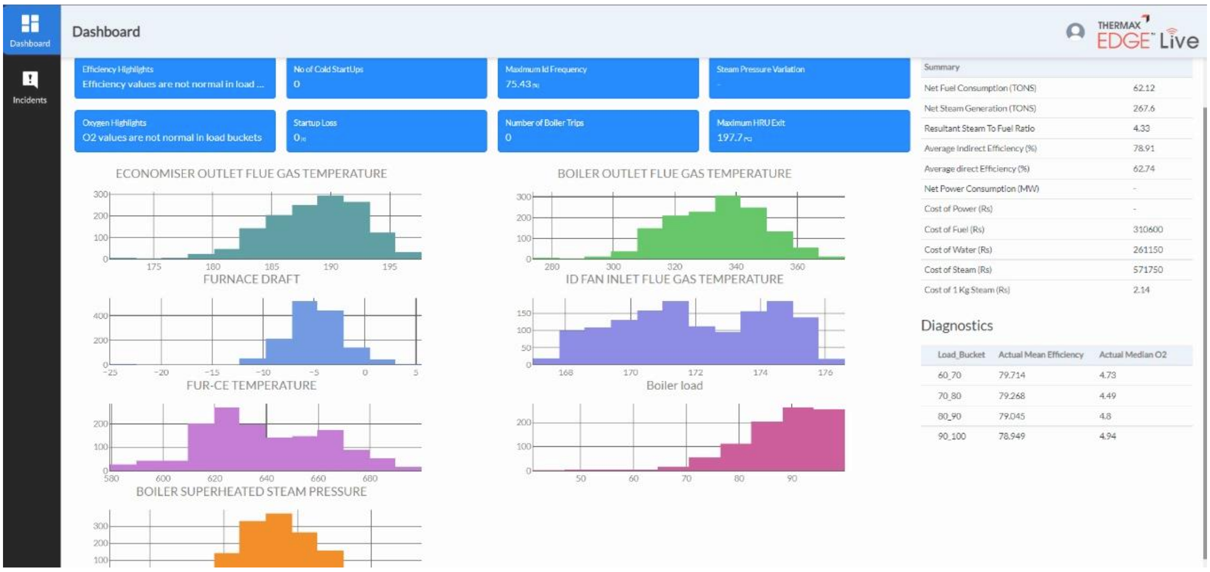
321700
Cost of Water
298968
Cost of Fuel (₹)
Cost of Water (₹)
Fuel Consumption (Tonne)
Steam Generation (Tonne)
Direct Efficiency (%)
Steam To Fuel Ratio


Dashboard
Incidents
THERMAX EDGE Live
Efficiency Highlights
Efficiency values are not normal in load ...
No of Cold StartUps
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Maximum Id Frequency
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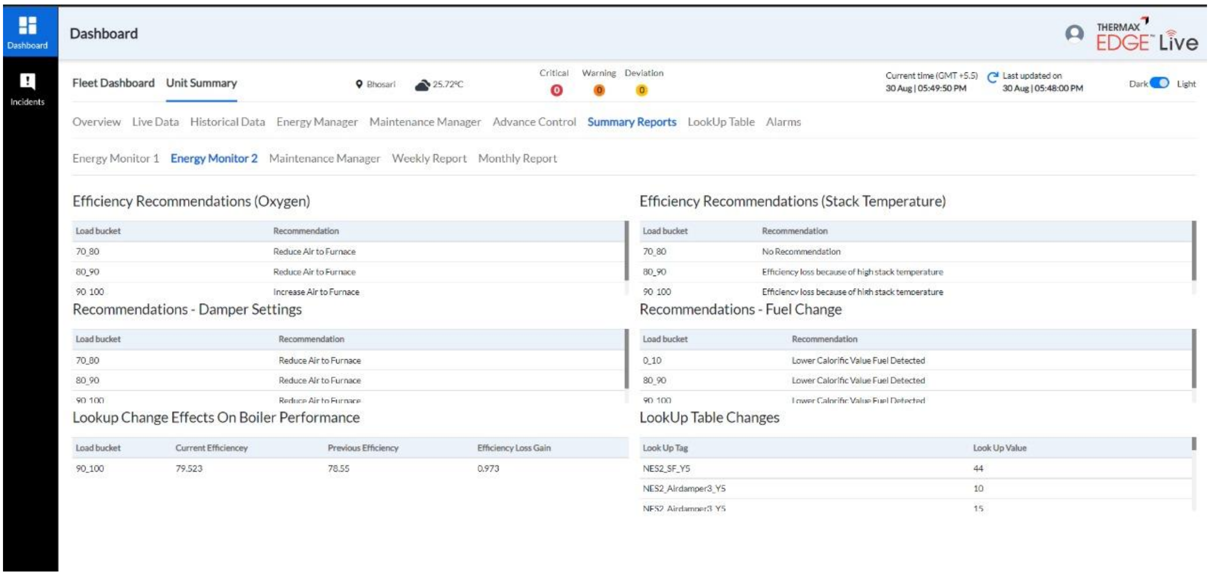
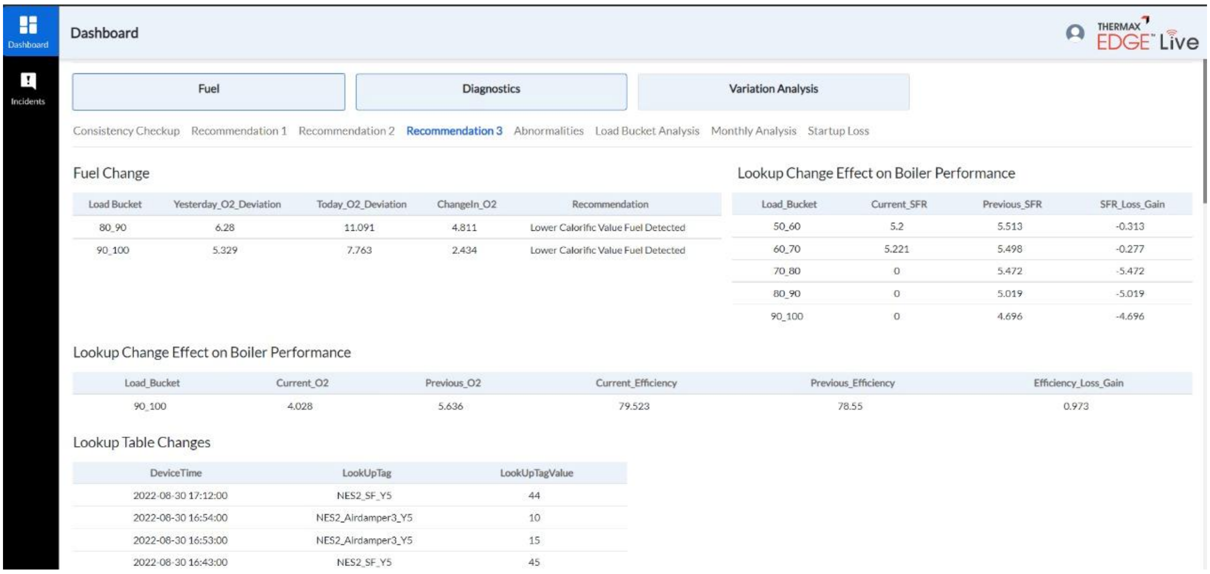
Steam Pressure Variation
Oxygen Highlights
O2 values are not normal in load buckets
Startup Loss
0
Number of Boiler Trips
0
Maximum HRU Exit
197.7
ECONOMISER OUTLET FLUE GAS TEMPERATURE
BOILER OUTLET FLUE GAS TEMPERATURE
FURNACE DRAFT
ID FAN INLET FLUE GAS TEMPERATURE
FUR-CE TEMPERATURE
Boiler load
BOILER SUPERHEATED STEAM PRESSURE
Summary
Net Fuel Consumption (TONS) 62.12
Net Steam Generation (TONS) 267.6
Resultant Steam To Fuel Ratio 4.33
Average Indirect Efficiency (%) 78.91
Average direct Efficiency (%) 62.74
Net Power Consumption (MW) -
Cost of Power (Rs) -
Cost of Fuel (Rs) 310600
Cost of Water (Rs) 261150
Cost of Steam (Rs) 571750
Cost of 1 Kg Steam (Rs) 2.14
Diagnostics
Load_Bucket Actual Mean Efficiency Actual Median O2
60_70 79.714 4.73
70_80 79.268 4.49
80_90 79.045 4.8
90_100 78.949 4.94


Dashboard
Incidents
Dashboard
THERMAX EDGE Live
Fleet Dashboard
Unit Summary
Bhosari
25.72°C
Critical
Warning
Deviation
Current time (GMT +5.5) 30 Aug | 05:49:50 PM
Last updated on 30 Aug | 05:48:00 PM
Dark
Light
Overview
Live Data
Historical Data
Energy Manager
Maintenance Manager
Advance Control
Summary Reports
LookUp Table
Alarms
Energy Monitor 1
Energy Monitor 2
Maintenance Manager
Weekly Report
Monthly Report
Efficiency Recommendations (Oxygen)
Load bucket
Recommendation
70_80
Reduce Air to Furnace
80_90
Reduce Air to Furnace
90_100
Increase Air to Furnace
Efficiency Recommendations (Stack Temperature)
Load bucket
Recommendation
70_80
No Recommendation
80_90
Efficiency loss because of high stack temperature
90_100
Efficiency loss because of hith stack temperature
Recommendations - Damper Settings
Load bucket
Recommendation
70_80
Reduce Air to Furnace
80_90
Reduce Air to Furnace
Recommendations - Fuel Change
Load bucket
Recommendation
0_10
Lower Calorific Value Fuel Detected
80_90
Lower Calorific Value Fuel Detected
Lookup Change Effects On Boiler Performance
Load bucket
Current Efficiency
Previous Efficiency
Efficiency Loss Gain
90_100
79.523
78.55
0.973
LookUp Table Changes
Look Up Tag
Look Up Value
NES2_SF_Y5
44
NES2_Airdamper3_Y5
10


Dashboard
Incidents
Dashboard
THERMAX EDGE Live
Fuel
Diagnostics
Variation Analysis
Consistency Checkup
Recommendation 1
Recommendation 2
Recommendation 3
Abnormalities
Load Bucket Analysis
Monthly Analysis
Startup Loss
Fuel Change
Load Bucket
Yesterday_O2_Deviation
Today_O2_Deviation
ChangeIn_O2
Recommendation
80_90
6.28
11.091
4.811
Lower Calorific Value Fuel Detected
90_100
5.329
7.763
2.434
Lower Calorific Value Fuel Detected
Lookup Change Effect on Boiler Performance
Load_Bucket
Current_SFR
Previous_SFR
SFR_Loss_Gain
50_60
5.2
5.513
-0.313
60_70
5.221
5.498
-0.277
70_80
0
5.472
-5.472
80_90
0
5.019
-5.019
90_100
0
4.696
-4.696
Lookup Change Effect on Boiler Performance
Load_Bucket
Current_O2
Previous_O2
Current_Efficiency
Previous_Efficiency
Efficiency_Loss_Gain
90_100
4.028
5.636
79.523
78.55
0.973
Lookup Table Changes
DeviceTime
LookUpTag
LookUpTagValue
2022-08-30 17:12:00
NES2_SF_Y5
44
2022-08-30 16:54:00
NES2_Airdamper3_Y5
10
2022-08-30 16:53:00
NES2_Airdamper3_Y5
15
2022-08-30 16:43:00
NES2_SF_Y5
45

Future of Edge Live

- Rule based expert system (Using basic stat & knowledge of Thermal engineering)
- Soft computing & evolutionary technique
- Hybrid system- Combination of Phenomenological model & soft computing

Soft computing

Soft computing : Prominent tools

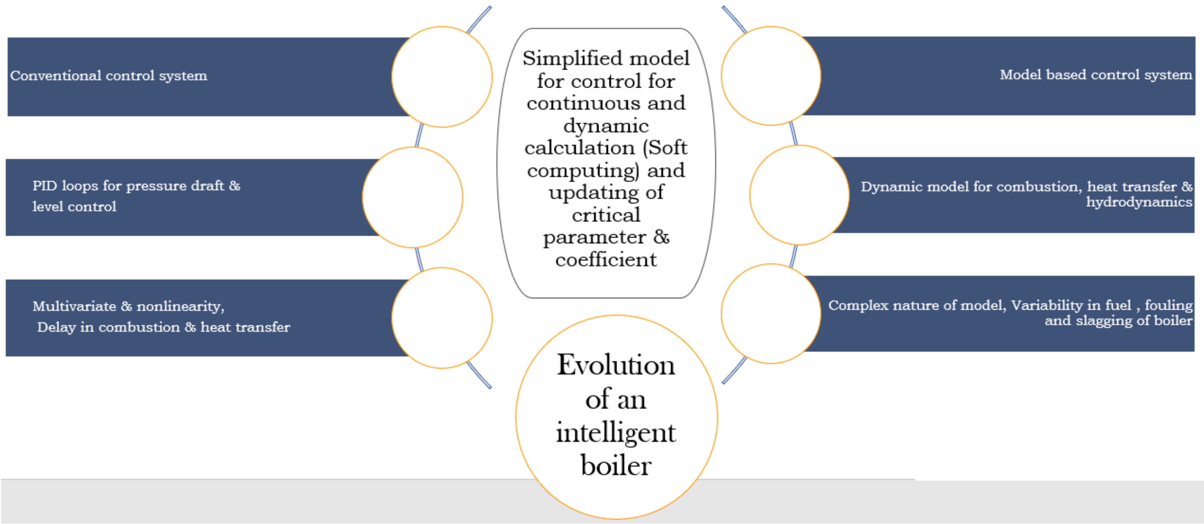
STATISTICS	MACHINE LEARNING	OPTIMIZATION
Exploratory Statistics Fuzzy Logic Correlation Analysis Time Series Analysis Bayesian Techniques	Clustering Classification Regression Neural Networks	Stochastic Methods Evolutionary methods Gradient Based Methods Deterministic Methods

Need of Soft Computing

Characteristics of boiler/heater data	Characteristics of Big data
Complex Dynamic Non-Linear Multivariate	High volume High velocity High variability High veracity

Complex system can't be modeled by only phenomenological model

Need of hybrid system

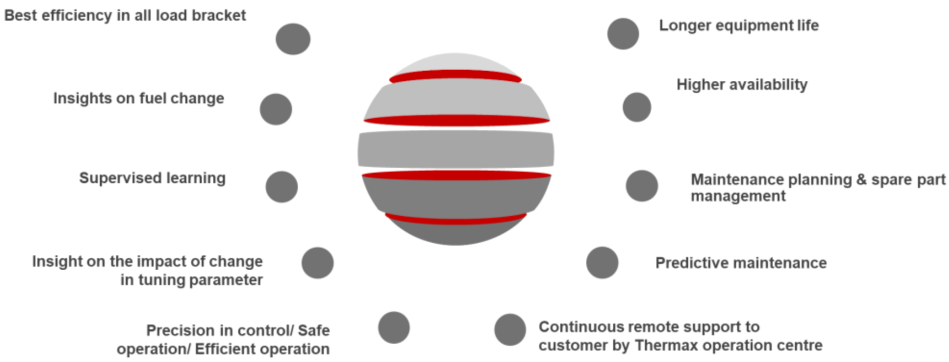


Evolution of an intelligent boiler

Concept of an intelligent boiler

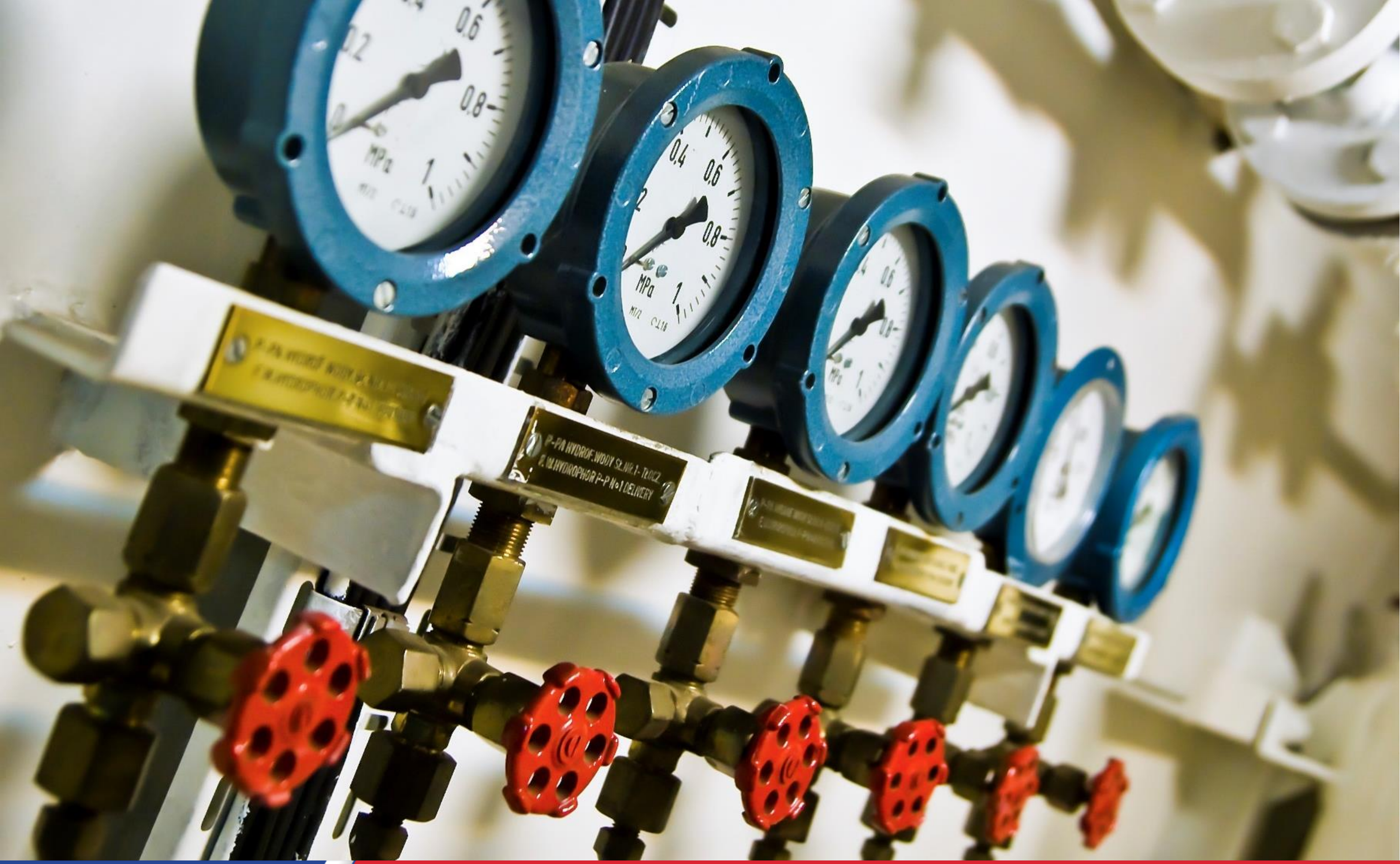
- Boiler can recognise external(Fuel & ambient condition) & internal(Slagging, fouling, leakage) change
- Boiler can recognise the best set operating parameter and its impact on the boiler performance
- Boiler can identify the change requirement and execute the change

Customer Benefits



Collaborative Approach

Connect. Collaborate. Care



WATER TREATMENT

By Mr. Udayan Shrouti
Libra Agencies, Nagpur

Name: Udayan Shrouti
Organisation: Libra Agencies, Nagpur
Designation: CEO
Education: B E (Hons.) Mechanical Engineering BITS, Pillani

Libra Agencies is registered MSME. Libra Agencies functions in the domain of utility services as a solution provider. Commencing activities from choosing right technology to application deployment and finally monitoring with maintenance services, a seamless solution is offered to customers. Libra Agencies is specially focused on most vital natural resource – Water. Good water for all is our vision. We propose to achieve our vision by deploying technology inspired from nature.

We offer fully customized solutions as well as standard pre-engineered water and wastewater treatment plants. Our wider diversified work experience delivers most cost competitive solutions to our valued customers.

We also provide Sunir Water Care Services (SCS) a comprehensive program providing customers with the products and support services to maintain water treatment systems operating performance and minimize lifecycle cost.

We have successfully executed projects for diverse processes such as Water Purification System for drinking water, Boiler Feed water for process and power boilers, Cooling Tower make up, Cooling Tower recirculating water, Water treatment systems for industrial fluid preparations, Special water treatment systems for recycle and reuse of industrial waters, Wastewater purification system.

We have in depth experience spanning three decades in treating water and wastewater for industries such as Textile, Food processing, Steel, Edible Oil Industry, General Engineering, Rubber, Power Plants, Milk Dairy, Hospitals, Hospitality, Agro and Agro processing Industries.

Water Purification Systems for Process Heating Boilers

Boilers are heat transfer devices, where in water in the form of either liquid or gaseous steam is commonly employed as a medium for the transport of heat to some distant point of use.

Water is particularly suitable because of its relative abundance, low cost, and high heat carrying capacity. It is generally, the medium of choice in most boiler applications, whether for domestic, commercial, institutional, or industrial purposes.

However, a boiler can only carry out its primary functions of transferring heat to water and (in steam generators) separating steam under pressure from water most efficiently if the quality of the various types of water used (such as makeup water, feedwater, and boiler water) are effectively and continuously controlled. The difficulty in this quality control process is that water is a "universal solvent, " and as a result, all sources of water contain various natural concentrations of dissolved minerals and gases in addition to suspended solids and biological matter. The relative amounts of each of these impurities tend to vary considerably with geographic location and season. This phenomenon results in countless permutations of water type and quality around the world, each potentially available as a source of makeup supply to boiler plant systems, evaporators, and other forms of water heating and steam generating devices. In many industrial applications, the negative impact of these natural impurities may be further compounded by the presence of small concentrations of process contaminants.

The effect of these various impurities or contaminants is to hinder the heat transfer and steam generation processes, to adversely affect the quality and purity of steam, and to act as primary instigators in the corrosion and wastage of boiler plant system materials of construction. A wide variety of chemical reactions and physical mechanisms can and will take place, including the deposition of various crystalline and non-crystalline scales on the water side of heat transfer surfaces, the formation of sludges, metal corrosion, and carryover of contaminants into the steam. The function of boiler water treatment, therefore, is to control the waterside chemistry of boiler plant systems within certain agreed and relevant parameters and specifications. As these adverse processes are by no means limited to the boiler itself, in practice, boiler water treatment also includes pre-boiler and post-boiler functions and further requires that all the various types of water utilized are controlled through a comprehensive treatment and proactive management program. Clearly, the lack of or the use of an inappropriate boiler water treatment program creates significant operational difficulties and impacts the economics of the entire process, from start to finish.

Water is converted into gaseous form in an industrial boiler to provide heat energy in the process plant. Apart from providing heat energy to the process, the water also keeps the boiler heat exchanger portion cool and healthy. In order to ensure that water acts as a most appropriate cooling medium it is essential to ensure that water without any hindrance continuously keeps the heating area wet, corrosion and scale free.

The various impurities in water are either in the form of dissolved salts, gases or suspended solids. The various impurities that need removal are: - Suspended Solids, Turbidity, Hardness, Acidity, Alkalinity, Oxygen, Total Dissolved Solids, Dissolved Carbon Dioxide, Alkalinity, Organic matter and silica.

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

Sr.	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 CaCO3 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 Na2SO3 mg/l	30 – 50	20 - 30	--------------
	Residual Hydrazine as N2H4 mg/l	0.1 to 1.0 (if added)	0.1 – 0.5 (If added)	0.05 – 0.3
	Ratio Na2SO4/Caustic Alkalinity as NaOH	Applicable to riveted boilers only		
	Phosphates as PO4 mg/l	20 – 40	15 - 30	5 – 20
	Total Dissolved Solids mg/l max	3500	2500	1500
	Silica as SiO2 mg/l	Less than 0.4 of caustic alkalinity		15.0

The boiler feed water and boiler drum water confirming to the above standards ensures fairly trouble-free operation of the boiler. In 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.

The various equipment's deployed to treat the feed water are as under:

- Water Softening Plant
- De Alkalizer Plant
- Demineralization Plant
- Reverse Osmosis Plant

Water Constituent Vs. Technology

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

Blowdown

Even after installation of water treatment plant and regular dosing of the chemicals the concentration of the salts occurring in the boiler is limited by removal of concentrated boiler water. This process of removal of concentrated boiler water is named as blow down. There are two types of blow down in a water tube boiler namely continuous and intermittent. The continuous blow down is given to the boiler drum to ensure maintenance of total dissolve salts at level specified under IS 10392 – 1982. The intermittent blowdown is given to scrub the heat transfer surfaces. Intermittent blow down controls the suspended, dissolved solids and also prevents accumulation of sludge.

Selection Process for New Water Treatment plant

It is vitally important to know the feed water sources in terms of quantity and quality of the water. At the same time, it is prudent to ensure maximum condensate recovery. The condensate temperature is far greater than the ambient water temperature resulting in saving of the fuel. Higher feed water temperature implies lesser fuel to reach the intended steam pressure and temperature. The condensate has very low dissolved solid content. Higher condensate recovery ensures lowering of the boiler feed water TDS and assists in reducing the fuel loss attributable to the blow down.

Any water treatment plant operation has capital cost and operational cost associated with its installation and operation. The operation cost of water treatment plant consists of following:

- Raw water cost
- Chemical cost
- Electricity / Energy cost
- Manpower cost
- Wastewater treatment cost
- Maintenance cost

The net cost per unit of treated water is calculated on above.

Once the net cost of treated water is arrived at savings if any to reduce the fuel cost associated with the blow down can be worked out and the most appropriate Water Purification plant can be deployed to treat the boiler feed water.

It is of vital importance to treat the boiler feed water including condensate to ensure that all the water parameters are well within the limits. Proper boiler water treatment ensures scale, corrosion and carry over free boiler operation. This leads to best boiler utilization and productivity.

RESIDUAL LIFE ASSESMENT AND CONDITION MONITORING

By Dr. S. K. Nath & Mr. Rajesh Ranjan
Central Power Research Institute, Nagpur

Name: Samir Kumar Nath
Organisation: Central Power Research Institute, Nagpur
Designation: Joint Director
Education: Bengal Engineering College (Calcutta University), IIEST (BE & ME), IIT Madras (PhD)

Specialized in solving operation and maintenance problem of power plants by developing new and novel inspection techniques in the area of non-destructive evaluation (NDE). Has more than 28 years of experience in both Research & Development and Engineering Services. Professionally qualified in ASNT/ISNT Level-II/I in UT, MT, PT, RT, and ET.

As an expert and experienced professional in remnant life assessment (RLA) and NDE based condition assessment of plant components has rendered many field engineering & consultancy services, carried out many R&D projects, published many research papers in national & international journals of repute, coordinated many seminars/workshops/training programme, guided many UG/PG scholars and delivered many invited technical lectures in industries and academic institutions.

- Received “Shri B M Naidu Award for Best Research Paper” of CPRI in the year 2015
- Received a patent in 2021 (Patent No. 380101)

Name: Rajesh Ranjan

Organisation: Central Power Research Institute, Nagpur

Designation: Joint Director

Education: B.E (Mech.), M.E (Material Science), ASNT Level-II, Auditor ISO/IEC 17023:2017

Working In Central Power Research Institute, Thermal Research Centre, Nagpur. Expert in the field of metallurgy, Non-Destructive tests, taken up many failure analysis of various power plant components and condition assessment of boilers and turbine components including pressure parts, Chemical and elemental analysis of materials and deposit analysis.

26 years of experience in the field of non-destructive tests and metallurgical analysis. Expert in guidance to minimize the frequent boiler tube failures in various Thermal Power plants and Process Industries of India.

- 4 technical papers in International Journals
- 12 technical papers in national journals and conferences
- Training provided to many officials of Power sectors on failure analysis of power plant components.
- Expert guidance to many power sectors for the solutions to minimize the pre mature failure of power plant components.

Working in CPRI since 26 years. Testing, evaluation and consultancy for CPRI in the field of material characterization, failure analysis, condition assessment of power plant components, RLA study of boiler and turbine, life prediction of plant components through metallurgical analysis.

Remnant life and Condition assessment of Boiler Pressure Parts and Role of Boiler Inspectorate during Assessment.

Abstract:

Boilers are made up of large amount of tubing and pipes of different materials which will have to withstand high pressure and temperature. The pressure parts undergo aging due to various reasons and subsequently starts failing leads to outages of plant. These aging boiler pressure parts are required to be monitored and assess through condition assessment and Remnant life assessment. Indian boiler regulation act has discussed in article 391A (b) of IBR -1950 and made mandatory to assess these components through non-destructive and destructive test to find the life span and present conditions of the pressure parts components. Life estimation of all the components of boiler is very important maintenance tools for predictive maintenance.

Introduction:

Boiler, a steam generator is an integral system of a thermal power plant. In addition to the utility boilers there are large numbers of process steam boiler. The components of boiler mainly the pressure parts are continuously subjected to high temperature and pressure throughout the service life. Failure of any components not only leads to the loss of power generation; it poses threat to the safety of the surrounding working environment. Thus, safe running of a boiler is of prime importance. Healthiness of a boiler with respect to its fitness for the purpose is monitored by the Government statutory body-inspectorate of boilers on a regular basis. Remnant life assessment and condition assessment of boiler pressure parts is carried out and is mandatory to ascertain the health status of all pressure parts and other related components of boilers.

RLA & Condition assessment of boiler components using non-destructive techniques provides the healthiness of the components at present condition which ensures and prevents the premature failures. The condition assessment also ensures its full utilization up to its useful life. It will also result in enhancing the original rated capacity by utilizing earlier conservative design consideration. The industrial growth and improved living standard for Indian population has exceeded the available supply of power in this country and needs to huge additional power to fulfil the target of power on demand and to achieve these requirements it is required to install new power generating units. In addition to installing new power plants, generating power from the existing aged power stations to the maximum extent possible has gained importance.

Augmentation of power generating capacity of the old power plants by renovation and modernization can significantly contribute to achieve the target.

The quicker, cheaper and more practical solution to increase the existing available power supply is to carry out condition assessment and life extension program for the operating power plant components.

It is necessary to evaluate the condition of the boiler which had to withstand fatigue stress, creep damage, oxidation, corrosion attacks etc.

Some of the non-destructive techniques are discussed herewith.

The components of boilers like headers, tube of different zones is subjected to high temperature and pressure during steam generation. The tubes and other related components may fail due to several regions without alarming any symptoms. This leads to huge generation loss. The reasons of failure are very much important to analyse to minimize the pre mature failure in future so that the losses due to unforeseen causes may be control. The tubes and other related components in boiler may failed due to various reasons like short term and long overheating, corrosion, fatigue, creep, erosion, oxidation, scale deposits, etc. Hence failure analysis of power plant components is very vital investigation to minimize the pre mature failure.

The dynamic structures like TG decks are subjected to continuous cyclic loading, various operational loads, vibrations etc results distresses and formation of cracks in the hardened concrete structures. The operation loads like mechanical imbalance, sudden impact due to various reasons like electrical shocks, temperature condition, ageing effect create abnormal conditions in the concrete structures.

The condition assessment and routine inspection of hardened structures are very important for continuous operation. It is essential to determine the distress and deterioration occurred in the structures.

RLA of Boilers - Role of Indian Boiler Regulation

Article 391A (b) of IBR 1950 states that the boilers which are operating at a temperature of 400°C (main steam outlet temperature) and above including utility and industrial boilers and all boiler parts operating in the creep range shall be tested non-destructively as per the table-1(391A (b)) after they are in operation for 1,00,000 hours for assessment of remnant life of parts.

The boilers which are operating at a temperature less than 400°C (main steam outlet temperature) on completion of a life of twenty-five years are to be tested for its remnant life of its components as per table-2. (391A (b))

However, the boilers working at a pressure less than 50kg/cm2 and temperature less than 400°C (main steam outlet temperature), such elaborate remnant life assessment is not mandatory but in such cases drums and headers of such boilers shall be inspected by non-destructive tests like ultrasonic test, Magnetic particle test and Dye penetrant test.

Heat recovery steam generators (HSRGs) which are operating at a temperature of 400°C (main steam outlet temperature) and above shall be non-destructively tested by Remnant Life Assessment organization for their components as per Table 3 (391A (b)).

If results are acceptable as per standard laid down by Central Boiler Board, a certificate shall be issued by the Chief Inspectorate of Boilers for extending the life of boiler for a period of further period not exceeding six years or such fewer periods as recommended by the Remnant Life Assessment Organization. This assessment shall be carried out thereafter every six years.

The assessment of remnant life shall be carried out thereafter by the organizations working in the field of boilers and remnant life and extension thereof after such organization is approved by the Central Boilers Board. Such organization shall work in close coordination with the office of the Chief Inspectorate of boilers in the field of remnant life assessment and extension.

Non-Destructive Evaluation (NDE)

Various NDE techniques for detection of cracks, effects of corrosion/erosion etc. in addition to commonly adopted techniques such as Ultrasonic thickness gauging, Ultrasonic flaw detection, Dye Penetrant testing, Fluorescent magnetic particle testing, specialized techniques such as assessment of hydrogen damage by Ultrasonic, measurement of steam side oxide scale by in-situ ultrasonic, video probe examination of critical components are employed. Metallurgical tests such as in-situ metallography using replica method, in-situ chemical analysis by metal spectroscope / X-ray fluorescence method, in-situ hardness measurement etc.

NDE techniques adopted in the residual life assessment of plant components can be broadly classified as conventional and specialized techniques. Conventional techniques include Visual examination & Dimensional measurement using appropriate tools, Ultrasonic thickness gauging, penetrant testing, and Magnetic particle inspection using wet fluorescent method.

Specialized NDE techniques include video probing using fibre optics to assess the damage on the internal surfaces specially for corrosion, erosion, cracks and the presence of foreign materials, in-situ replica technique to study the material degradation and the presence of micro cracks, ultrasonic testing using high frequency pulse transducer for measurement of oxide scale on the steam side, ultrasonic attenuation measurement to detect hydrogen damage.

Advanced Ultrasonic Techniques

Failures of super heater and re-heater tubes and other related components can be considered as one of the most prevalent causes for the unforeseen outages of a thermal power plant. The failures are often attributed to creep deformations which can lead to rupture. Such premature failures are caused by the steam side build-up which can cause an increase in the operating temperature of the tube. Using a high frequency Pulse-Receiver and using specially designed high frequency transducers operating in the frequency range (20 – 50 Hz), it is possible to measure the oxide scale thickness on the steam side.

Hydrogen damage failures of water wall-tubes are generic for some utilities where condenser leaking occurs for prolonged periods. Since the damage is initiated from the waterside surface of the tubes, the same cannot be revealed on the outside surface. Ultrasonic examination using a 5 MHz longitudinal wave transducer and measuring the attenuation characteristics can indicate the regions where micro-fissuring due to hydrogen damage has occurred. Replacement of tubes can be done in time to avoid unplanned outages.

Micro Structural Damage Evaluation

Engineering materials are subjected to several damage mechanisms while in service. Before the damage becomes perceptible to the unaided eye, the microstructure would have responded to the degradation of material.

In high pressure and high temperature components, the consequential damage mechanism is creep, which manifests itself in the form of cavities in the microstructure. The morphology (shape characteristics and orientation) of the cavities lends clue to the status of the component.

The phenomenon of creep is guided by the following factors: Temperature, Stress, Time and Material Properties

Given a material is subjected to constant temperature and stress (pressure), creep damage evident in the microstructure will be a function of time (expended life fraction).

Neubauer and Wedel related the creep-life consumption of plant components to cavity classification as shown in the table given below:

They characterized cavity evolution in steel at five stages – i.e., undamaged, isolation cavities, oriented cavities, linked cavities (micro-cracks), and macro-cracks. They also formulated the recommendations corresponding to the different stages of cavitation. For undamaged & class A damage, no remedial action would be required. For class B damage, consisting of oriented cavities, re-inspection within1 ½

To 3 years would be required. For class C damage, repair or replacement would be needed within six months. For class D damage, immediate repair would be required.

Structural Classification	Microstructure features	Action needed	Expended life fraction
Undamaged	Ferrite & Pearlite	None	0.12
A	Isolated cavities	None until next major scheduled maintenance outage.	0.46
B	Oriented cavities	Replica test at specified interval preferably within 1 ½ to 3 years	0.50
C	Linked cavities (micro-cracks)	Limited service until repair and better to inspect within 6 months	0.84
D	Macro-cracks	Immediate repair	1.00

Test Procedures:

Visual Examination

Visual examination is carried out to assess material wastage due to oxidation, erosion/corrosion, fouling of heat transfer surfaces. This includes inspection of drum internals to ensure proper steam/water separation. Visual inspection the observations made with reference to discoloration of coils, prior evaluation of pressure part condition based on experience and design knowledge from similar plants makes sample selection more rational. Samples from the regions thus determined are most susceptible to failures. Such samples from each component are selected for an evaluation of the metallurgical condition.

Ultrasonic Testing

By using high frequency sound waves, the surface and sub-surface flaws in the components are detected. Cracks, laminations, shrinkages, cavities, flakes, pores etc. that act as discontinuities in the components are detected.

Magnetic Particle Inspection

The technique is adopted for locating surface and sub-surface discontinuities like seams, laps, quenching and grinding cracks and surface rupture occurring on welds. This method is also used for detecting surface fatigue cracks developed during service.

Magnetic Particle Inspection helps to detect cracks and discontinuities on the surface in ferromagnetic materials. Magnetizing at least two mutually perpendicular directions ensures detection of flaws in all possible orientations.

In-Situ Oxide Scale Thickness Measurement

Ultrasonic equipment with high frequency probes is used for in-situ oxide scale thickness measurement for the specific coils/tubes exposed to high temperature. The measured oxide scale thickness becomes an important input for determining the extent of degradation. In-situ evaluation of SH/RH tubes by Non-Destructive evaluation (Ultrasonic) for steam side oxide scale gives clear indication of average tube metal temperature, since the growth of oxide scale is a function of time and temperature.

Ultrasonic technique using high frequency probes is employed for measurement of thickness of steam side oxide scale. The ultrasonic method used is based on transmitting a sound wave through the tube thickness. The thickness is calculated by measuring the time difference between the signals reflected from the metal/scale interface and the tube ID surface. The outer surface of the tube under inspection region is made free of fireside oxide deposits and polished to expose the base metal. The ultrasonic energy of high frequency (25 MHz) from a specially designed focused beam type transducer is transmitted through the sample tube. With the knowledge or working hoop stress and metal temperature, it is possible to determine the time to creep rupture failure from the ISO data of specific tube material.

Dye Penetrant Inspection

This technique is adopted primarily for detection of the discontinuities that are open to the surface of a part, like surface porosity, pitting, pinholes etc. In principle the dye/liquid (Penetrant) is applied to the surface to be examined and allowed to enter into the discontinuities. All excess penetrant is then removed; the surface is dried and the developer is applied. The developer serves both as a blotter to absorb the penetrant and as contrasting background to enhance the visibility of the indication.

In-situ Metallography

Power plant components which operate at high temperatures, creep is a major cause of cracking especially on the highly stressed brittle regions. Creep damage occurs in different stages and the first sign in the formation of microscopic cavities at grain boundaries. Application of an NDE technique using a plastic film replica on the metal surface can assess the creep damage and the presence of micro cracks. The findings of this examination have recommended replacement of the header at the first available opportunity.

The process involves preliminary preparation of the metal surface using polishing equipment. When the spot is ensured free from rust and scale polishing is carried out using abrasive paper of varying grits from 120, 200, 400 and 600 in sequence. Subsequently diamond paste lapping is done followed by etching to reveal the microstructure.

The microstructure of component is transferred to a film and this is called replication. The microstructure is further examined in laboratory with magnification up to 500X and more to assess the metallurgical damages like creep cavitation etc.

Hardness Measurement

A portable hardness tester is used for in-situ hardness measurement of various critical components like steam drum, high and low temperature headers, pipelines etc. Hardness measurement aids in assessment of metallurgical status/condition of component.

Dimensional Measurement and Thickness Measurement

Outside diameter measurements are generally employed to determine the swelling (bulging) due to creep. Diameter measurements are made using digital Vernier callipers and bow gauges. Thickness measurements at critical areas give a measure of thickness loss over the years due to erosion and corrosion. The thickness measurements are made using ultrasonic thickness gauge.

Video probing using fibre-optics Fibroscopic Inspection

The internal condition of many power plant components needs examination. High temperature headers may develop cracking due to creep or fatigue or a combination of both. Video probing using fibre-optics can detect the presence of these cracks in time for further evaluation. In addition, the presence of corrosion pitting and foreign particles may also be detected by this examination. Based on the above finding, chemical cleaning of the boiler may be recommended. This inspection reveals the valuable information about the internal condition of the components.

Deposit Analysis

Deposit samples carefully collected after the visual inspection from critical components like drum (internal), external deposits on high and low temperature coils etc. Those samples are subsequently analysed in laboratory for elemental analysis by conventional chemical methods/atomic absorption spectrometer.

Mechanical Properties:

The selected tubes from various zones of boilers have to be collected. These tubes are tested for Creep rupture test, Tensile and flattening test to assess their present conditions of available strength.

Improved Suggestions for Conducting RLA of Boilers

The following improvements are suggested while conducting RLA of boilers:

A. Location details of all the weld joints of the pressure piping namely main steam line (MSL), hot reheat (HRH) line, cold reheat (CRH) line, feed water line should be well documented by the owner. With the availability of such document, a particular weld joint of interest based on the findings of the analysis of the piping any other analysis can be exactly bared open (de-insulated) for conducting various tests with not much loss of time and more reliably during RLA study at site.
B. Detected weld defects in thick section components e.g., headers, pipelines etc should be reassessed by ultrasonic time of flight diffraction (TOFD) method.
C. Leakage points causing ash accumulation in pent house should be identified and repaired. Clean pent house immensely helps in better NDE of all the critical pressure parts e.g., headers, link pipes etc located there within the short shutdown period.
D. In-situ replication for assessing microstructural degradation is carried out during RLA study. Location details specific to a particular pressure part where the replica of the microstructure is taken, should be marked and documented and included in the report. Given an opportunity subsequently, replication at the same location can be conducted to reassess the damage accumulation with respect to creep, a high temperature damage mechanism in boilers. This will help in obtaining a trend analysis of the microstructural damage of the part and better prediction of the life remaining.
E. Failure investigation of each boiler tube leakage (BTL) should be arranged to be conducted by the owner. Consolidated report of all such leakages and investigation

conclusions should be made available to the assessment organization since it will serve as an important technical input for RLA study.

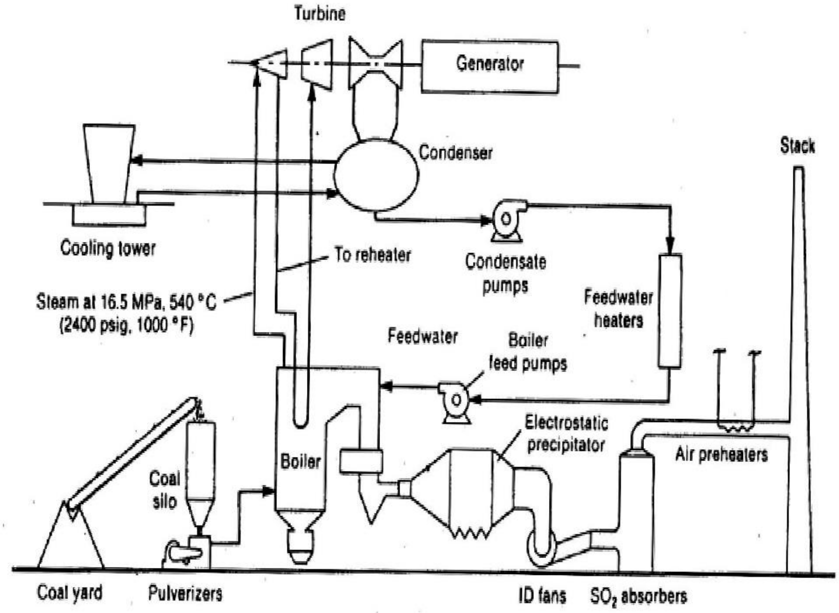
F. In-situ material mix-up survey should be conducted during RLA study. Especially appropriateness of the material grades of the new tubes going as replacement should be confirmed. This may reduce certain forced outage due to BTL subsequently.

Conclusions:

The RLA Study and condition assessment of boiler pressure parts and its components helps in recommendation for safe operation and maintenance practices and also in RUN / REPAIR / REFURBISH / REPLACE OR MODIFICATION / REINSPECTION based on the thorough analysis with close guidance and monitoring of inspectorate of boilers

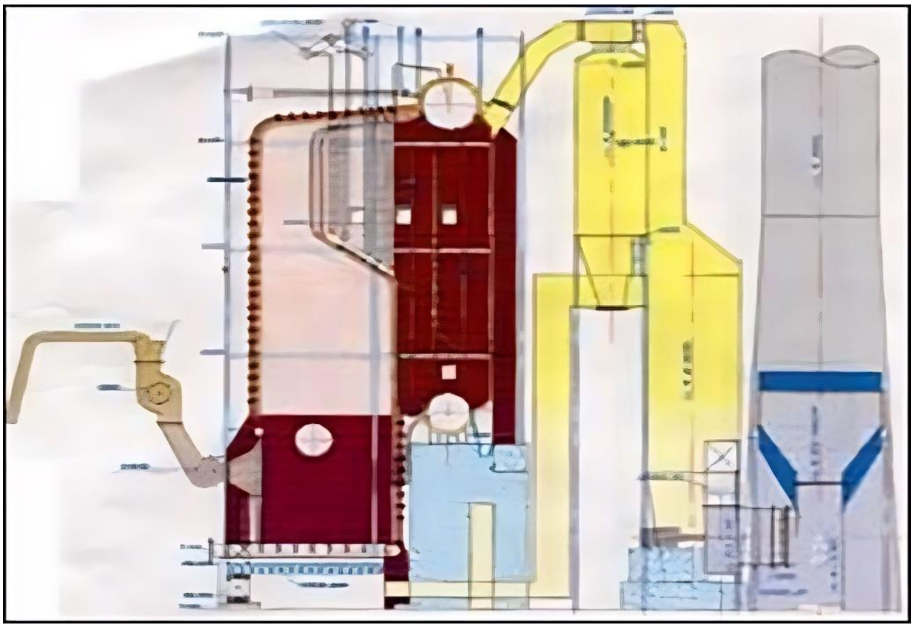
CPRI has successfully conducted the RLA and condition assessment study of more than 150 boilers of different capacities ranging from 50MW to 500 MW in both utility and non-utility category as per the stipulated guidelines of IBR throughout the country.

Residual Life Assessment (RLA) and Condition Monitoring of Boiler



Schematic diagram of a coal-fired steam power plant

Boiler



Operational Effects on Boiler Components

- High temp. effects (ageing)
- High temp. corrosion (ash attack)
- High velocity flue gas with particulate burden (erosion)
- Thermal cycling (crack)
- Water chemistry effects
- Maintenance repairs (weld, foreign materials entrapment)
- Material mix-up during repair

Manifestation

- Mechanical
    - Material loss, wall thinning
    - Weld defect
    - Crack
    - Swelling
    - Slagging, fouling
    - Loss of material strength
- Metallurgical
    - Hydrogen embrittlement
    - Creep life
    - Structural integrity
- Steam Starvation
    - Sudden rupture

Various damage mechanisms and suitable NDE methods (Boiler)

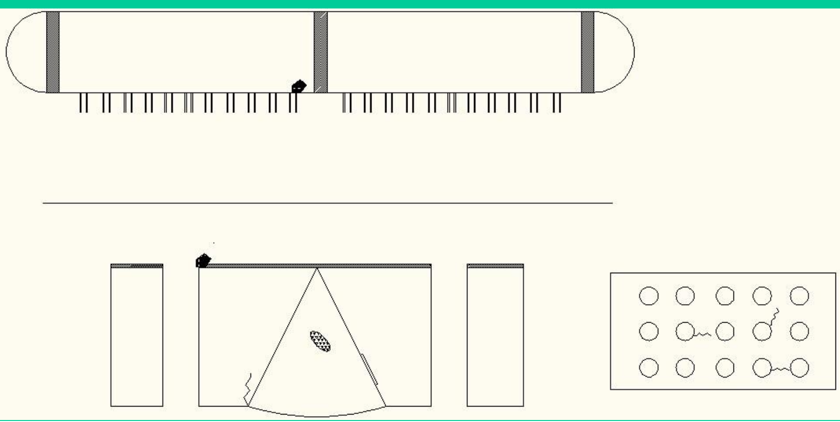
Damage Mechanism	NDE Methods for detection
Erosion	Visual Examination (VE), Ultrasonic Thickness Survey
Blockade in water circuit	Fibroscopy
Welding defects	Ultrasonic Test (UT), Magnetic Particle Test (MPT), Dye Penetrant Test (DPT), Radiographic Test (RT)
Hydrogen Embrittlement	Ultrasonic Test (UT),
Creep	In-situ Metallography, Hardness Measurement
Oxide Scale growth	Ultrasonic Test (UT)
Crack detection and sizing	Ultrasonic Time of Flight Diffraction (TOFD) inspection, Phased Array Ultrasonic Test (PAUT)
Short Term overheating	In-situ Metallography, Hardness Measurement
Swelling	Dimensional Measurement (OD)

Header

Areas of Inspection:

- Parent body
- Weldments
- Stub and opening joints
- Inter-opening ligament area

Flaws



Pre-existing	Post-operative
• Slag • Sidewall lack of fusion (look for whether these are active or not)	• Cracking (weld, ligament) • Oxide scale built-up • Foreign material entrapment

Selection criteria for NDE methods

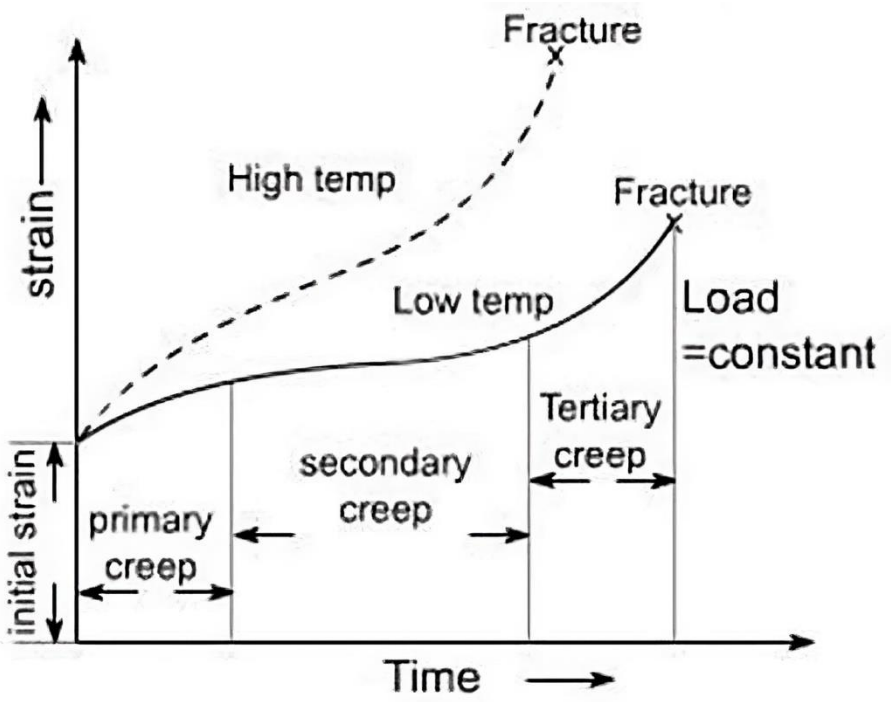
NDE Methods	
Dye Penetrant Test (DPT)	Time of Flight Diffraction (TOFD)
Magnetic Particle Test (MPT)	Phased Array (PA)
Fibroscopy (FIB)	Oxide Scale Measurement (OT)
Ultrasonic Test (UT)	Radiographic Test (RT)

Outlet Header (Secondary Superheater)

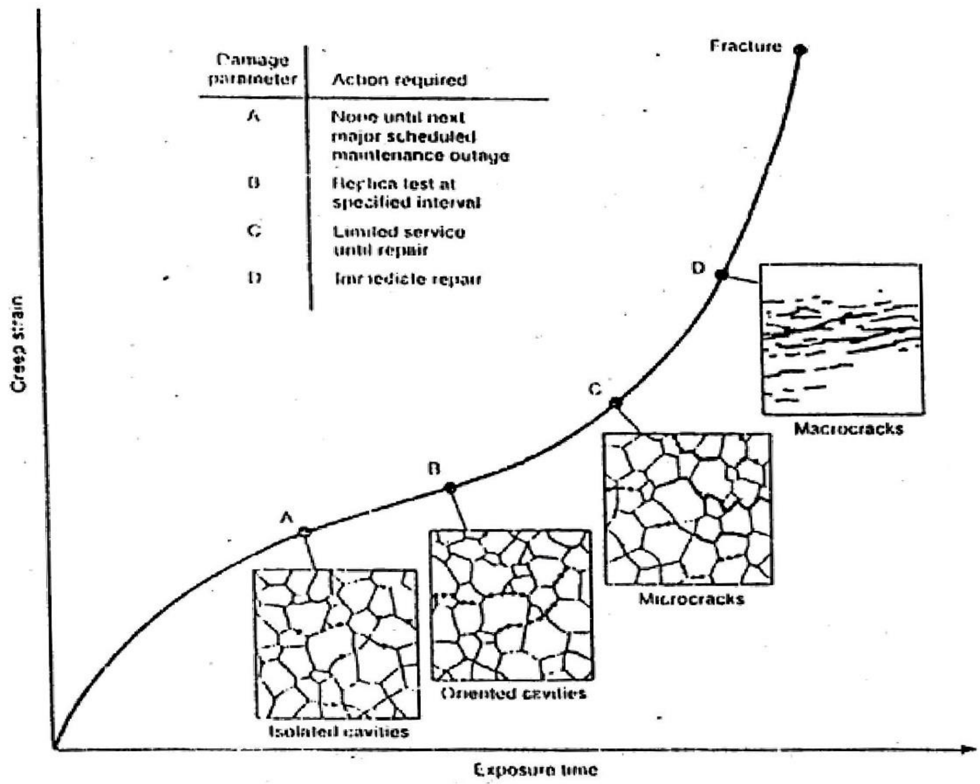
Failure Mechanism	Assessment Method
• Creep • Fatigue • Corrosion	• Replica • Internal Inspection • Dimensional Measurement • Dye Penetrant Test • Ultrasonic Flaw Detection • Magnetic Particle Inspection • Stub tube Magnetic Particle Inspection

What is Creep?

The time dependent, thermally assisted deformation of components under load (stress) is known as creep.



[Typical creep curve]



Structural Classification	Microstructure features	Action needed	Expended life fraction
Undamaged	Ferrite & pearlite	None	0.12
A	Isolated cavities	None until next major scheduled maintenance outage	0.46
B	Oriented cavities	Replica test at specified interval preferably within 1.5 to 3 years	0.50
C	Linked cavities (micro cracks)	Limited service until repair and better to inspect within 6 months	0.84
D	Macro cracks	Immediate repair	1.00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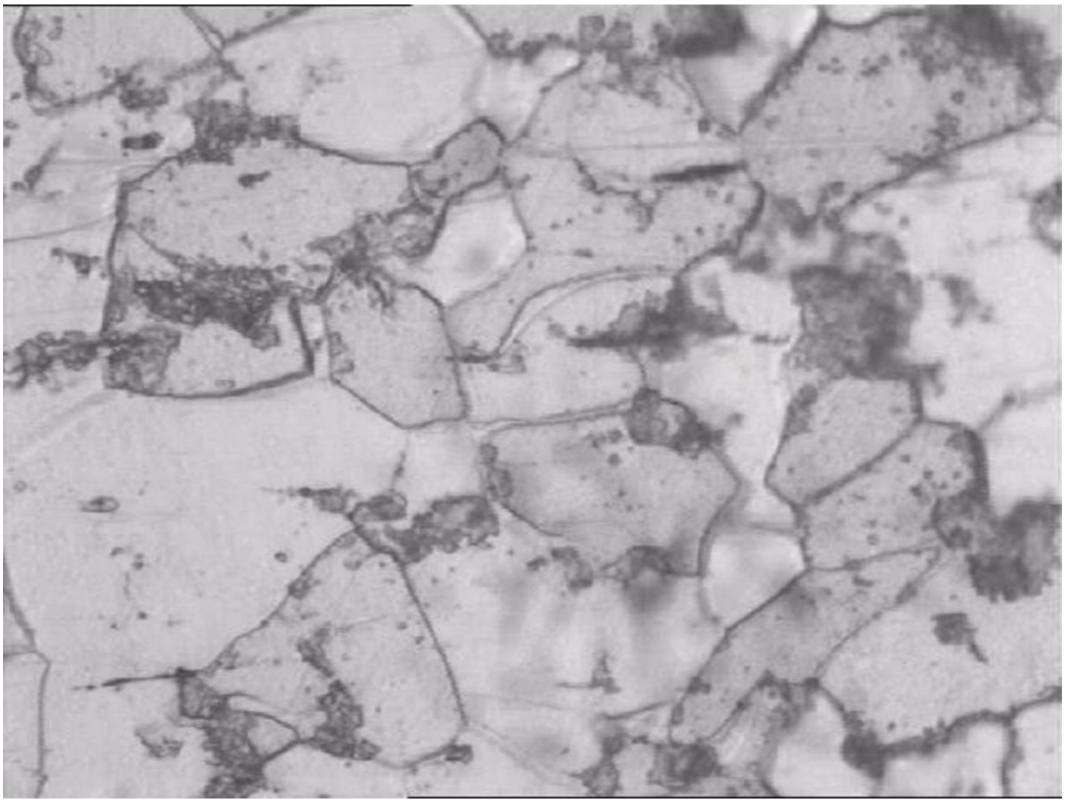
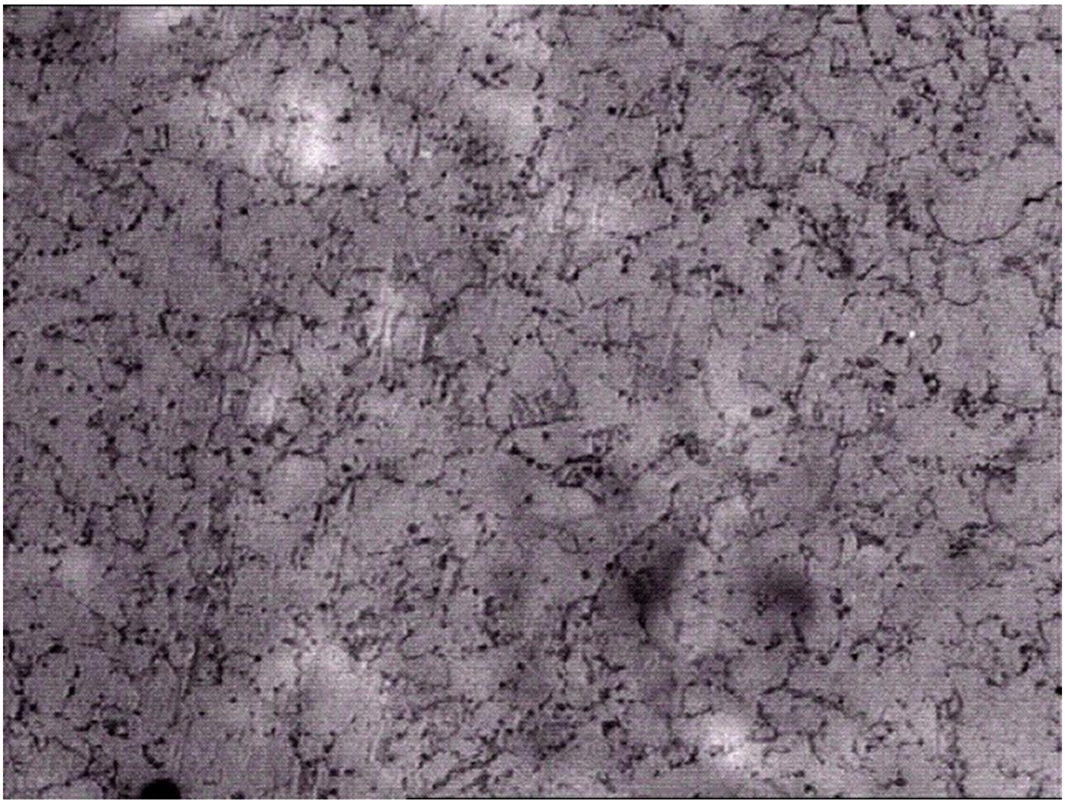




Residual Life Assessment (RLA) & Renovation & Modernisation (R&M)

Objectives

Health Check-up
Safety to Continue Operation
Scientific tool for Design Options

- Run
- Repair
- Refurbish/ Retrofit
- Replace
- Operational Improvements

Methodology

- 1A - Past History Review
    - Interview with Plant Personnel
- 2A - Present Condition Assessment
    - Hot walk down Survey

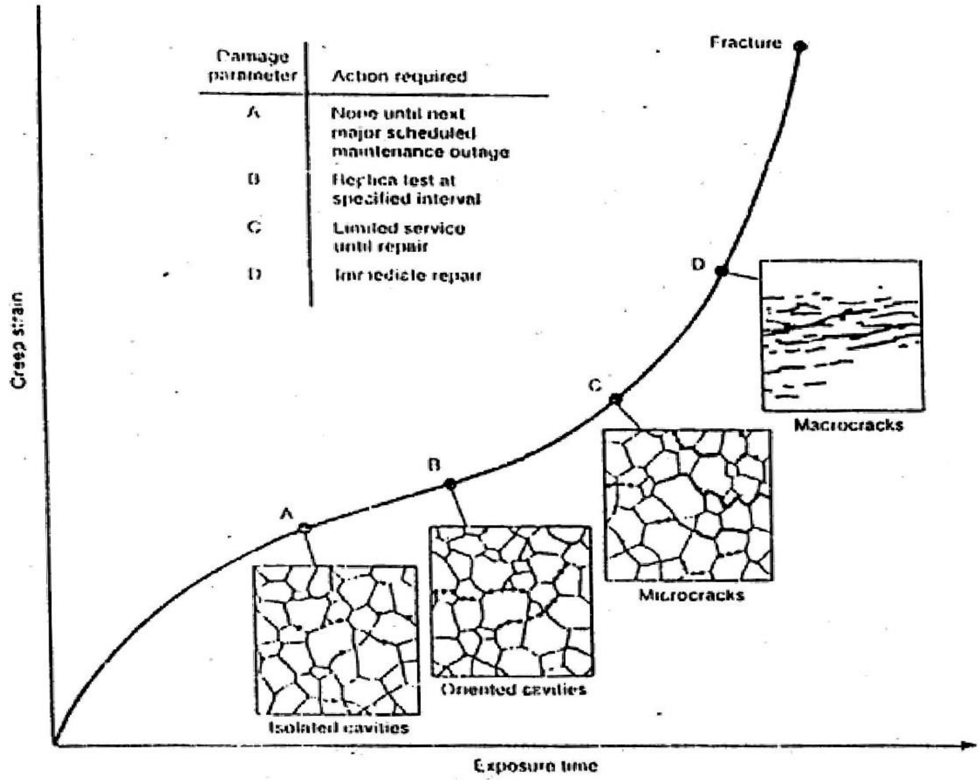
    - Tests/ Inspection in Running Condition
    - Hot/ Cold Spots, Leakages
    - Cold Walk down Survey
    - Tests/ Inspection in Cold (Shutdown) Condition
        - NDT
        - Sampling & Further Laboratory Analysis
    - Pre-light up Study
        - Cold Air Velocity
- 3A - Home Office
    - Compilation & Data Analysis
    - Recommendations
        - Component Level
        - Sub-System Level - System Level

Condition Assessment

- Destructive Test (on samples)
    - Creep life (quantitative)
    - Tensile strength - Bend test
    - Flattening test
    - Corrosion products
    - Metallurgical structure of cross section
- Non-destructive Test (in-situ/field)
- Visual
    - DPT
    - MPT
    - UT
- RT
    - TOFD
    - LEFT
    - Replication and Hardness
    - In-situ oxide scale measurement

RLA Calculation Criteria

- Neuber's Structural Classification
- Stress Rupture Test
- Oxide scale thickness



Structural Classification	Microstructure features	Action needed	Expended life fraction
Undamaged	Ferrite & pearlite	None	0.12
A	Isolated cavities	None until next major scheduled maintenance outage	0.46
B	Oriented cavities	Replica test at specified interval preferably within 1.5 to 3 years	0.50
C	Linked cavities (micro cracks)	Limited service until repair and better to inspect within 6 months	0.84
D	Macro cracks	Immediate repair	1.00

Residual Life Assessment Studies

Remaining life prediction

Creep Base

Assess accumulated Creep Damage

- Metallography (Replication)
- Accelerated Creep Rupture Test on Post-service sample

Oxide Scale Base

- Oxide Scale Thickness

Accelerated Creep Rupture Test Method

Collection of Specific sample from the identified area
Test under accelerated Conditions (Iso-Stress)

P = T (20 + log t) **T= Temperature (°R)**
t = Time (hrs.)
P = Larsen-Miller parameter

An illustration of conducting such a confirmatory test is explained below:
Given that data are as follows:

i. Material: 1 ¼ Cr _ ½ Mo _ Si Steel
ii. Working Stress: 8 ksi
iii. Working temperature: 900°F

Calculate LMP at working temperature (900°F) for rupture time of 10 years, say 10^5 hours

$P = 1360 (20 + \log 10^5) = 34000$

Using LMP = 34000 calculate for higher temperature the time of the rupture which corresponds to a rupture time of 10^5 hours at 900°F (working temperature)

Following table gives a calculated data temperature in °C for convenience

LMP 3400	Temp °C	540	550	560	570	580	590
	Time in Hours	1675	875	465	250	137	76

Conduct the accelerated creep test under iso-stress condition at any of the elevated temperatures in the above table and confirm if the sample passes the test for the duration of time as per the above table.

Sample passes, for example, 465 hours in Iso-stress Creep Rupture test conducted at 5600°C, the life extension can be recommended for 10 years.

Under the above condition the sample ruptures at say 300 hours.

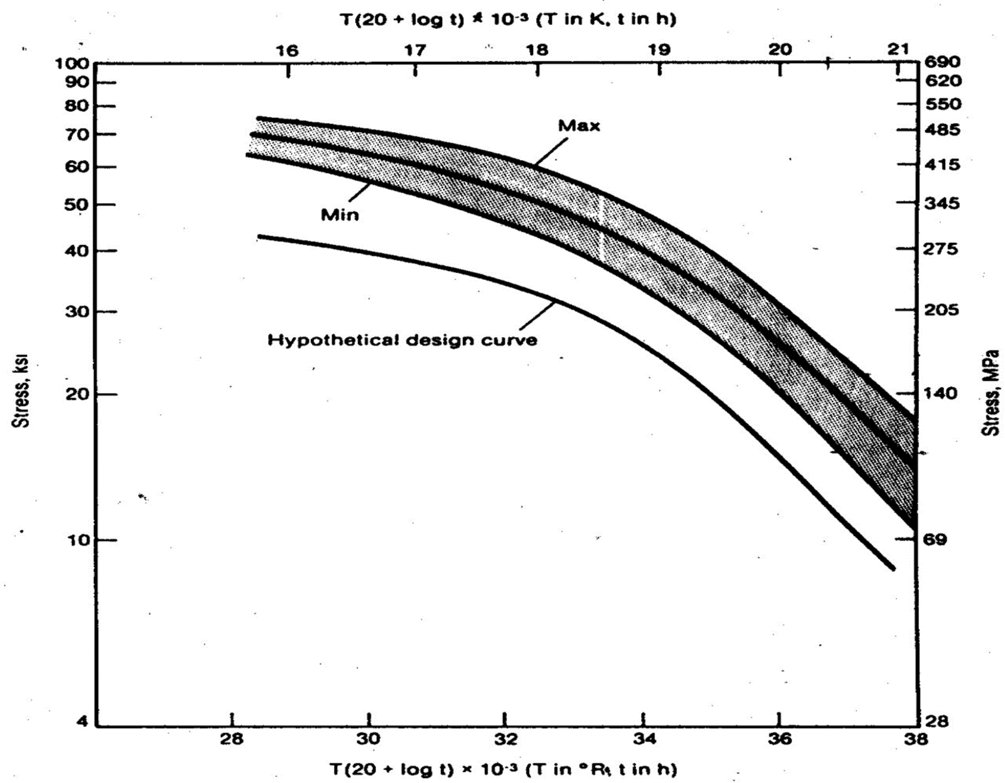
The LMP corresponding to this time and temperature is P = 33715

Using P = 33715 calculate rupture time at working temperature (900°F)

33715 = (900 + 460) (20 + log tr) $t_{rupture}$

(at 9000 F, 8 ksi) = 61722 hours

Recommended extension of life = 61722 hours (7 years)



Larson-Miller stress-rupture curve for 1Cr-1Mo-¼V rotor steel.

Oxide Scale Thickness Method

Oxide Scale Thickness Measurement

- Optical Microscope
- Non-Destructive Technique (Ultrasonic Method)

$\text{Log } X = 0.00022\ P - 7.25$ X= Oxide Scale Thickness in Mils

$P = T\ (20 + \log t)$ P= Larsen-Miller Parameter
T= Temperature in °R
t = Time in hrs.

Name of the component: Convection Super heater

Oxide scale measured: 2.8 mils
Running Time t – 1,00,000 hours (approximately)
Stress = 4.6 Kg/mm

Calculation of equivalent temperature exposed:

$\text{Log } 2.8 = 0.00022\ P – 7.25$
$P = 34987$
$P = T\ (20 + \log t)$
$34987 = T\ (20 + \log 10^5)$
$T = 1399.48°R$
$= 504°C$

LMP rupture at working stress (4.6 Kg/mm^2) is
P =37500 (from standard data curves)

Using the formula P = T (20 + log t)
$37{,}500 = 1399.48\ (20 + \log tr)\ tr$
$504°C = 62.5 \times 10^5$

Remaining life using life fraction rule

$t_{rem} = tr - t_{exp}$
$= 62.5 \times 10^5 - 10^5$ hours
$= 61.5 \times 10^5$ hours

The remaining life (t_{rem}) = 61.5 x 10^5 hours

Boiler tubes

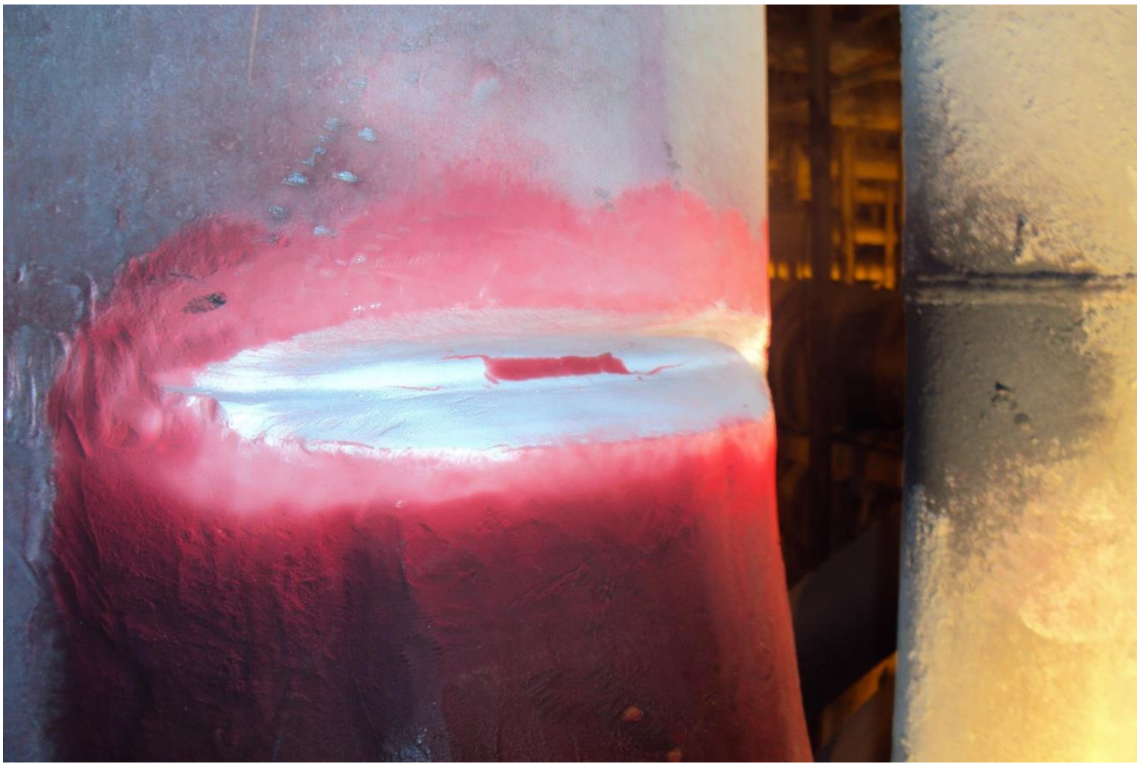
MSL (RHS)


MAR 18 2008

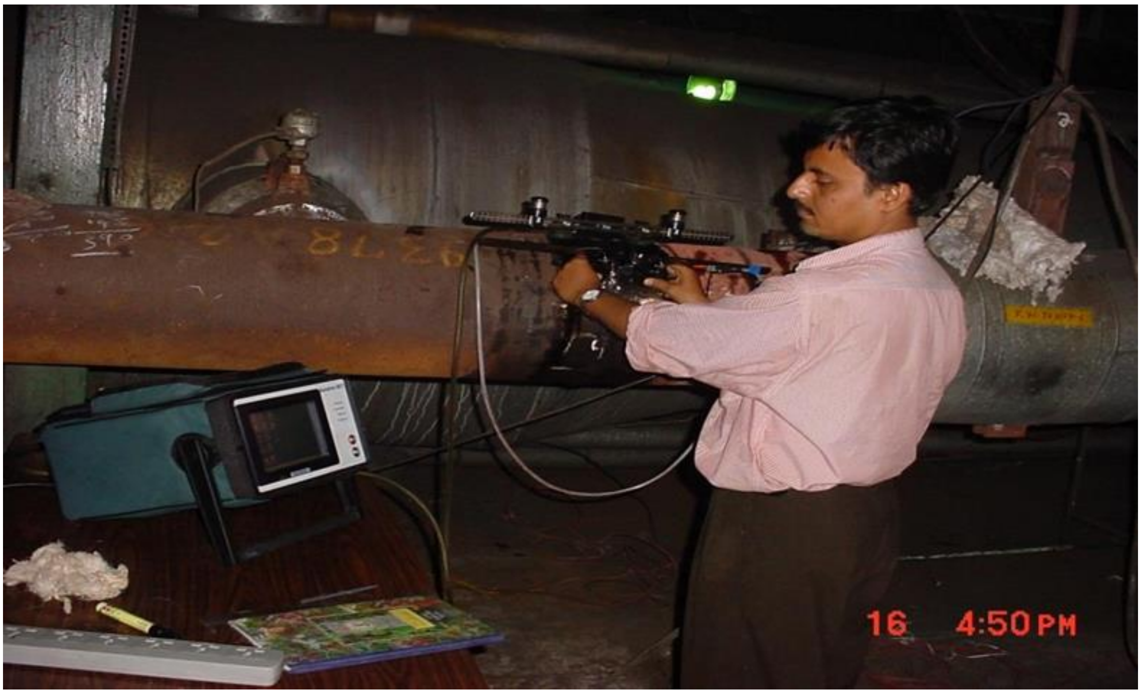

MAR 18 2008

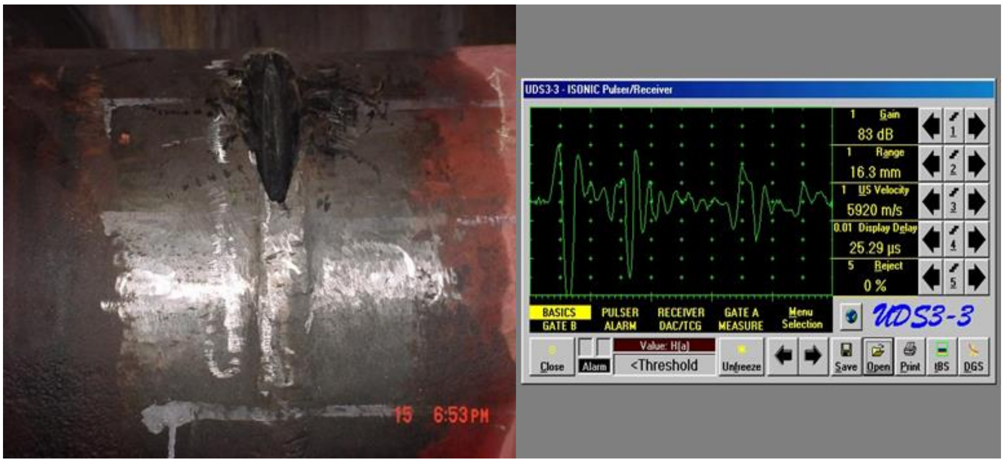
Major Findings

Crack In Boiler Piping



Field trial: TOFD inspection of weld in feed water pipe line of thermal power plant





Equipment:

1. Image analysis system for metallurgical evaluation
2. In-situ (field) Metallography (Replication) Test Facility
3. In-situ (field) Hardness Test facility
4. In-situ Chemical Analysis / Material Grade Identification Test Facility.
5. In situ Oxide scale measurement facilities

6. Ultrasonic test facility (Pulse-Echo, TOFD, Phased Array)
7. Dye penetrant test facility.
8. Magnetic Particle Inspection.
9. Dimensional measurement test facility.
10. Video Image scope for remote visual inspection for boiler, turbine, and other components.

AMENDMENTS WITH REGARDS TO RLA. ELLIGIBILITY, PERIODICITY & VALIDITY OF CERTIFICATE

By Mr. G. D. Wankhede
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Education: B.E. (Mechanical), DIT (CEDTI) (Visvesvaraya National Institute of Technology, Nagpur)
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 Sectional Committee, BIS.

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 400^0C)	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/cm^2 and temperature less than 400°C (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 Superheater 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	Ultrasonic Testing	Magnetic Particle Inspection	Liquid/Dye Penetrant Inspection	Replication	Sampling	Deposit Analysis	Outside Diameter (OD) and Thickness	Fibre Optic Inspection	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°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/cm^2 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) up to 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.

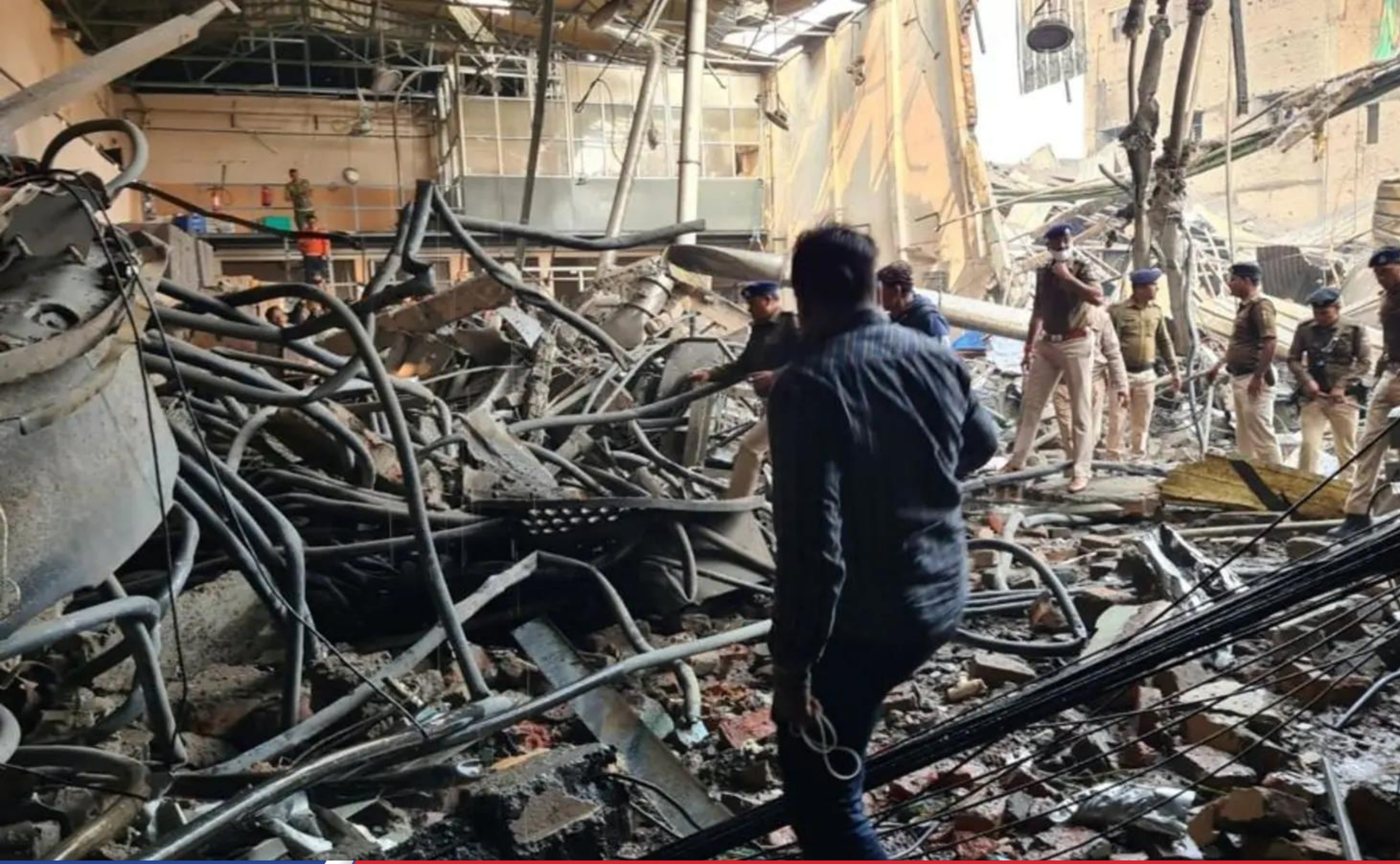
(1) Boiler more than twenty years of age shall continue to be subjected to inspection as provided in regulation 390 every year to the satisfaction of the concerned Competent Person in the State.

(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.”



FAILURE ANALYSIS AND BOILER ACCIDENTS

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Boiler can explode / fail to work, 1) if material used in manufacture of a boiler is of inferior quality, 2) if design / manufacturing process / welding process is not as per standards, 3) if boiler is not inspected periodically & defects observed are not rectified, 4) if boiler is not operated as per standard operating procedures & 5) if it is not in-charge of proper competent person. Any negligence to above can result in boiler accidents.

Boiler accidents may involve loss of property / loss of production / injury to innocent persons in vicinity or sometimes loss of lives also. Boiler accidents are highly catastrophic in nature because of their high explosive power and therefore every attempt should be made to prevent them.

It is therefore necessary to understand - 1) What are boiler accidents? 2) What are the causes of boiler accidents? Once we identify/ find out the reasons as to why accidents occur to the boiler, we shall definitely be able to prevent them.

Before going into details, let us see ‘What are boiler accidents?’. Section 2(a) of The Boilers Act, 1923 defines accidents as follows - “accident” means an explosion of a boiler or boiler component, which is calculated to weaken the strength or an uncontrolled release of water or steam there from, liable to cause death or injury to any person or damage to any property. When we look towards definition of accident, it is clear that not only explosion of boiler is accident, but any damage to boiler is also accident under the definition of Act.

Now let us see, what are the causes of boiler accidents. Various causes of boiler accident are as follows:

1) Low Water Level in Boiler
2) Flue Gas Explosion
3) Faulty Erection
4) Fire Hazards
5) Flame Impingement
6) Failure of Tubes
7) Idle Corrosion
8) Improper Feed Water Treatment
9) Faulty Operation
10) Clogged Flue Gas Passages
11) Over Steam Pressure or H.T. Pressure
12) Faulty Design

1) **Low Water Level in a boiler:** This is most common cause of the accident. Water shortness in boiler causes major accidents. Water shortness results in overheating of pr. parts such as furnace, tubes in smoke tube boilers or headers, tubes in water tube boilers. Overheating results in loss of metal properties and causes development of bulges to furnace or headers and distortion of tubes. Water contents of water tube boilers being small, time between safe and unsafe condition is much less. Shortness of water results in overheating & bulging of drum & headers if not properly insulated. Fall in water level bares the tube ends & if expansion is weak, tubes may slip causing tube holes & tube ends to become oval in shape. Water tubes fitted with fins often crack at the junction of fin & tube. During investigations, it was found that most boiler accidents have occurred by placing too much reliance on auto level control & neglecting attention to the gauge glass. During investigation several reasons were found to have resulted in water shortness in boiler, which are as follows:

   a) **Loss of water in feed water tank**: In many industries, water is stored in big storage tank. This storage tank receives water from either softener, D.M. plant or return condensate of plant. This water is then transferred by pump to small water tank called 'day tank' in boiler house. If capacity of this tank is very small i.e., for one hour or so, and if water level is not maintained there will be no water in tank and BFP will run dry resulting in low water level in boiler. Leakages in this tank also results in its level to drop & thus supply of water to the boiler may get affected. In case of deaerators, if level of deaerator is not maintained continuously, then as capacity of deaerator is usually small there is immediate chance of water shortness in boiler.

   b) **High Feed Water Temperature:** This is usual where condensate is returned to storage tank or when the feed water is preheated. If feed water tempt is more than 70°C, BFP may lose suction due to vapor lock or due to low NPSH & therefore can result in water shortness in boiler.

   c) **Failure of BFP or leakages in feed line or economiser:** Failure of BFP or leakages in feed line or in economiser, in case where economiser is used, results in water shortness. Defective check valves may also prevent supply of water to the boiler & may result in low water level in boiler.

   d) **Mobrey / Level controller does not work:** Failure of Mobrey / Level controller results in water shortness in boiler. In the investigation it was found many times that mobrey has failed because either its float is punctured or electrical switches have become inoperative or the float rod is bend or jam to move. In many cases it was found that inlet pipes from boiler to mobrey are choked with scale. Photograph shows bottom connection of mobrey fully choked with scale.

e) **Water Level in Gauge Glass is not visible:** Water level in G.G. may not be visible if it is not cleaned properly periodically or if it is full. In sugar industries, steam drum and G.G are located at large height & when level control is on manual, boiler attendant may not be able to see water level in gauge glass properly. Such instances cause confusion in the mind of boiler attendant & may result in water shortness in the boiler. Photograph shows fully choked bottom standpipe for level gauge.

f) **Eye sight of Boiler Attendant:** If eye sight of boiler attendant is such that he is not able to see the water level in G.G., it is likely, he may feel that there is water in boiler when actually there is no level in gauge glass. This is especially true of aged boiler attendants.

g) **Human Error:** Boiler attendant may get dizziness after lunch or after dinner and when level control is on manual naturally, he will be unable to maintain true water level in boiler.

2) **Flue Gas Explosions:** Flue gas explosions cause accidents to the boiler. Mixture of unburnt fuel with air in explosive proportion & application of sufficient heat to raise the tempt of this mixture to ignition point causes flue gas explosions. Loss of ignition, fuel valve leakages, insufficient purging, failure of ID fan, secondary combustion of fuel results in such type of explosions. These explosions are highly catastrophic in nature.

3) **Faulty Erection:** Faulty erection may result in accidents to the boiler. If the condensate tank or day water tank for boiler are erected just above the boiler due to space constraints, it is likely that water from the tank may overflow or leaks from tank may fall over the boiler causing thermal stresses thereby causing.

4) **Fire Hazards:** Oil tanks are sometimes installed just above the boiler due to space constraints. Overflow or leaks from this tank may fall on boiler catching fire. If such spillage is on boiler shell, and if fire is caught shell of boiler may bulge or boiler may even explode. Such spillage on floor or in cable ducts can cause fire in entire boiler house.

5) **Flame Impingements:** If the burner flame is not uniformly spread due to partially clogged burner or damaged diffuser & if it hits furnace wall, localised overheating occurs resulting in loss of metal properties thereby developing bulges to furnace or headers. This causes accidents to the boiler.

6) **Failure of Tubes:** Tubes in boiler fail due to various reasons causing accident to the boiler. Sudden release of steam due to failure of tube can result in distortion or secondary damage to several tubes in vicinity. Some of the reasons for failure of tubes are:

a) **Excessive length or weight of tube** – this causes hogging or sagging of tubes which can pull out tubes from header, drum or endplate.

b) **Excessive stress on tube end or frequent expanding** – this causes leakage through expanding. This, along with inadequate cross section of plate at tube hole can cause ligament cracks and bending stresses.

c) **Improper feed water** causes oxygen pittings, wasting, corrosion, scale formation, cracks, grooving, etc.

d) **Tempt stresses, overheating, high heat flux rates, poor circulation, thinning, blockage of expansion, carry over, high drum level, heavy steam** draw causes distortion or sudden rupture of tubes or SH coils. Following photograph shows several tube defects.

e) **Low Tempt Corrosion** - causes fast wasting / pitting & rupture of tubes.

f) **Erosion of tubes** - is caused by soot blowing, abrasive action of flue gas/bed material, in FBC boilers & heavy draft.

7) **Idle Corrosion:** Boilers when not in use are liable to deterioration from corrosion and unless well cared for and made rust proof; they may depreciate more rapidly than when in use. This may cause general smooth wasting, pitting of shell/ furnace, grooving of stay bars and gussets. Reduction in thk of pressure parts makes it unfit to be used at original intended WP and if used cause boiler accidents.

8) Improper Feed Water Treatment: causes oxygen pittings, wasting of plates of shell/furnace, scale formation, cracks, corrosion & grooving of stay bars or gussets, which can lead to boiler accidents.

9) Faulty Operation: Overloading, high fluctuating loads, sudden heavy draw of steam, very high or low water levels, raising steam very fast can drastically reduce life of boiler due to thermal & mech. fatigue.

10) Clogged Flue Gas Passages: Recently, tendency of industries has been towards conversion of firing for boiler, from oil to coal or agro waste fuels due to economic considerations. However, if flue gas passages are not of adequate cross section or if gets choked frequently, it causes overheating of pressure parts & thereby develops bulges to furnace or headers. This can also cause bulging & rupture of tubes.

11) Over Steam Pr. Or H.T. Pr.: Tendency to meet increased steam demand may tempt user to work the boiler at a pr. higher than the pr at which boiler is certified for use. If the boiler is worked at such higher pr, it can result in explosion of boiler / development of bulge to shell due to tension or can even collapse furnace due to additional compressive load causing accident to the boiler. It is also observed that negligence towards pr gauge during H.T. of boiler can cause permanent damage to furnace/shell due to excessively high HT pr, especially when positive displacement pumps are used to raise the HT pr.

12) **Faulty Design:** Faulty design usually results in overheating of furnace, development of bulges to furnace, cracking of tubes, sagging & pull out of tubes from tube hole, bulges to shell, distortion of end plates, bulges to end plate & development of ligament cracks in tube plates. In water tube boilers it can result in overheating of tubes & headers, distortion of tubes, bulges to the tubes or headers, sudden rupture of tubes, erosion of tubes, development of ligament cracks drum or header tube holes & damage to SH coils. These usually occur due to poor circulation, high heat transfer rates & carryover.

We have seen causes of boiler accidents. Now, if we can eliminate above said causes of accident, then we can definitely prevent the accidents. Following guidelines will help prevent the accidents.

1) Proper feed water treatment is most essential for smooth working of boilers and most of the causes of boiler accidents related to feed water can be fully eliminated with proper feed water treatment. Energy stored in the boiler is enormous & accidents are catastrophic in nature & therefore water quality & water level protection devices are of paramount importance.
2) Discipline & strict adherence to the operating & maintenance controls is must for safety.
3) Non – conformance in operating parameters must be reported in Boiler Log Book & appropriate action must be taken immediately & recorded.
4) Continuous training of boiler operators is must to upgrade their skills.
5) Expert supervision by the people with adequate knowledge in boiler operations is required at supervisory & managerial levels. National Board of Boilers & Pressure Vessels Inspectors, U.S., in their incident report has mentioned that primary cause of boiler accidents is Low Water condition & Operators Error calculated to @ 80%.
6) Day water tank should be of adequate capacity, preferably to supply feed water for at least 2 hours at MCR. Tank should be periodically inspected & any defects or leakages should be attended immediately. This tank should have two independent audible alarms for low level, for boiler attendant's attention. Deaerators must be provided with automatic water level controllers & the level in deaerator should be maintained constant. Tempt of feed water should be controlled & selection of BFP should be such that there shall not be any vapor lock. Day water tank should be installed at sufficient height so that adequate NPSH is available for BFP. Leakages in feed line / economiser should be attended immediately. Maintenance of electric motors, pumps & switch boards, feed check valves should be carried out periodically. At least two water level controllers should be provided to each boiler & their impulse lines should be taken out from two different positions on boiler shell. Mobrey /level controllers should be periodically cleaned and checked for their

fitness, rather alertness. It must be ensured that inlet pipes from boiler to mobery / level controllers are clean all the time. G.G should be frequently drained & true water level must be maintained at all the time during working of boiler. G.G stand pipes should be of adequate size. Level column should have facility for cleaning & should be drained to ensure that there is no accumulation of scale. It must be ensured that inlet pipes from boiler to G.G are clean all the time. Where G.G are located at large height, remote water level indicator should be provided. Boiler attendants should be asked to get their eyes checked from doctor, in case of any doubt regarding eye sight. This is especially necessary for aged boiler attendants. It should be ensured that boiler attendant does not sleep on duty either in day or at night.

7) Sufficient number of explosion doors should be provided to prevent accidents from flue gas explosion. Proper purging should be carried out before firing boiler each time. Ignitors, fuel valves, ID/FD fans should be serviced periodically.
8) Condensate tank or day water tank should never be installed just above the boiler.
9) Oil tanks should never be installed just above the boiler. Spillage from tank should be cleaned immediately. Electrical cables should be kept dry and free from oil all the time. Sufficient number of fire extinguishers should be kept in boiler house.
10) Burner is important firing equipment. Every care should be taken to ensure that diffuser is in order, burner tips are clean, flame is uniformly spread and does not hit furnace wall, tubes.
11) Excessive long tubes should be avoided. Proper hangers / baffles for proper support should be used to avoid sagging or hagging. Tubes in steam or mud drum should not be excessively & frequently expanded. More attention should be paid to periodical cleaning & feed water treatment to enhance life of tubes. Conditions that cause tempt stresses, overheating, high heat flux rates, poor circulation, thinning, blockage of expansion, carry over, high drum level, heavy steam draw should be avoided through proper operation & maintenance. Low tempt corrosion not only cause fast wasting / pitting of tubes but also reduces life of chimney drastically & therefore should be prevented by controlling flue gas tempt. Flue gas tempt is good indicator of what is happening to a boiler and therefore it should be closely monitored. Erosion of tubes, in some cases, cannot be controlled fully. However, proper periodic / predictive maintenance can help prevent unexpected breakdown of a boiler.
12) Idle corrosion can be prevented by dry or wet preservation methods. Boilers, which remain idle for long time, should be thoroughly inspected & non-destructive tests should be conducted before use of such boilers.

13) Proper feed water treatment is most essential ingredient for reliability of boilers in industries. Proper feed water treatment automatically solves all the problems related to feed water such as pitting, wasting, scale formation, cracks, corrosion, grooving, etc.
14) It must be ensured that flue gas passages are free & there is sufficient area for flue gas to flow.
15) Periodical cleaning of boiler & overhaul of all the valves and mountings not only increase reliability of boiler but also gives us opportunity to locate hidden defects, if any. Proper & safe operation of boiler not only prevent accidents but also enhances life of boiler. Boilers should be inspected with extreme care to avert boiler accidents / explosions.
16) Boiler should never be worked at a higher pr than a pr for which it is certified. Periodical servicing, setting of SVs at certified pr & testing of safety valves can help prevent accidents due to over steam pressure. Boiler should never be hydraulically tested to a pr higher than prescribed by IBR, 1950. Special attention should be given to pressure gauge & the pressure parts during hydraulic tests. It should be ensured that in no case HT pr exceeds reqd. HT pr, especially when positive displacement pumps are used to raise the HT pr.
17) Faulty design many times makes so called good boiler unreliable & unsafe for use. Safety, Reliability, Efficiency & Economy are the four key words & important aspects in good boiler design. In today's world of competition, often, economy is given more consideration which may result in loss of reliability & safety aspect of boiler. A good designed boiler not only can achieve three important aspects of boiler design Safety, Reliability & Efficiency, may be at slightly extra cost, but also can fetch good fame, distinct recognition & prosperity in long term for the boiler manufacturer.

Statutory Instructions:

1) Boiler shall not be used unless it is registered and certified.
2) Boiler shall not be used after expiry of period mentioned in Certificate / P.O.
3) Boiler shall not be used unless transfer is reported to Director of Boilers.
4) Boiler shall not be used at higher pressure than the max. pressure for which it is certified.
5) Boiler shall not be used unless it is in-charge of person holding the certificate as required by Rules.
6) Explosion of boiler / boiler component shall be reported to Director of Boilers within 24 hrs. Such report shall contain true description of nature of accident and of the damage, if any, caused to boiler / boiler component, the injury / death caused to person or damage to any property.
7) Works, such as repairs, welding, tube replacement, etc shall not be carried out to boiler / boiler component without sanction of Director of Boilers in writing.

Photographs of some the boiler accidents and defects are shown on NEXT PAGE. These photographs are numbered from 1 to 24. The description of accident / defect is as follows:

1) Explosion of shell due to Undercut at long seam.
2) Bulge to the furnace due to Flame Impingement.
3) Shell damaged to 50 mm depth due Mishandling.
4) Final Conv. SH Header, 70 mm thk cracked due to Creep.
5) Boiler turned upside down due to Explosion.
6) This boiler got damaged due to Explosion of other boiler in vicinity.
7) Badly Scaled smoke tubes.
8) Tube failure due to Hydrogen Damage.
9) Dissimilar Weld failure due to use of Improper electrodes.
10) Fully choked feed stand pipe of a boiler due to Scale.
11) Header bulged due to Scale.
12) Collapsed furnace due to Fatigue crack at FEP.
13) Bulged furnace due to Low water level.
14) Bottom connection of Mobrey choked with Scale.
15) Bottom stand pipe of G.G. choked due to Scale.
16) Tube failure due to erosion.
17) Tubes bulged due to long term overheating.
18) Tubes ruptured due to short term overheating.
19) SH coil bend choked due to Scale.
20) Dissimilar Weld failure due to Improper workmanship.
21) 76.2 mm OD tube bulged due to Scale - Elevation.
22) 76.2 mm OD tube bulged due to Scale - Side View of 21.
23) Lamination of Furnace Plate.
24) Shell ruptured due to Undercut.

Photographs of the Boiler Accidents and Defects are shown as follows:


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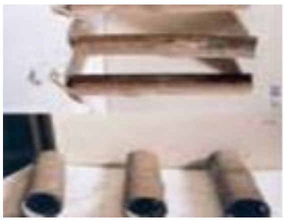
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EFFICIENT STEAM DISTRIBUTION, UTILIZATION AND CONDENSATE RECOVERY

By Mr. Narpendra Singh
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Name: Narpendra Singh
Organisation: Maxima Steam Works
Designation: CEO
Education: B.E Mechanical Engineering (D. Y. Patil College of Engineering, Pune)

Developing and executing business strategies based on my steam knowledge, by focusing on new technologies, products, services and ultimately gaining customer confidence. Designing, supplying and installing steam systems of world class quality that are safe, efficient & highly responsive with minimal operating costs. Building a Company where all stakeholders play an important role in our growth path, while protecting the environment as well as giving back to society.

I have been fortunate to work with Forbes Marshall for close to 25 years which has given me a strong foundation in the steam engineering domain. I have had the opportunity to visit reputed international companies worldwide, which has provided a great inter-personal and technological learning experience. This tenure helped me gain vast exposure in people management, customer relationship management and manufacturing excellence.

Post completion of my graduation, I spent 25 years working with Forbes Marshall, handling 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 a number of products.

I have been trained in Steam Systems from Spirax Sarco, UK and have had the opportunity to visit many steam engineering companies as well as customers across the globe, which increased my knowledge on international operations.

I was associated with CII and ACMA as a member of the jury for their various assignments and have conducted audits for many reputed companies in manufacturing excellence and quality systems. I have been also privileged to be the guest speaker and a part of panel discussions on topics such as IoT, industry 4.0, zero defects and manufacturing excellence in various conferences organised by CII and ACMA.

Introduction

Steam is one of the oldest forms of energy. The first industrial usage of steam was in 1712, when Thomas Newcomen’s atmospheric steam engine was used to pump water out of the coal mines. Today, steam is used in almost all process industries such as food, beverages, chemical, pharmaceutical, textile, power, cement, oil & gas, dairy, cement, rubber, etc. Which begs the question, what makes steam such a popular energy source over all others?

The abundance and easily availability of water, which is the source of steam, has led to it being a versatile option. Steam carries a lot of latent heat in small volumes, and can be easily transferred from one place to another. Saturated steam has a very direct relationship between pressure and temperature. It can be generated at high pressures as well and can be easily controlled at different pressures as well as temperatures. Steam plants are easy to maintain, and can be easily automated and controlled with simple control systems. Steam can be used in direct as well as indirect heating. Being sterile, steam is used in sensitive processes in pharmaceutical and food industries, and in hazardous areas as well.

The Quality of Steam

It is essential to ensure that steam used for processes should be as dry as possible. Greater the dryness fraction of steam, better is the heat content and heat transfer in the system. To achieve better dryness fraction, we generally use moisture separators in the main steam lines. Moisture separators efficiently removes moisture from steam, and steam traps are placed at the drain point outlet of the separator, to separate out the condensate. To improve the steam quality, we can also use strained to filter out dirt and muck from the steam lines. *By improving the steam quality, we can improve process thermal efficiency by 10%.*

Steam Distribution

An optimized steam system layout in a plant can improve its efficiency significantly. It is important to ensure that the steam supplied to different parts of the plant is as per required quantity and pressure. Steam lines installed should neither be oversized nor undersized, as both have their own disadvantages.

Oversized lines increase the capital costs and radiation losses, while being prone to wet steam. By increasing the steam line by just one size, *capital costs can increase by 40% and radiation losses increases around 20%.*

Undersized steam lines cause starvation of pressure and pressure drop. Velocity increases due to smaller line sizes, leading to erosion, water hammering and other safety hazards to the entire system.

Designing Steam Lines

Steam lines are designed on the basis of the velocity of steam. For saturated steam, 25 - 40 m/s velocity range is considered and for superheated steam, 50 – 70 m/s velocity range can be considered as there are no chances of condensate or water hammering.

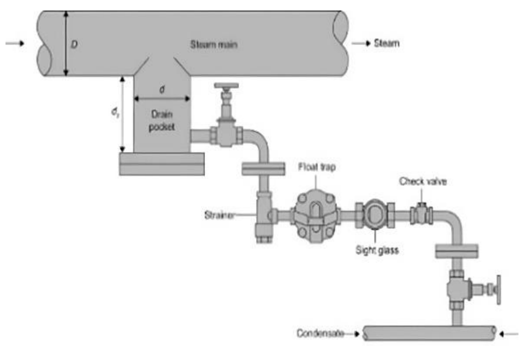
Steam should be generated and distributed at the highest possible pressure. The main advantage is that the quality of steam is better at higher pressure, as it is drier. When we run a boiler at higher pressure, the thermal storage capacity is higher, so it can take care of fluctuating loads better. Piping and insulation costs are lowered as smaller piping networks are required at higher pressures.

At the point of utilization, steam should be used at the lowest possible steam pressure, as the latent heat increases when the pressure reduces. Hence, when the steam condenses, the latent heat released at lower pressure is higher than at higher pressure. For example, 1 Bar steam has 2201.1 KJ/kg of latent heat as compared to 2030.9 KJ/kg of latent heat at 8 Bar. Thus, an additional *8.38% of latent heat from steam can be obtained at 1 bar than at 8 bar.*

To achieve lower pressures, pressure reducing stations are installed in the steam lines. PRS systems are built around pressure control valves, which control the pressure as per requirement. The system also includes moisture separator and strainers for better steam quality, inlet, outlet and bypass valves for operation and maintenance, and safety valves.

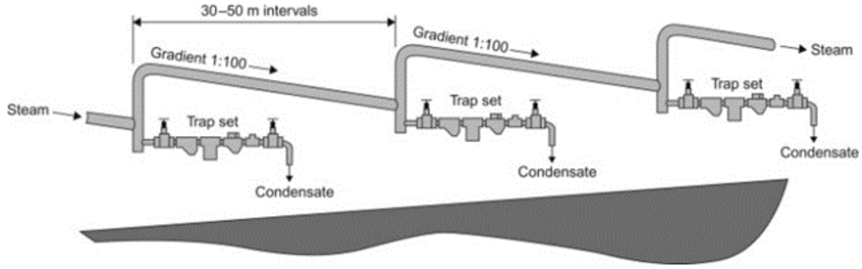
Main Steam Line & Steam Line Layouts

Main steam lines are under continuous condensation due to radiation losses. This condensate should be removed as soon as its formed. To ensure this, steam lines should have a gradient of 100/1 towards the direction of the flow, to ease the flow of condensate, and steam traps must be installed every 30 mts of running length of the steam line. The layout of drain points is equally critical, as improper layout will lead to poor



Main diameter D	Pocket diameter d_1	Pocket depth d_2
Up to 100 mm	$d_1 = D$	Minimum d_2 = 100 mm
125 – 200 mm	d_1 = 100 mm	Minimum d_2 = 150 mm
250 mm and above	$d_1 = D/2$	Minimum $d_2 = D$

condensate evacuation from the main steam lines. Also, proper layout of branch lines and drop leg is important for dry steam to reach the plant.



Steam Trapping

No steam system design is complete without steam traps. There are different types of steam traps such as:

1. Thermodynamic steam traps
2. Ball Floats steam traps
3. Inverted Bucket steam traps
4. Thermostatic steam traps
5. Bi Metallic steam traps

Selection of steam traps is very critical for optimizing steam system efficiency. While designing steam systems, correct steam traps with sizing as per application should be selected for maximum efficiency.

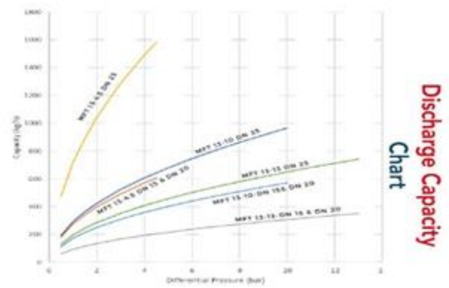
Thermodynamic traps are used for main line and header application, as they are robust and have excellent water hammering resistance. They are very versatile and can be used for a wide range of pressures.

Float traps are ideal for process applications, as they are continuous discharge traps. These traps have high discharge capacities and can handle air venting through air vents, and can operate easily with fluctuating loads and pressures

Inverted bucket traps have very good water hammering resistance. They can be operated at higher pressure with ease and can also be used for super-heated steam.

Thermostatic traps are compactly designed for air venting and start up load. They are ideal for tracing line applications and ensuring automatic adjustment for steam pressure variations.

As trap size increases, the discharge capacity of the traps increases. At higher differential pressure, the discharge capacity increases and capacity increases for lower sized internals. Based on the above principle, we can size any traps as per the discharge capacity chart.



Proper installation of steam traps is critical for functioning of steam traps. We should never do group trapping and install NRV after the trap, in a closed loop system, to prevent trap leakage. To tackle the challenge of keeping steam traps working at all times, one should keep doing routine checks and take corrective actions on the leaking traps. Leaking traps is a big source of decreased steam system efficiency. For example, a full-bore leak of 3 mm at 10 Bar can leak up to 21 TPH of steam per month.

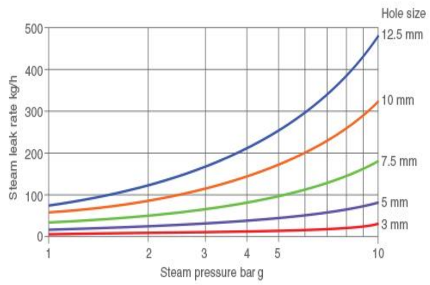


Fig. 10.3.15 Steam leakage rate through holes

Optimizing heat transfer

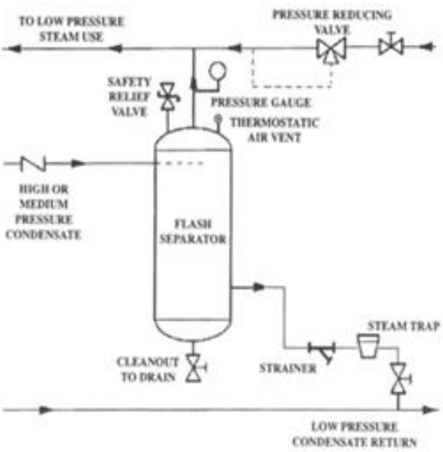
The simple way to optimize heat transfer is to remove any heat transfer barriers. Air causes 2500 times more barrier than steel, and is generally the biggest barrier of heat transfer. Thus, air venting in steam lines is very important.

As steam condenses, it forms a small layer on the surface, which acts as a barrier to heat transfer. To minimize this, drop wise condensation should be done instead of film wise condensation, as dropwise condensation creates lesser barrier to heat transfer. Scale formation should be kept in control as it is also a barrier for heat transfer.

Condensate Recovery

Pure and treated condensate water is released, once the steam transfers its heat and condenses. Returning condensate provides a lot of advantage with respect to heat energy. Generally, by increasing the feed water temperature by 6 degrees, we can save 1% of fuel. This means that an increase of feed water temperature from 30 degrees to 90 degrees will save us 10 % of fuel. In addition, there is a reduction in water costs, treatment costs and blowdown losses. Condensate return can be achieved by steam operated pumps, which can pump condensate with the power of steam itself. These pumps are purely mechanical and very robust in operation.

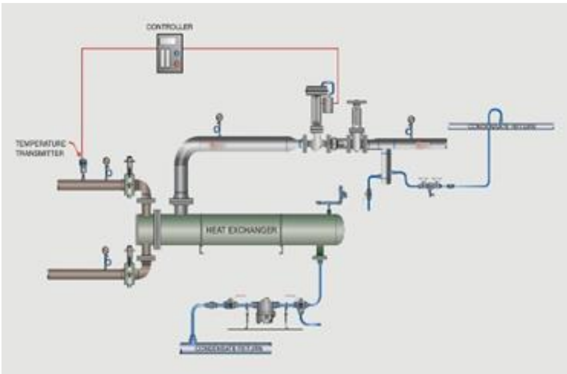
Flash Steam Recovery



When high pressure condensate is exposed to lower pressure, i.e., atmospheric pressure, certain amount of steam flashes into the atmosphere. Higher the condensate pressure, the more flash steam will be generated. This flash steam can be separated by installing flash vessel, which separates flash steam from condensate.

Steam System Controls

For efficient running of steam systems, there are many important parameters that require proper control systems. The three main types of control systems are automatic control, on-off control and continuous control. Steam pressure, steam temperature, levels, flow, blowdown, oxygen and various other parameters can be easily controlled, to ensure an efficient steam system that is easy to use and maintain.

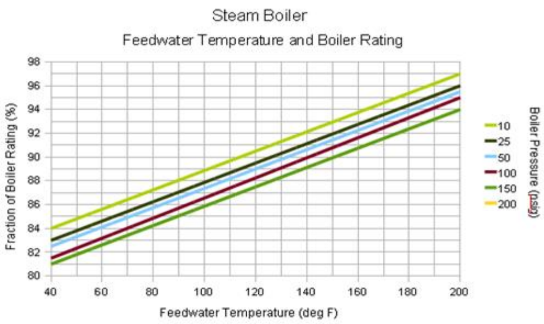


Steam pressure is controlled by PRS. Temperature can be controlled by temperature control valves, resulting in precise steam temperature and better control of the processes. Controls play an important role in achieving overall system efficiency and higher productivity. Moreover, they make the entire system safe to operate.

Flow can be measured for steam, fuel and condensate by using flow meters. The meters are designed to measure flow and level of the steam system and can be automated into the main system.

Feed water temperature control is another important component of steam system control and efficiency. At 100°F (37.7°C) Feedwater Temperature, the Boiler Rating is 89% while at 200°F (93.3°C) Feedwater Temperature, the Boiler Rating is 97%. This collaborates our earlier point of increased boiler Rating with temperature rise in feedwater temperature.

Every boiler needs periodic blowdown to remove the total dissolved solids i.e., TDS generated and chemical dosing in the system. To be on the safer side, in a manual system, blowdown is done more than required as we cannot control blowdown manually.



We can optimize blowdown losses and precisely control TDS by installing automated blowdown systems, which can sense TDS levels and give on-off signal to BDV accordingly.

Thus, by ensuring that steam systems are designed and controlled according to the processes and required parameters, we can achieve optimal steam and condensate in plants, which in turn, can help us achieve major savings in plant operations.

Thus, by ensuring that steam systems are designed and controlled according to the processes and required parameters, we can achieve optimal steam and condensate in plants, which in turn, can help us achieve major savings in plant operations.

NOx ABATEMENT BY PROVEN TECHNOLOGIES TO REDUCE POLLUTION

By Mr. Gaurav Samkariya
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Organisation: Yara Environmental Technology Pvt Ltd.

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Over 12 years of experience in promoting Air Pollution Control Equipment & boilers in different industry sectors in India.

NOx abatement by proven technologies to reduce pollution caused during combustion to meet current regulatory norms

Abstract

Power sector is currently seeking for the cost-effective minimization of NOX emissions. This demanding challenge is being met by Yara through advanced technologies successfully applied in European and other power plants.

Our, advanced technologies reduce the nitrogen oxides for any operating scenario with NOX abatement solutions such as Advanced Selective Non-Catalytic Reduction (SNCR) or reduced-size configurations of Selective Catalytic Reduction (SCR).

The Indian Environment Protection Amendment rules establish new NOX limits for the thermal power plants (TPP) depending on the year they were installed. Selection of the most cost- effective solutions to meet the new standards will be critical. The variety of characteristics of the Indian coal plants (unit capacity, burner layout, coal composition, boiler age, cycling operation, etc.) requires specific analysis of the plants and unique approaches different to the conventional ones.

Introduction

Increasingly stringent worldwide environmental legislation is requiring the coal power sector to install high-efficiency abatement technologies to comply with the pollutant emission limits imposed by the applicable their national standards.

The Indian Environment Protection Amendment rules establish new environmental limits for the thermal power plants (TPP) depending on the year they were installed. Table 1 summarizes the values indicated by the Ministry of Environment.

Pollutant	TPP before Dec 31, 2003	TPP after Jan 1, 2004 before Dec 31, 2016	TPP after Jan 1, 2017
Particulate matter	100 mg/Nm3	50 mg/Nm3	30 mg/Nm3
SO2	600 mg/Nm3 units < 500 MW,200 mg/Nm3 units ≥ 500 MW		100 mg/Nm3
NOX	600 mg/Nm3	450 mg/Nm3	100 mg/Nm3
Mercury	0.03 mg/Nm^3 units ≥ 500 MW	0.03 mg/Nm^3	0.03 mg/Nm^3

Table 1. MOEF notification

In particular, nitrogen oxide (NOX) reduction can be performed by the application of different strategies. Secondary measures of abatement control are those systems that reduce the NOX content after the formation in the combustion using a chemical reagent. These are SNCR (Selective Non-Catalytic Reduction) and SCR (Selective Catalytic Reduction) systems.

- SNCR is the most appropriate and widely used technology to reach reduction efficiencies of up to 50% required in many processes.
- SCR is the catalyst bases technology use to reach high reduction efficiencies of up to 99% required in most of the countries.

Technical Approach

1) SNCR technology

In order to minimize NOX emissions under a cost-effective approach, YARA has developed a non-catalytic abatement technology which is an effective complement to SCR systems.

In general, the maximum potential of non-catalytic secondary measures, such as SNCR, has been shown in small industrial boilers. However, the abatement efficiency achieved in larger coal- fired power units has been lower, mainly due to their size and the difficulties in identifying optimum temperature windows with variable operating scenarios. The following are the key performance parameters in the SNCR process:

- Temperature – O2 and CO concentrations define the operating temperature window where the abatement reactions occur at high efficiency rates.
- NOX profiles – NOX profiles are produced in the combustion zone based on the specific design of the boilers. However, these profiles are non-uniform and not constant over time due to the dynamics of the combustion process. Precise knowledge of the NOX content in the injection zones is needed to achieve optimized injection of the correct reagent quantity per injection port.

The approach designed by YARA is intended to fit these features by achieving a highly flexible reagent injection in the most suitable furnace areas. The availability of advanced in- furnace monitoring capabilities provides a temperature profile and composition (NOX, O2 and CO) upstream the injection zone to assure optimized injection profiles based on the individual control of reagent injection in each lance. This optimized injection approach brings two direct benefits: higher NOX reduction rates compared with conventional applications and effective control of ammonia slip.

2) SCR technology

The abatement of NO_x (NO and NO_2) is achieved by the use of a "Selective Catalytic Reduction (SCR) system". This is a dry flue gas treatment process, which uses ammonia (NH_3) as a reducing agent and a catalyst.

The selective catalytic reduction of NO_X is performed on a catalyst (substrate material TiO_2 as Anatase and transition metals such as V, W and/or Mo as active sites) with ammonia as a reducing agent forming harmless reaction products according to the following reaction mechanisms:

$NO_2 + NO + 2\ NH_3 \leftrightarrow 2\ N_2 + 3\ H_2O$ $4\ NO + 4\ NH_3 + O_2 \leftrightarrow 4\ N_2 + 6\ H_2O$ $2\ NO_2 + 4\ NH_3 + O_2 \leftrightarrow 3\ N_2 + 6\ H_2O$

Ammonia (NH_3) is injected into flue gas and reacts with NO_x on the SCR catalyst resulting in nitrogen (N_2) and water (H_2O).

In this case aqueous ammonia (24%) is used as reduction agent. Few side reactions occur under certain conditions.
One of these is oxidation of SO_2 into SO_3, the so-called SO_2 conversion.

$2\ SO_2 + O_2 \leftrightarrow 2\ SO_3$

This reaction has to be minimized by optimal catalyst design to avoid the formation of ammonia - sulphate compounds in the catalyst and downstream of the SCR system.

Industrial Environmental Solutions

Emission Standards Notified in India in 2020

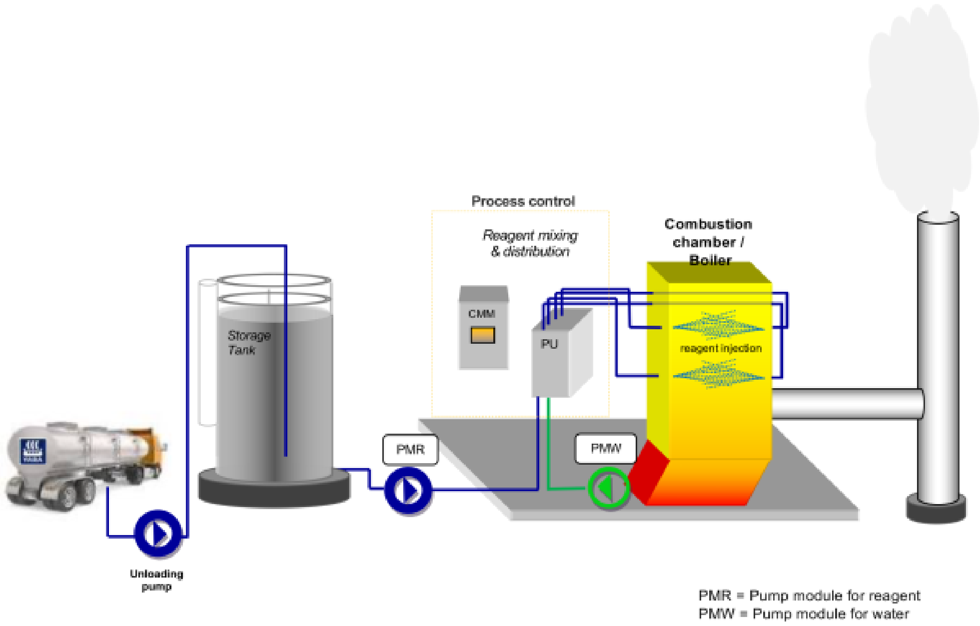
S. No	Parameters	Older norms	New Notified Norms		
			TPP Units installed before 31 Dec 2003 (1)	TPP Units installed after 2003 To 31 Dec 2016 (1)	TPP Units installed after 1 Jan 2017 (2)
1.	Particulate matters.	150mg/Nm^3	100mg/Nm^3	50mg/Nm^3	30mg/Nm^3
2.	SOx	Stack ht >500 MW : 275 M >210 MW : 220 M <210 MW : H = 14(Q)^3 where Q is Sox emissions in Kg/Hr	1. 600mg/Nm^3 for units smaller than 500 MW 2. 200mg/Nm^3 for Units equal to more than 500 MW	1. 600mg/Nm^3 for units smaller than 500 MW 2. 200mg/Nm^3 for Units equal to more than 500 MW	100mg/Nm^3
3.	***NOx***	***- do-***	***600mg/Nm^3***	***450mg/Nm^3***	***100mg/Nm^3***
4.	Mercury	No Limits	-	0.03mg/Nm^3	0.03mg/Nm^3

(1)- TPPs (Units) shall meet the limits within two years from date of the notification.
(2)- Includes all the TPPs (units) which have been accorded Environmental Clearance and are under construction.

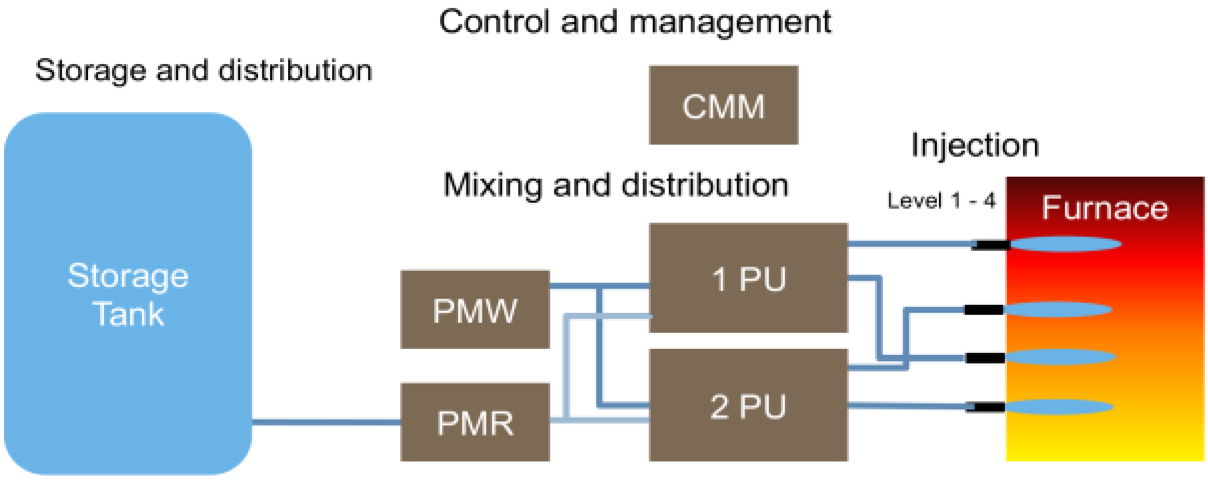
NOx Reduction Technology

SNCR system

Removal of Nitrogen oxides (NOx) using Selective Non-Catalytic Reduction (SNCR) technology.



YARA SNCR low NOx system



SCR system

Removal of Nitrogen oxides (NOx) using Selective Catalytic Reduction (SCR) technology.

SCR catalytic reduction method

The SCR is the best developed and most widely used method for removing NOx from flue gases.

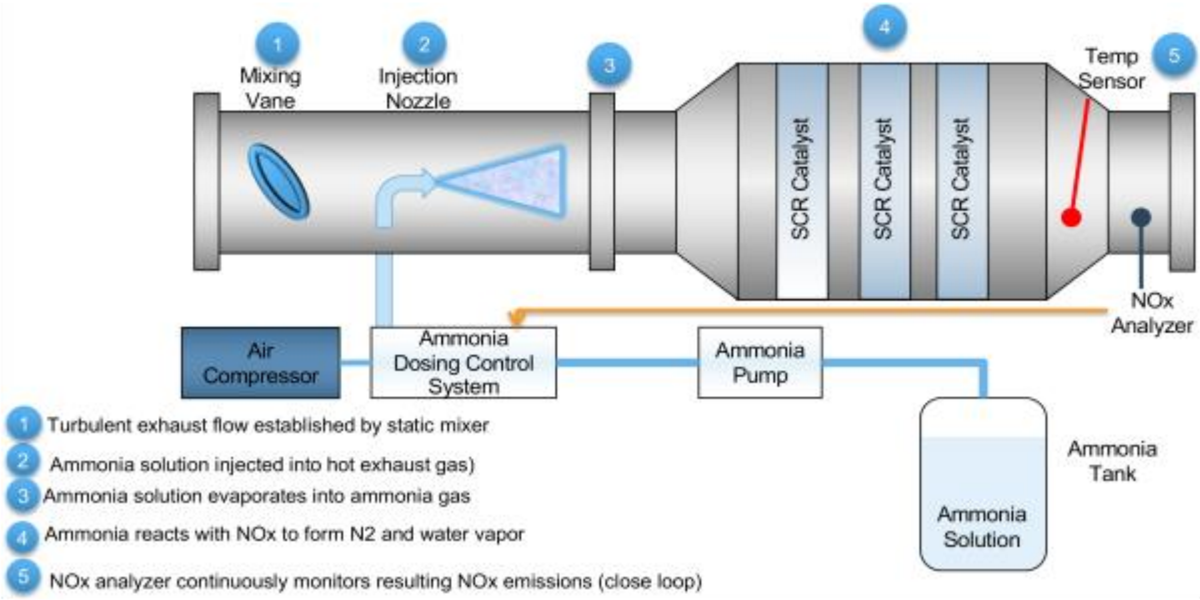
- It consists in the reduction of NO and NO2 to N2 under the influence of ammonia on the catalyst layer.
- The general reactions are:

$$4\ NO + 4\ NH_3 + O_2 \rightarrow 4\ N_2 + 6\ H_2O$$

$$NO_2 + 4\ NH_3 + O_2 \rightarrow 3\ N_2 + 6\ H_2O$$

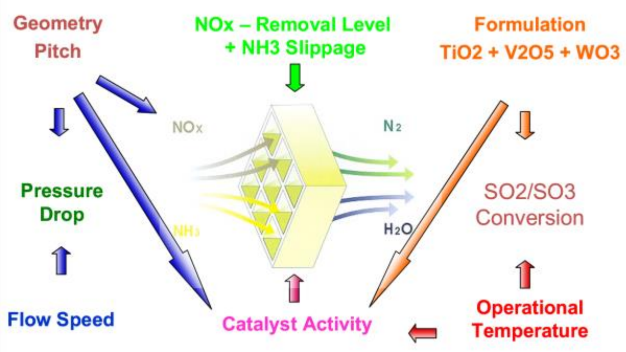
- The optimal temperature range for the reaction is 315 - 400 °C.
- Typically, ammonia is added in the form of ammonia water in an amount less than stoichiometric (0.8 - 1.0 mol / mol NOx)

NOxCare SCR System



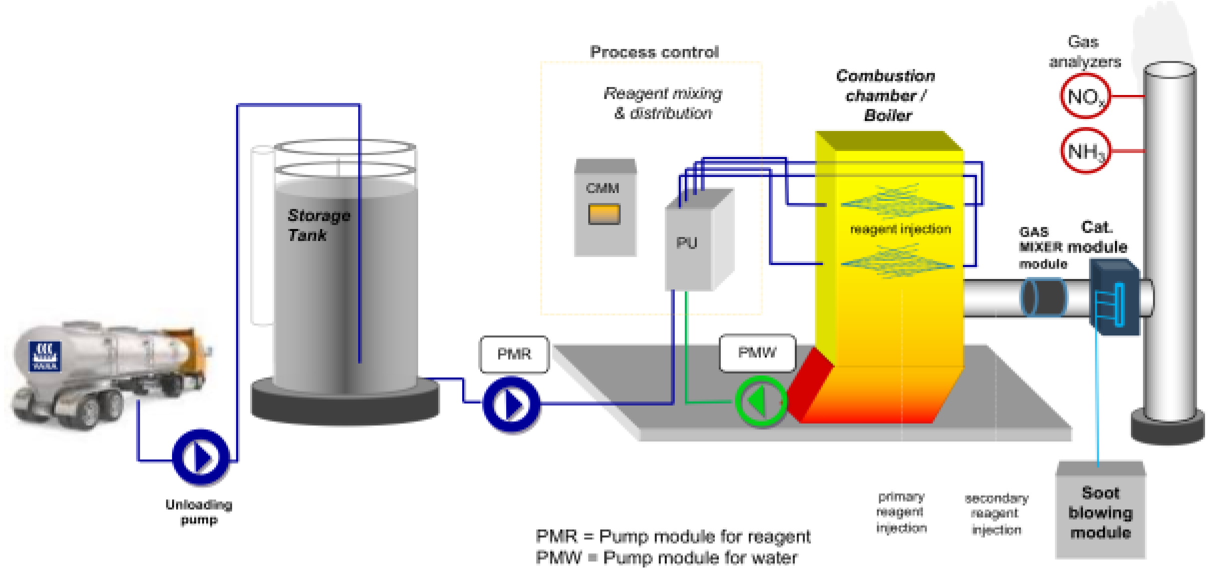
SCR design criteria

- Highest NOx removal efficiency
- Lowest possible NH3-slip
- Lowest possible pressure drops
- Highest possible availability
- Highest possible flexibility across the whole load range
- Lowest possible impact on existing system



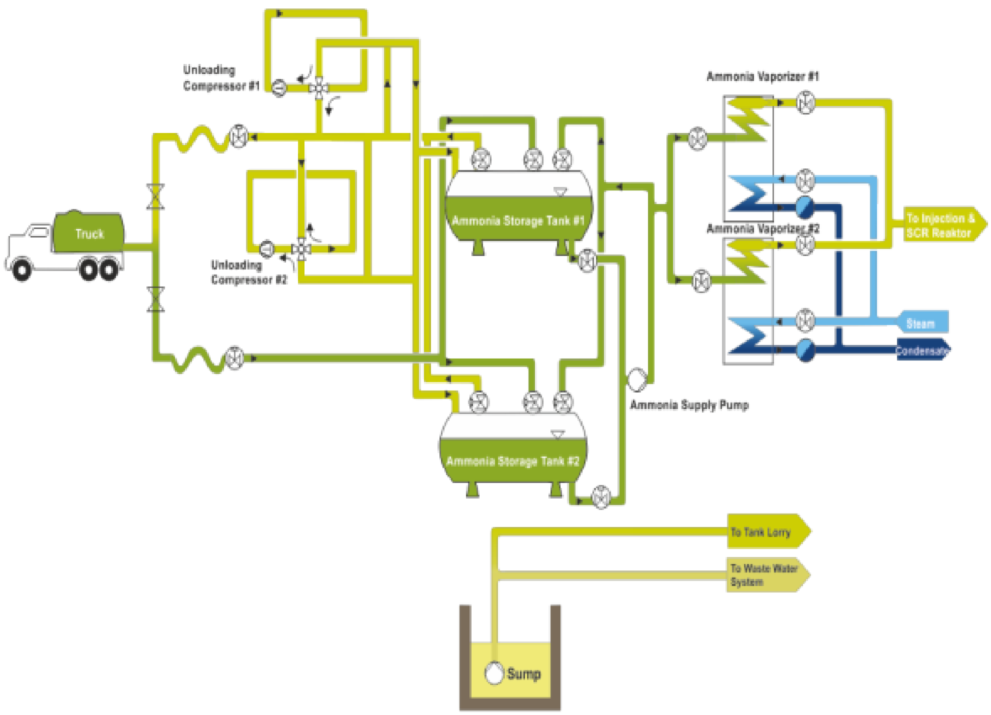
- AND: OPTIMUM SOLUTION INVEST- vs OPERATING COSTS

The Yara Hybrid System



Anhydrous Ammonia Storage & Handling System

- AMMONIA UNLOADING COMPRESSOR SKIDS
- COMPRESSORS-2 N0'S MIN. 1100 LPM, RECIPROCATING OIL FREE TYPE
- PESO/CCOE GUIDELINES RESTRICT EFCV SHUTDOWN AFTER 570 LPM
- COMPRESSOR REQUIREMENT IS FOR 1100 LPM, ITS POSSIBLE WITH 2-BAY TRANSFER



Short Introduction on Thermal Oxidizer

A Direct Fired Thermal Oxidizer destroys Volatile Organic Compounds (VOCs) and Hazardous Air Pollutants (HAPs), that are created through chemical processes found in industrial exhaust streams. The chemical process of thermal oxidation is quite simple; the exhaust stream temperature is raised to between 850 to 1200°C, a temperature at which the chemical bonds that hold the molecules together, are broken. It is the most widely used abatement technology for industrial processes that produce exhaust streams with high levels of pollutants and can achieve over 99% hydrocarbon destruction rate.

Simple Yara TYBT: EV2 Plant in Mailiao

LATEST SOOT CLEANING TECHNOLOGY

By Mr. Dilip Ambekar, Trust Well

Name: Dilip Ambekar
Organisation: Trustwell Group of Companies
Designation: Founder & Director
Education: B.E in Chemical Engineering (Pravara Engineering College Shrirampur)

Trust Well Engineers was in the top 10 boiler manufacturers in India according to the survey taken by the Industrial Outlook Magazine in 2021. Trust Well Engineers is honoured to have such an esteemed customer base from ISRO to the Navy and many more Indian Oil Refineries.

Trust Well Engineers India Pvt. Ltd. design and manufacture all types of Waste Heat Recovery Boilers and low temperature heat recovery products. With facilities for all extended heating surface equipment (e.g., Finned tubes, Gilled tubes Studded tubes etc), we provide Tailor Made Solutions for WHRB, Economizers, and other Boiler accessories to suit various types of fuels.

We also design and manufacture all types of online cleaning systems viz Soot Blowers using Steam/ Air as media. With EIL (Engineers India Limited) certification and IBR certification. With a team of over 100 People, we recently celebrated our 22nd Year of establishment.

Trust Well Global Services is a provider of highly engineered Soot Blower Spare Parts its related services and aftermarket assistance with a particular focus on providing 'ANY OTHER MAKE' soot blower spare parts and services for Power Plants, Oil Refineries and Process industries.

Introduction

In this article type of soot blower / installation procedures / precautions while installation and operation philosophy are elaborated to help operators. Since soot blower is very important auxiliary of boiler and helps to get maximum efficiency of boiler. Steam is a blowing media for soot blowers. Steam required for soot blowing is tapped from super heater header of boiler. Operation and control of soot blower is very crucial since it saves fuel required to boiler.

Soot blowers are used to keep the boiler surfaces free from deposits of dust & grit which would otherwise reduce the rate of heat transmission in the boiler, reducing the boiler efficiency, reducing availability. This loosely adhering layer is a definite impediment to the transfer of heat & should be removed after it has built up sufficiently to result in significant increase in flue gas temperature, Regular soot blowing is essential for Boilers, Superheaters & Economizers heating surfaces if the high thermal efficiency is to be maintained.

The Soot Blowers consists of:

- Element Rotating mechanism (Head) manual or motorized with loose valve or built-in valve.
- Element (Blowing Tube): Stainless steel or carbon steel depending upon the flue gas temperature.

The usual form of element is a dead-end tube projecting through the boiler setting & extending into the tube bank. Number of small lateral ventury nozzles of special alloy are provided on the tube & the external head is arranged so that high pressure steam can be admitted to the tube (element) & at the same time the element rotated around its axis, to ensure maximum coverage of heating surface. The element can be rotated through any desired blowing angle.

Type of Soot Blowers

1) Rotary Soot Blowers
    a) Manual
    b) Motorized
2) Retractable Soot Blowers
    a) Short Retractable (Motorized)
    b) Long Retractable (Motorized)
    c) Wall Blowers (Motorized).

Aspects for Soot Blowers Selection.

1) High Efficiency Cleaning.
2) Minimum Steam Consumption.
3) Simple and Robust Construction.
4) Minimum Maintenance.
5) Selection of proper location and type of Soot Blower.

Long Retractable Soot Blower Installation.

The Long retractable soot blower is generally used in radiation zone or where flue gas temperature is more than 700ºC.

The element is having two nos. of ventury type nozzles at a distance of 50mm and at opposite direction and two nozzles carry out the helical movement. The lance tube is driven by the carriage and steam is fed into the Lance tube through soot blower valve.

When soot blower drive motor is switched on, the carriage moves forward and lance rotate into the furnace and steam is blown and coils are cleaned. After reaching the element at front end position, the limit switch is activated and carriage reverses back and soot blower stops when rear end limit switch is activated.

Installation aspects OF Long retractable Soot Blowers (LRSB).

We have noticed that, there are problems faced while commissioning of Long retractable soot blowers. Procedure for installation of Soot blower:

1) We have observed that, the soot blower consignment is of low weight. Normally soot blowers for one boiler will weigh @ two to three tons. In such cases when transporter is paid on weight basis, they try to load some other material on the soot blowers; damaging the soot blowers. You are requested to instruct the transporter in writing that he should not load any other material along with soot blowers. Once the I beam of Long retractable soot blowers is bent, the problems start before we erect the same. If soot blowers particularly Long Retractable are damaged better to replace.
2) While lifting the soot blower, it is wrong to tie the rope along with S.S. Element; which causes bending of element & feed pipe. Two hooks are provided on I beam at both ends. Tie rope at these points for lifting.

3) It is recommended that wherever possible soot blowers should be stored under cover. If this is not possible, due to site conditions, it is recommended that the soot blowers should be stored on a dry firm base. Total assembly should be covered with water proof material.
4) While locating the soot blower, please mark the position on boiler wall/casing/panel and see that there should be minimum 150 mm gap between soot blower element and super heater coils. Previously in some cases it was found that due to misalignment of SH Coils, element was rubbing with coils.
5) After soot blower is erected, check that soot blower element is free from all sides. There is possibility that element is jammed due to refractory inside.
6) Prevent all flue gas leakages coming out from mounting box. Leakages increase the temperature of soot blower parts.
7) After doing electrical connection, operate the Limit Switch (boiler side) manually and confirm that soot blower retracts. In most of the cases Limit Switches get damaged in the first trial. If the soot blower does not retract, please check electrical wiring.
8) Before boiler is commissioned, one should operate soot blowers without steam when boiler is in cold condition, to check working of soot blowers. Normally, soot blower is given less importance and erected in hurry which do create problems.
9) After few operations, tighten chain. Chain tightness required is mentioned at trolley end. A sketch shows name of parts.
10) Normally it was found that steam line is not flushed before putting soot blowers into operation. This causes damage to the seal due to foreign particles. Hence please flush the steam line and then reconnect to soot blowers.
11) Steam should be dry. Hence drain the soot blower line. Water will damage the gland packing.
12) If steam supply pressure is more than 15 kgs/cm^2 then pressure reducing device must be installed. In some cases, we give orifice plate, which should be put between soot blower inlet flanges.
13) Soot blower is to be operated once in a shift. If you need more soot blowing you can do it twice or thrice in a shift. Do not operate continuously. Give some gap so that element becomes cold.
14) In lot of bagasse or coal dust gets deposited on soot blower. Hence clearing by air blowing on soot blower is required.
15) For soot blowers, high temperature grease should be used.

Installation and Operation of Control panel of Soot blower

Description

Controls Panel controls sequential operation of motorized soot blowers automatically. Each soot blower motor is run by its switch gear. Indicating lamps are provided on panel, facilitates knowledge of operation condition of blower motor. This helps operator to monitor and control the operation effectively from remote place. Remote push buttons are provided near blower to operate soot blower from locally. Panel door interlock facility is provided for safety purpose. All overloads have single phasing preventing feature.

H.R.C. fuses are provided for safety of the motor. It enables the three modes of operation, namely

a) Manual Mode
b) Automatic Mode
c) Semi - Automatic Mode

Modes Of Operation

1. Manual Mode

   In this mode auto/manual selector switches of all soot blowers are kept in manual position. Manual push button which is provided on panel or locally mounted push buttons are used for operation. Indicating lamps are provided on panel, indicates blower operation. Valve status indicator can monitor valve operation. Valve indicator will switch off and on in every one revolution. Illuminated indicator indicates steam valve on soot blower is close and illuminated indicator indicates valve is open. In this mode soot blower operates till push button is pressed. Always keep steam valve on soot blower in close position. In Auto mode & semi auto mode panel can be operated in.

   - Single cycle mode
   - Recycle mode

2. Automatic Mode

   In this mode, all auto/manual selector switches of all soot blowers are kept in auto position and auto on push button is actuated. Soot blowers will start operating serially in sequence. Soot blower motor stops after completion of cycle. Auto cycles interrupt, if stop button PBST is pressed.

3. Semi-Automatic Mode

This mode enables operation of even single soot blower in automatic mode. Those soot blowers, which are not working or have to be operated in manual mode for some reason, are kept in manual and others are kept in auto mode When Auto On button pressed, blower, which are kept in auto, works serially in sequence. In case of single blower operating in auto mode, blower will operate and will stop after laps of set delay. (Set on Timer T-1)

In case of recycle mode all soot blower’s work serially in sequence as mentioned above. But once again first soot blower, which is serially in sequence, operates after laps of time set on ‘recycle interval’ timer T-5.

Erection

1. Erection of soot blower is very important factor for trouble free running of the equipment. Seal box has to be fabricated by customer and considering expansion of membrane panel slope to soot blower has to be provided. If expansion will be downwards then rear end of soot blower will be down than front end; so that in hot condition the soot blower will be in perfect horizontal position.
2. While Commissioning of soot blower move the carriage by 500mm by hand crank. After soot blower starts it should go forward. Manually press the limit switch at the front end and insure that soot blower carriage reverses. If not then check electrical wiring and correct the same.
3. All Steam Lines, Drain Lines should be cared of all grit and cutting by blowing steam or air until they are clean.
4. While connecting Steam line no force should be exerted on Soot Blower flange to watch the holes. In case of Boilers having Steel casing, care should be taken so that if location of Soot Blower head changes piping also should be free to move with head, otherwise head will not be horizontal while operating.
5. Erection of Soot Blower is very important point but it is being neglected by most of the erectors assuming small auxiliary plant compared to boiler. Wrong erection of Soot Blower results in damages of element and Soot Blower parts.

Frequency of Operation

The interval between soot blowing periods should be determined by observation under service condition. As a guide line the boiler should be cleaned.

a) Shortly after start up when full W.P. obtained.
b) Approximately every eight-hour service.

c) Observe flue gas temperature at Boiler outlet. If the temperature is increased by 10ºC then soot blowing is required.

The boiler should be on @ 75% load when soot blowing to ensure that increased gas velocity through the boiler helps to carry away the loosened deposits originating from the soot blowing.

a) Do not start two soot blowers at a time.
b) Never run a soot blower without steam when boiler is running.
c) Normal sequence of soot blowing is to follow the gas flow through the boiler. The first soot blower to be operated should be nearest the burner.

Warming up

To avoid damage to the boiler and to the blowers necessitates the use of dry steam. Hence it is important to use a certain procedure for warming up.

a) 'Crack' the steam supply valve to warm up the steam pipes to allow drainage of condensate through the drain valves.
b) After approximately 5 minutes the drain valve has to be closed allowing the steam valve to be opened fully.

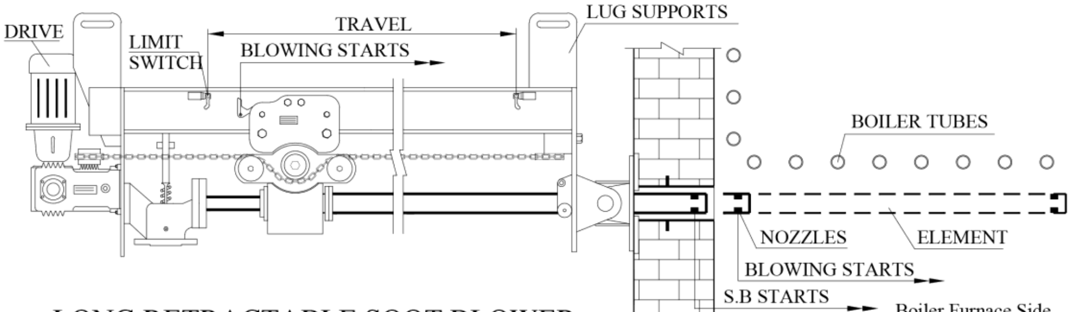
Scavenge Air / Scaling Air

Each blower is provided with air scaled mounting box with air inlet of 1" BSP. The inlet pressure required should be 50 to 76 mm of water gauge more than boiler furnace pressure. In positive pressure installations it is necessary to fit separate scaling and scavenging air-piping systems from the F.D. fan ducting.

Conclusion

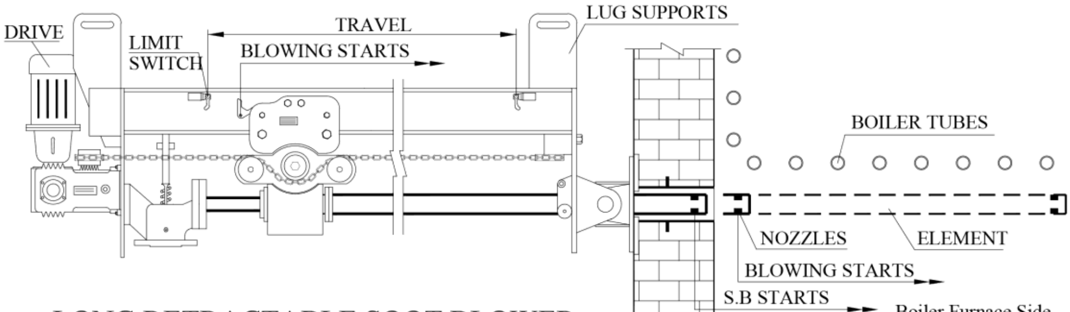
Installation and operation of soot blowers are very important because it helps in keeping heating surface clean without fouling and to get maximum possible heat transfer for maximum efficiency.

SITSON INDIA PVT. LTD.



LONG RETRACTABLE SOOT BLOWER

* Motorised OR Manual
* Fully Automatic With Sequential Operation
* Rotary
* Reciprocating
* Short Retractable
* Long Retractable
* Wall Blower



LONG RETRACTABLE SOOT BLOWER

* Motorised OR Manual
* Fully Automatic With Sequential Operation
* Rotary
* Reciprocating
* Short Retractable
* Long Retractable
* Wall Blower

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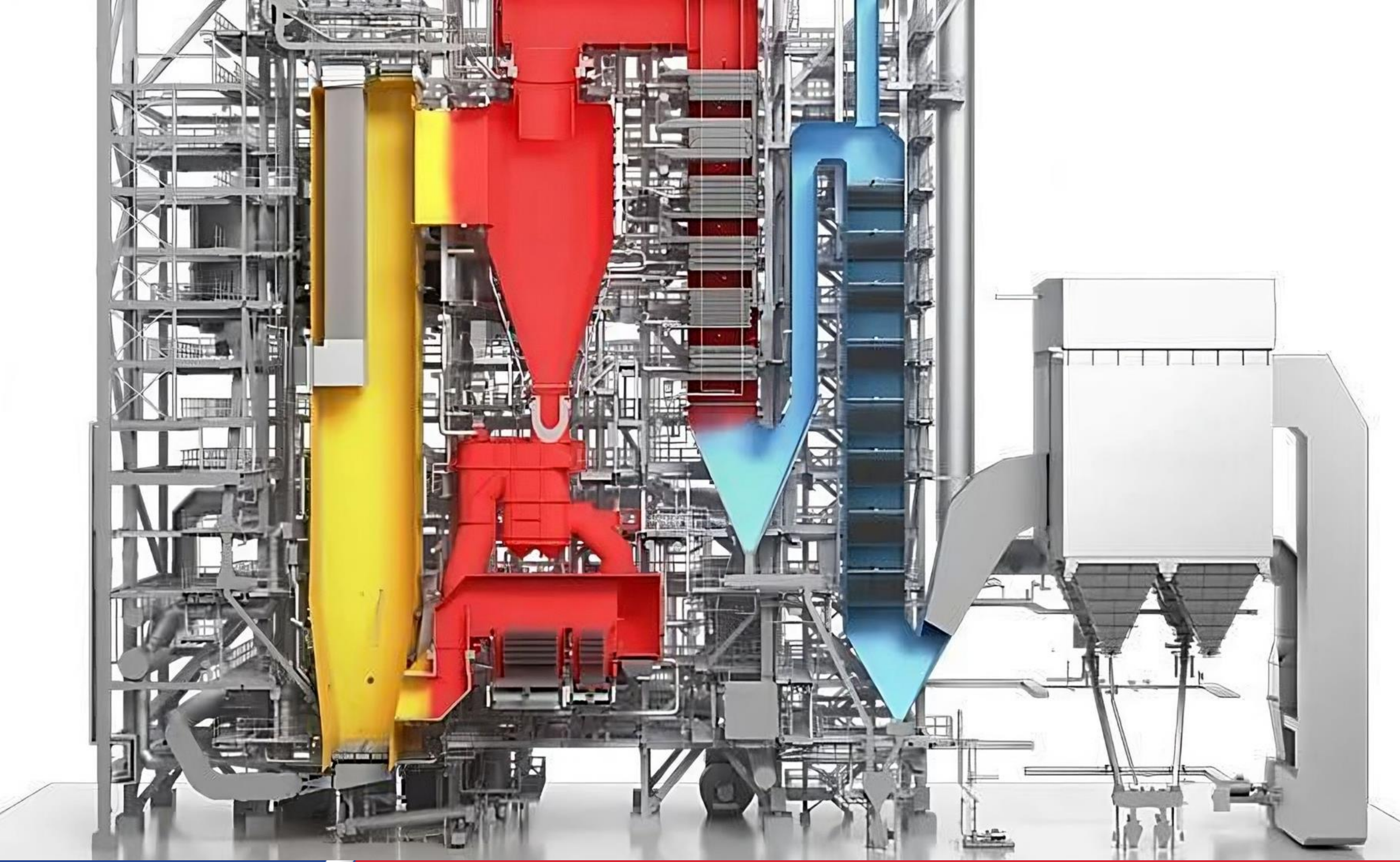


Incineration Boiler for Spent Wash

By Mr.Prashant Bahirgonde
Esbee Power Solutions Pvt. Ltd.

Name: Prashant S Bahirgonde
Organisation: Esbee Power Solutions Pvt. Ltd.
Designation: Director
Education: Completed a three years Diploma In Mechanical Engineering from 'Government Polytechnic, Pune' post SSC, followed by Graduation In Mechanical Engineering (BE MECH) from the 'Pune University'. Completed a course in Post Graduate Diploma In Business Administration with specialization in Marketing Management from 'Symbiosis Centre for Distance Learning', Pune.

Detail oriented, Strong technical background, Effective problem solver, Systematic and Organized, Analytical approach, Leadership qualities, able to work independently and as an integral part of a team, Good communication and presentation skills with individuals at all levels.

- Working as 'Director' at Esbee Power Solutions Pvt. Ltd., Pune since Apr 2008. This is own company (80% shares).
- Worked as 'Regional Sales Manager' at Triveni Engineering & Industries Ltd., Pune from Aug. 2006 to Mar 2008.
- Worked as 'Product Manager – International Operations' at Forbes Marshall Pvt. Ltd., Pune from Dec. 04 to Sept. 06.
- Worked as 'Sr. Executive – International Marketing' in the Energy Systems Division at Thermax ltd., Pune from May 03 to Nov. 04.
- Worked as 'Executive – Sales' in the Energy Systems Division at Thermax ltd., Mumbai from Oct. 01 to April 03.
- Worked as 'Project Engineer' in the PHD-Projects division at Thermax ltd., Pune from Aug. 2000 to Sept. 2001.

Introduction

Incineration of Spent Wash is one of the tested & proven technology for disposal of spent wash for zero liquid discharge (ZLD).

SITSON was experimenting since 1994, First experiment at M/S. Pravara Paper Mill mixing with bagasse and burning in fluidized bed boiler. Second experiment in 1995 at M/S. Krishna S.S.K., DIEG project of VSI Pune, where the boiler and power portion were designed, erected and commissioned by SITSON. Power technology was used for spent wash conversion. The Boiler was generating hot air in addition to steam. This hot air was used for spray in spray drier. The Boiler was fluidized bed boiler with facility to burn coal and bagasse spent wash powder. Third experiment of burning of biogas spent wash along with LDO fire tube Boiler which was working satisfactory. SITSON has supplied more than 40 Boilers where biogas is burnt in bagasse fired Boilers.

Now SITSON has designed and supplied spent wash incineration boilers for concentrated spent wash with support fuels like biogas, coal, biomass. SITSON has both technologies,

1) Fluidized Bed Boilers and
2) Travelling Grate boilers

The main requirement in Incineration Boilers is:

1) Burning of concentrated spent wash in required quantity along with supporting fuel.
2) Trouble free boiler operation without maintenance and longer period of operation without any cleaning required in between.
3) To maintain Pollution control board norms.
4) There should not be any unburnt slop in ash which insures no contamination of water / effluent.

A. Travelling Grate Boilers.

This is the best option for support fuel Bagasse, Rice Husk, Coal and Biomass. SITSON could achieve all these requirements at,

1. L.H. Sugar Factories Ltd., Pilibhit, U.P.
2. Sir Shadilal Enterprises Ltd. U.P.
3. Yedeshwari Agro Products Ltd., Pune, M.S.
4. Cooperative Company Ltd., Saharanpur, U.P.

Boiler specifications at L.H. Sugar and Sir Shadilal Enterprises

Boiler capacity- 36TPH / Pressure - 45 Kg/cm2 (g)

Steam Temp. - 415 deg. C

Supporting Fuel- Bagasse

Quantity of conc. Spent wash (60deg. Brix) burn- up to 16 t/h

Observations

1. The Boiler is running without any stoppage for cleaning in between even up to 250 days of working.
2. The Ash is dry creamish in colour and not sticky.
3. The Boiler was run only on concentrated spent wash for @6 hrs. Without any support fuel. No problem was observed.
4. As the ash is dry Sitson started offering ESP instead of Bag Filters.

B. Fluidized Bed Boilers

This is best option for support fuel Coal and/ or Rice Husk. The fluidized bed boiler- 24 TPH /42 KGC pressure/415 deg. C temp., at M/s. Lahag Group in UP can burn coal and rise husk as a support fuel. Since the ash content is more in coal and rise husk its self-cleaning and hence boiler can run without any cleaning in between during operation even for a year. For coal, rice husk as support fuel this is the best technology.

SITSON can make provision to burn bagasse up to 50% in AFBC boiler as we have tried in biomass fired AFBC boilers at various places.

<u>The points to be looked into</u>

1. Proper placement of H.S. of boiler, S.H., evaporators and economizers.
2. Proper soot blowing arrangements
3. Proper ash removal arrangements
4. Proper design of Travelling Grate
5. Proper design of ESP or bag filters
6. Proper design of conc. Spent wash feeding and burner system.

Spent wash generation with respect to feed stock for 60KLPD ethanol plant

SN	FEED STOCK	FEED STOCK REQUIREMENT	ETHANOL YEILD	SPENT WASH GENERATION
1	Cane juice	800 t/d sugar cane	75 litre/MT	385 tpd (solid 4%) 24 tpd (solid 58%)
2	B-Heavy Molasses	190 MT/Day	315 litre/MT	510 tpd (solid 12%) 102 tpd (Solid 58%)
3	C-Molasses	240 MT/Day	250 litre/MT	624 tpd (solid 15%) 168 tpd (solid 58%)

Other Technologies besides Incineration.

a. Spent wash evaporator for incinerator.
b. Spent wash evaporator followed by ATFD
c. Biodigestor followed by MEE
d. Biodigestor followed by MEE + ATFD

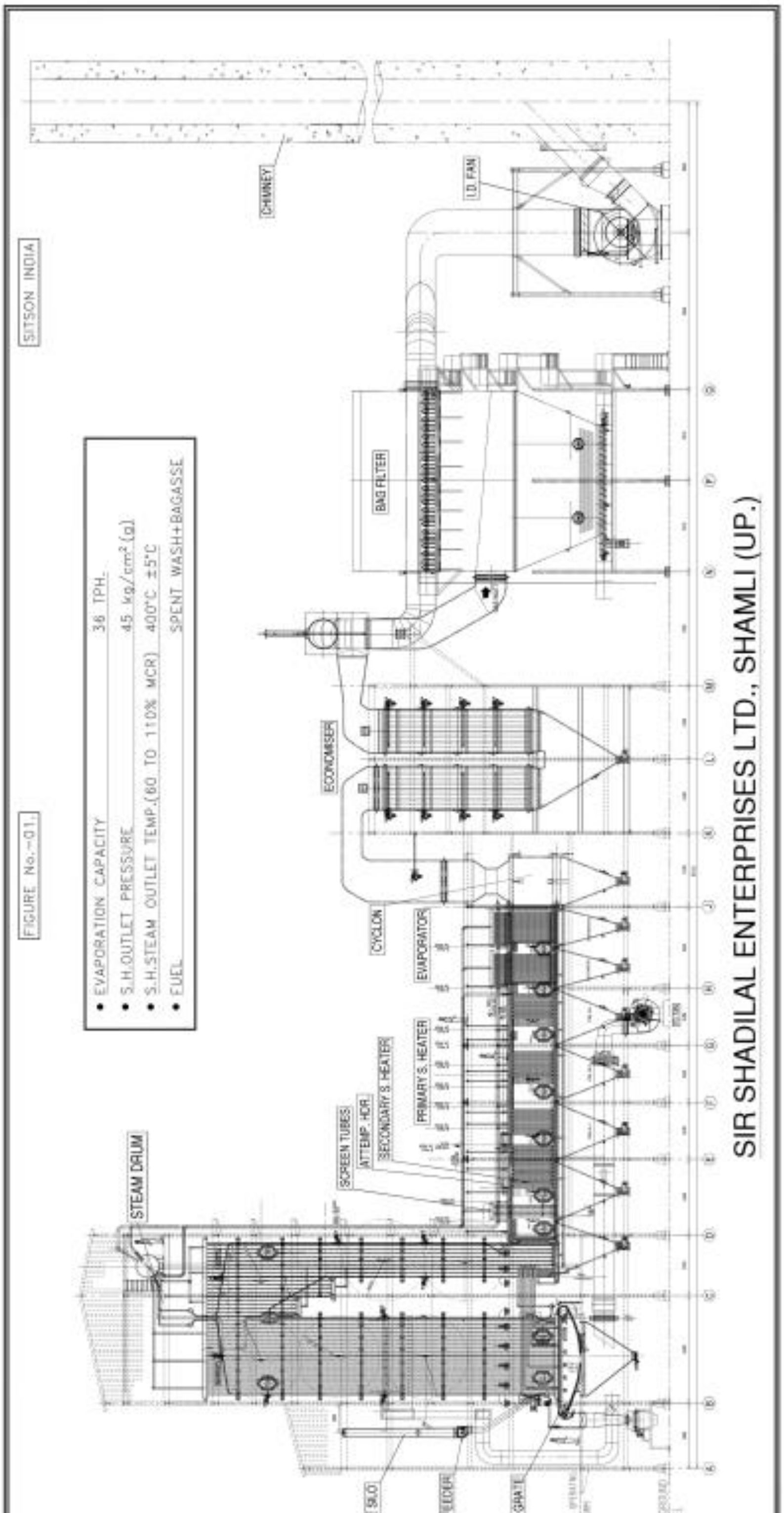
Conclusion

Advantages of Incineration Boiler from Spent wash

1. Saving in Fuel Cost by burning concentrated Spent wash in boiler reduced fuel required for boiler.
2. Recycling more water in to the system as we have concentrated.
3. Meet Norms of ZDL as bio-composting is not allowed now a days.
4. Though the initial cost is more, which can be recovered within 2 / 3 years as for other methods additional fuel required is more.

Note:

1. Typical General Arrangement drawing for Travelling Grate Boiler suitable for Spent Wash + Bagasse or Coal or Rice Husk is as per Fig. – I attached.
2. Typical General Arrangement drawing for AFBC Boiler suitable for Spent Wash + Coal or Rice Husk is as per Fig. – II attached.


SITSON INDIA
FIGURE No.-01.
EVAPORATION CAPACITY 36 TPH.
S.H.OUTLET PRESSURE 45 kg/cm² (g)
S.H.STEAM OUTLET TEMP.(80 TO 110% MCR) 400°C ±5°C
FUEL SPENT WASH+BAGASSE
CHIMNEY
I.D.FAN
BAG FILTER
ECONOMISER
CYCLON
EVAPORATOR
PRIMARY S. HEATER
SECONDARY S. HEATER
ATTEMP. HDR
SCREEN TUBES
STEAM DRUM
BAGASSE SILO
ROTARY FEEDER
TRAVELING GRATE
SIR SHADILAL ENTERPRISES LTD., SHAMLI (UP.)

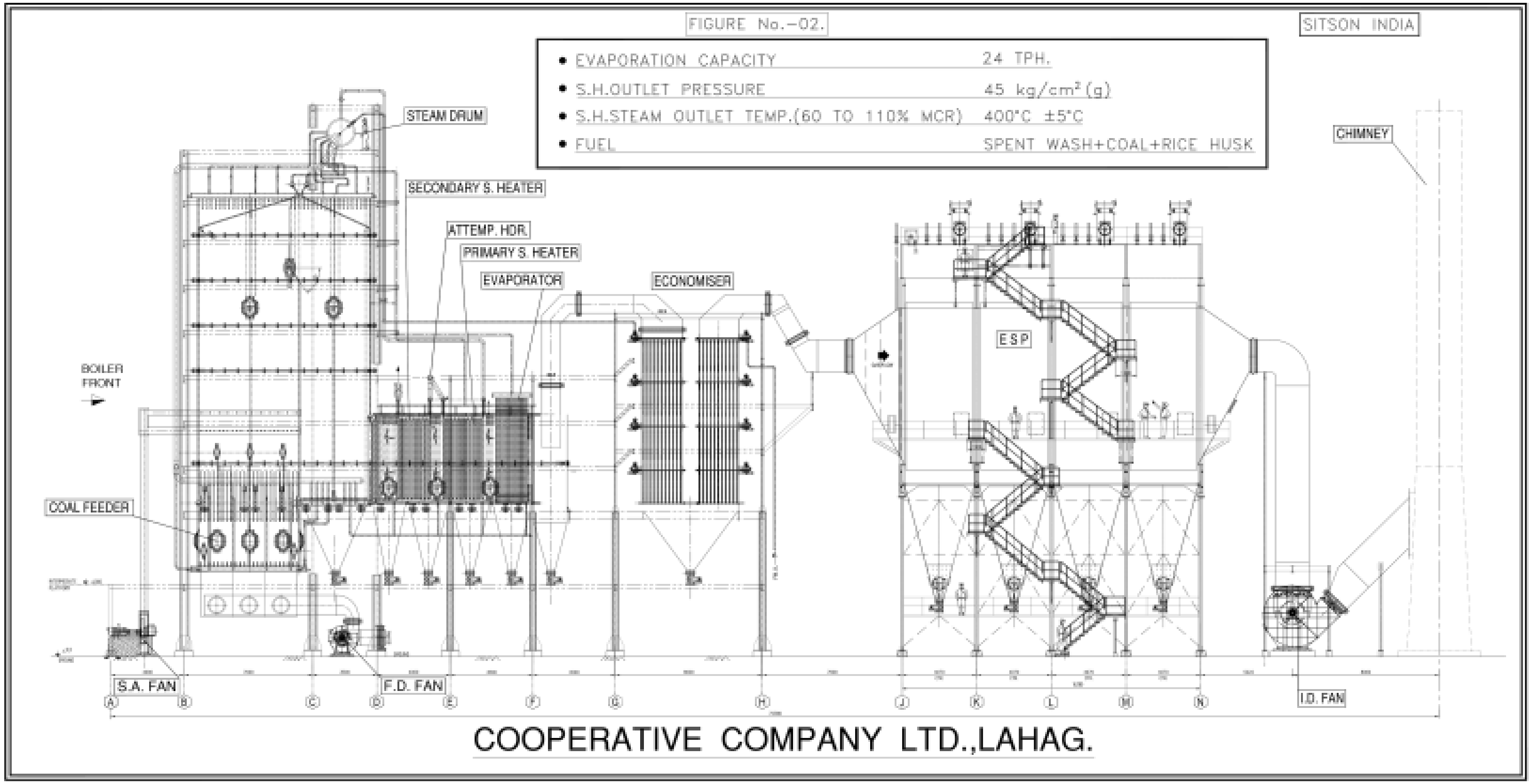


FIGURE No.-02.
SITSON INDIA
EVAPORATION CAPACITY 24 TPH.
S.H.OUTLET PRESSURE 45 kg/cm² (g)
S.H.STEAM OUTLET TEMP.(60 TO 110% MCR) 400°C ±5°C
FUEL SPENT WASH+COAL+RICE HUSK
STEAM DRUM
SECONDARY S. HEATER
ATTEMP. HDR.
PRIMARY S. HEATER
EVAPORATOR
ECONOMISER
ESP
CHIMNEY
BOILER FRONT
COAL FEEDER
S.A. FAN
F.D. FAN
I.D. FAN
A
B
C
D
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COOPERATIVE COMPANY LTD.,LAHAG.

Trends in Distillery Spentwash Incineration Technology

Typical Case of Distilleries Today

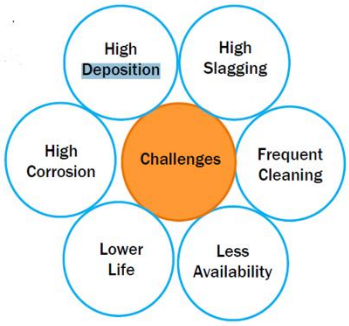
- One of the most important environmental problems faced by the world is management of wastes.
- Pollution prevention focuses on preventing the generation of wastes, while waste minimization refers to reducing the volume or toxicity of hazardous wastes by water recycling and reuse, and process modifications and the by-product recovery as a fall out of manufacturing process creates ample scope for revenue generation thereby offsetting the costs substantially.
- The aqueous distillery effluent stream known as spent wash is a dark brown highly organic effluent and is approximately 12-15 times by volume of the product alcohol. It is one of the most complex, troublesome and strongest organic industrial effluents, having extremely high COD and BOD values. Because of the high concentration of organic load, distillery spent wash can be a potential source of renewable energy if handled properly.

Introduction to Distillery Waste

TEST RESULTS			
Sl. No	Test Parameters	Unit of Measurement	Result
1	Kinematic Viscosity@30°C	cSt	236.15
2	Kinematic Viscosity@40°C	cSt	165.14
3	Kinematic Viscosity@50°C	cSt	114.38
4	Kinematic Viscosity@60°C	cSt	83.53
5	Kinematic Viscosity@70°C	cSt	58.47
6	Kinematic Viscosity@80°C	cSt	53.97
7	Kinematic Viscosity@90°C	cSt	35.98
8	Moisture	%	65.73

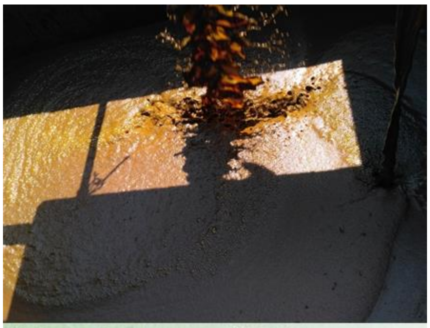
Method of Testing : As Per ASTM D95 & ASTM D445 .

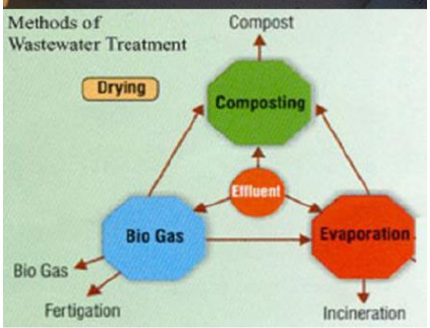
Challenges in Slop Combustion



- Low Calorific Value of Slop even at 60Brix (1200Kcals/Kg). However, it fluctuates between 45 to 60Brix.
- Low Ash fusion temperature due to high Alkali constituents in ash(K2O+Na2O).
- High Chlorides (>1%), Calcium Oxide and sulphatein ash.
- Low Silica in ash.
- Ensuring Continuous operation.

Typical Case of Distilleries Today





- EARSTWHILE EFFLUENT TREATMENT SOLUTION: Bio-methanation followed by Composting using Press mud from Sugar plant.
- ‘FORCED / INFLUENCED’ NEW SOLUTION: Incineration of Spentwash. Due to ‘Limitation’ in design available, RAW SW incinerated with Support fuel (Coal / Bagasse). Solution claimed to be a technological innovation but not in the REAL sense.
- ENERGY IMBALANCE DUE TO NEW SOLUTION: High Steam and Power generation than required So distilleries moved away from energy efficiency due to excess energy (steam) available.
- HIGHER COST OF O&M: Operation Cost increased; Cement Kiln Maintenance Cost increased.

Test Rig Plant at Lokmangal Agro Industries LTD. Solapur

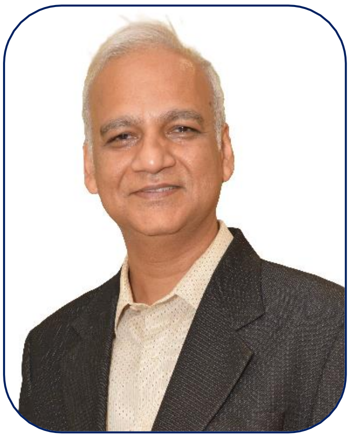
15tph, 45 Kg/Cm^{2}g, 410^{o}C Bio-Methanated Spent Wash Incineration Boiler at Utopian Sugars Ltd., Solapur (*PATENTED)

Highlights Of 'ESBEE' Technology

- NO FUEL COST (SINCE NO SUPPORT FUEL IS REQUIRED). Hence the Cost of Operation of the Distillery (production cost of Ethanol) is lower.
- PERFECT ENERGY BALANCE (STEAM AND POWER PRODUCED MATCHES WITH STEAM AND POWER REQUIRED).
- HIGH QUALITY ASH – Ash generation is only of the Spentwash burnt, which is rich in Potash.
- FULLY AUTOMATIC OPERATION – Operation through BMS System. Skilled Operators Not required.
- HIGH RELIABILITY AND AVAILABILITY – Less ash, Less dependency on operators, Online cleaning mechanism.


THE TRANSFORMATION JOURNEY FROM VULNERABLE TO SUSTAINABLE

By Mr Mukul Agrawal
Deepak Fertilisers and Petrochemicals Corporation Ltd.

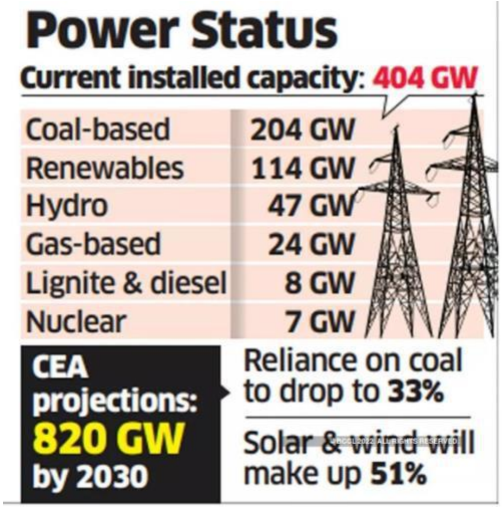


Name: Mukul Agrawal
Organisation: Deepak Fertilisers and Petrochemicals Corporation Ltd.
Designation: President - Operations
Education: Bachelor of Technology (Chemical Engineering) from Harcourt Butler Technical University, Kanpur, and a Post-Graduation Certificate in Business Management (Executive Education) from XLRI Jamshedpur.
Mukul Agrawal is President Manufacturing at Deepak Fertilizers and Petrochemicals, a leading producer of industrial and specialty chemicals and high-performance fertilizers in India. Deepak Fertilizer is market leader in most of its major products in India. Mukul served as Chief Sustainability Officer at Birla Cellulose, the Pup and Fiber business of the $48 billion Aditya Birla Group. Mukul also served as the Board Member of Sustainable Apparel Coalition and was member of the MMCF task force at Zero Discharge of Hazardous Chemicals and a was a member of National Water Mission at FICCI.

DFPCL aspires to be the Leader in the sectors that it operates in with a range of speciality high performance industrial chemicals and fertilizers that deliver higher value to end consumers. DFPCL also aspire to establish itself as a leader in the Sustainable Business practices in the industry. Mukul is responsible for strategizing and implementing the Manufacturing strategy for the business within its operations and across its upstream and downstream value chain.

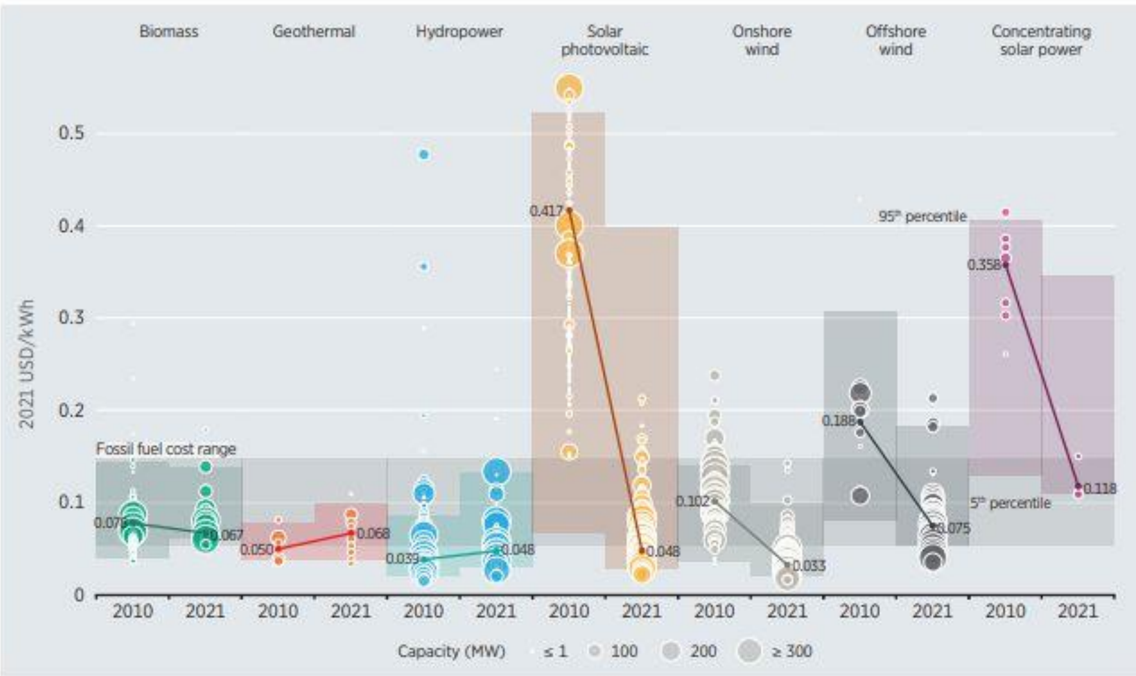
Collaboration with the internal and external stakeholders on the new initiatives in order to sustainably manufacture and enhance use of high-performance products is key to create a broader and larger positive impact in the society. In past Mukul had worked extensively with sustainability focused international organizations like Sustainable Apparel Coalition, ZDHC, Textile Exchange and Fashion for Good for developing manufacturing standards and supporting innovations and new technologies.

Introduction



The need to abate global warming mandates prudent usage of fossil fuels. Coal powered thermal power plants are under pressure to perform efficiently and reduce emissions. Currently, the power generation sector alone is responsible for nearly 41% of global CO_2 emissions, with coal power being the largest contributor of nitrogen oxides (NOx), Sulphur oxides (SOx), mercury (Hg) and particulate matter. Increased deployment of carbon capture, sequestration and utilization (CCUs) technologies can improve the sustainability quotient but may be insufficient to meet the climate goals set in the Paris agreement. Coal is still expected to provide 22% of global power and account for 68% of carbon dioxide (CO_2) emissions even in 20401. Leveraging the right technology can help thermal power plants to reduce emissions CO_2 emissions from 20% to 80%. Adoption of the latest digital technologies can help improve thermal plants'

Figure 1.2 Global weighted average LCOEs from newly commissioned, utility-scale renewable power generation technologies, 2010-2021



Source: IRENA Renewable Cost Database.

performance by reducing the consumption of fuel, auxiliary power, consumables, and greenhouse gas emissions. Existing thermal power plants, therefore, need to be equipped with these technologies to mitigate global warming

On 3rd Aug 2022, the Indian federal cabinet approved the new national emissions pledges, known as Nationally Determined Contributions (NDCs). The new NDC will commit India to reducing the emissions intensity of its GDP by 45% from its 2005 level in the next 7 years – a 10% increase over its previous 2016 pledge. India will also aim to meet half of its energy demands from renewable sources, such as solar and wind, by 2030. This, too, is a boost over its previous target of 40%, which the government said it had achieved in December 2021.

The updated NDC proposes about 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030.

How to transition Coal fired boilers to low carbon economy?

The energy dynamics will rapidly change in next 10 years and looking at the trend of last ten years, this journey can be even faster. There are two fundamental ways in which coal fired boilers can transition to more sustainable energy

1. Use of alternative fuels such as bio mass, bio-gas, refused derived fuel, bio-diesel etc and this has been the traditional fuel before coal was invented.
2. Deployment of Carbon Capture and Sequestration technologies, which are now beginning to get commercialized.

The term “biomass” refers to materials derived from plant matter such as trees, grasses, and agricultural crops. These materials, grown using energy from sunlight, can be renewable energy sources for fuelling many of today’s energy needs. The most common types of biomasses that are available at potentially attractive prices for energy use at federal facilities are waste wood and wastepaper.

One of the most attractive and easily implemented biomass energy technologies is co-firing with coal in existing coal-fired boilers. In biomass co-firing, biomass can substitute for up to 20% of the coal used in the boiler. The biomass and coal are combusted simultaneously. Coal cofiring was successful with up to a 20% biomass mix and most of the large corporates have already started to use the bio-mass in the boilers.

Results of extensive applications have shown that cofiring of biomass with coal have accomplished the following:

1. Reduce GHG emissions,
2. Significantly reduce fuel costs compared to coal or other fossil fuels (FO, NG, oil).
3. Reduced emissions of NOx and Sox.

Every ton of biomass cofired directly reduces fossil CO_2 emissions by over 1 ton. Woody biomass contains virtually no sulphur, so SO_2 emissions are reduced in direct proportion to the coal replacement. Biomass is a regenerable biofuel. When a fossil fuel is replaced by a biofuel, there is a net reduction in CO_2 emissions. Biomass can contain considerable alkali and alkaline earth elements and chlorine, which, when mixed with other gas components derived from coal such as sulphur compounds, promotes a different array of vapor and fine particulate deposition in coal fired boilers.

Application

Biomass co-firing can be applied at facilities with existing coal-fired boilers. The best opportunities for economically attractive co-firing are at coal-fired facilities where all or most of the following conditions apply:

1. annual coal usage is significant;
2. local or facility-generated supplies of biomass are abundant, across the seasons.
3. local landfill tipping fees are high, which means it is costly to dispose of Biomass.

Energy Challenges in India

Sub-critical pulverized coal (PC) technology is used in most of the coal based thermal power plants. Coal is required in large quantities for power generation and India has abundant reserves of this fossil fuel. However, indigenous coal production hasn’t been able to meet the demands and hence significant proportion of coal is imported from overseas.

Bio Energy in India - Significance and potential

India is a land of agriculture. It also receives regular sunshine almost throughout the year and hence suitable for the growth of energy crops as well. Consequently, there is an abundant supply of bioenergy that has the potential to complement the fossil fuels, mainly coal, in generating power for the steadily increasing population in India.

As per a recent study sponsored by MNRE, the current availability of biomass in India is estimated at about 750 million metric tonnes per year. The Study indicated estimated surplus biomass availability at about 230 million metric tonnes per annum covering agricultural residues corresponding to a potential of about **28 GW**. This apart, about 14 GW additional power could be generated through bagasse-based cogeneration in the country's 550 Sugar mills, if these sugar mills were to adopt technically and economically optimal levels of cogeneration for extracting power from the bagasse produced by them.

The Union Ministry of New and Renewable Energy (MNRE) announced central finance assistance for projects utilising biomass like bagasse, agro-based industrial residue, crop residues, wood produced through energy plantations, weeds as well as wood waste produced in industrial operations for power generation.

Biomass has the potential to change the rural energy landscape of India in three ways:

- Electrification of nearly 75 million rural households currently un-electrified in India (25,000 MWe)
- Using bioenergy has a multiplier effect on the development of the economy as about 60% of the total plant cost is circulated back into the rural economy and could also offer employment opportunities to the rural community.
- Help Reduce global warming which is already having detrimental impact on farming due to disturbed rainfall, flooding, famine etc.

Issues in the bioenergy sector in India

- Lack of infrastructure to collect and process biomass resources forcing farmers to burn in fields.
- Biomass transportation and handling issues
- Changes in availability and nature of agri-waste with season

The price for primary biomass is determined by three factors,

1. the supply side factor (technically achievable biomass supply volume with associated cost),
2. the demand side factor (energy demand, land demand associated with food and feed production/energy crop production/and other usages, the price of competing usage (i.e., fossil fuel price, food price)), and
3. the policy factor (i.e., tax incentives, blending mandate)

All three factors are dynamically interlinked and require economic models for detailed assessment. The supply cost of each biomass type needs to be estimated for each local region.

Co-firing of coal and biomass Options:

Estimations show that significant percentage of coal, up to 30%, could be replaced by biomass without any significant modifications in boilers and there would be an optimum level of biomass that can be co-fired with coal based on technical and economic limitation that need to be arrived at for each boiler by a process of optimization.

There are three major options generally available for co-firing biomass with coal. Each of them has its own advantages and disadvantages. All the options have been successfully employed either on a demonstration-or commercial-scale. In direct co-firing, both biomass and coal are combusted in the same furnace. Both coal and biomass may use the same fuel handling and feeding systems or different ones depending on the biomass characteristics. Direct co-firing is the cheapest and most commonly used method. Many companies are using the bio-mass as such after grinding, where as some companies prefer to convert it into briquettes. Using the bio-mass as such is a cheaper option and has problems associated with handling and feeding and may limit the use up to 15% in several cases. Converting into briquettes could be easier in handling but adds to the cost, Indirect co-firing utilises a gasifier to convert the solid biomass fuel into a gaseous fuel which could be co-combusted with coal in the same furnace. This method, although expensive, could be used for a broader range of biomass fuels; biomass fuels that are difficult to grind could especially be utilised through indirect co-firing.

Environmentally, the use of biomass briquettes produces much fewer greenhouse gases, specifically, 13.8% to 41.7% CO_2 and NOx. There was also a reduction from 11.1% to 38.5% in SO_2 emissions when compared to coal from three different leading producers, EKCC Coal, Decanter Coal, and Alden Coal. Biomass briquettes are also fairly resistant to water degradation, an improvement over the difficulties encountered with the burning of wet coal. However, the briquettes are best used only as a supplement to coal.

Challenges in the implementation of co-firing in India

India has an ideal situation where co-firing of coal and biomass should be in optimal use. However, it has not been the case.

The big question that immediately arises is why this technology has been overlooked?

Has it been tried and tested enough to be ignored? A preliminary analysis on this issue points to the following factors:

- Technical problems arising from the combustion of biomass (even if minor) in furnaces designed for coal combustion
- For higher than 15% co-firing, capital investment in the power plant to accommodate biomass storage, processing, and feeding
- Fluctuating availability of biomass and unpredictable prices and absence of organized biomass market
- Utilities ‘concern about issues arising from use of certain bio mass with high alkali content or ash content.
- Utilities’ mindset to only adopt conventional pulverized coal technology – need for change management.

Also, there is lack of support from boiler OEMs on co-firing and sometimes they are able to dissuade the co-firing citing the reliability issues in long term.

Co-firing has been in existence in India and globally for more than 20 years now and the standard operating procedures have been developed that allow the safe use of bio-mass based fuels in boiler to the extent of 30% or some companies are going beyond these limits as well. It is important to set the control parameters and procedures for handling, feeding and boiler operations for achieving high boiler efficiency and reducing the cost. Different type of bio-mass may need to be fed at different feed zones in boilers.

Government of India initiatives

The Ministry of New and Renewable Energy (MNRE) in India has taken up programmes on Biofuels through research, development and demonstration projects at various research, scientific and educational institutes, universities, national laboratories, industry, etc. India has adopted agenda and actions based on the UN post-2015 development agenda.

Transforming our world: the 2030 Agenda for Sustainable Development, with 17 Sustainable Development Goals (SDGs) for the people, planet and prosperity reflecting the commitment of shifting on to a sustainable and resilient path. The overall aim of the Integrated Bio Energy Mission would be to contribute to achieve the GHG emissions reduction targets as agreed in the Nationally Determined Contributions at COP 21 through the progressive blending/ substitution of fossil fuels such as coal, petrol, diesel, natural gas and LPG with biomass pellets, bioethanol, biodiesel, biomethane, and similar green fuels, both for electrical and non-electrical uses. The indicative outlay for the Mission would be Rs 10,000 Crore from 2017-18 to 2021-22. The major goals of the National Policy on Biofuels are the development and utilization of indigenous non-food feed stocks raised on degraded or waste lands, thrust on research and development on cultivation, processing and production of biofuels and a blending mandate of 20% Ethanol and Bio-diesel by 2017. The objective of biofuel programme is to support R&D, Pilot plant/Demonstration projects leading to commercial development of 2nd Generation biofuels.

Considerable potential exists in the country for utilisation of materials such as municipal refuse, paddy husk, coffee husk, saw dust, bark, wood waste etc., as fuels in boilers.

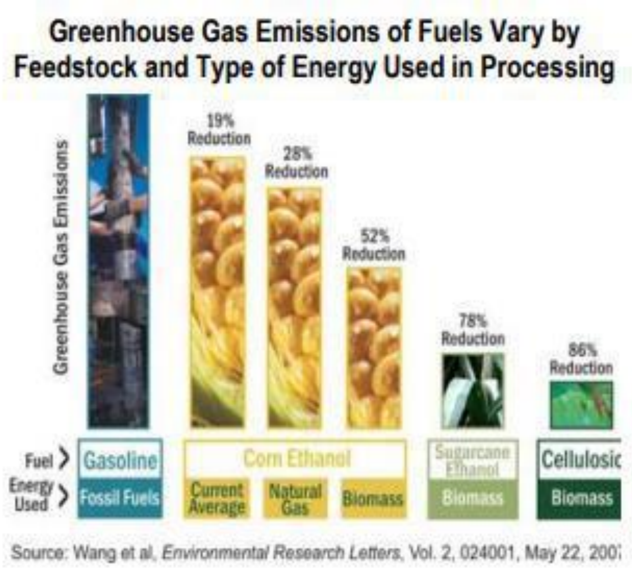
In the conventional stoker type boiler, when agricultural waste such as paddy husk, bamboo dust, bagasse, wood chips are to be burnt, a separate furnace is required from which the flue gas is led into the boiler. With FBC (fluidised bed consumption) boilers, there is no need for a separate furnace. This waste can effectively be combusted in FBC boiler without the use of supplementary fuel. Hence, it is one of the advantages of fluidised bed combustors, that they can be used for combustion of any kind of fuel to produce heat or as incinerator of combustible materials or for heat recovery proposal. Depending on the fuel characteristics, specific combustor design is required to burn agro waste either independently or in combination of either high or low quality fuel like coal lignite etc. in an effective way.

The advantages of fluidised bed combustion boilers are

- Ability to burn low-grade fuels
- High thermal efficiency
- Ability to burn fines
- Flexibility to burn agro waste fuel
- Less excess air higher Co2 in flue gas

Converting waste into Bio-gas

Biogas systems use the natural, biological process of anaerobic digestion to recycle organic waste, turning it into biogas, which is used for energy. Biogas is composed primarily of methane (50–70 percent) and carbon dioxide (30–50 percent), with trace amounts of other particulates and contaminants. Biogas can be produced from a variety of sources, including agricultural digesters, wastewater treatment facilities, and landfills. Biomass energy is derived from combustion of organic material. Sources of biomass include forest wood and crop residues; organic, animal and municipal waste; crops cultivated to serve as biomass fuel; and by-products such as black liquor, from the pulp and paper industry. Direct combustion is the most established and commonly used technology for converting biomass to heat. Renewable natural gas (RNG) is a pipeline-quality gas that is fully interchangeable with traditional natural gas and compatible with pipeline infrastructure. There are two principal technology platforms for producing renewable gas: (1) thermal gasification and (2) anaerobic digestion. Each platform involves the production of raw gas (i.e., biogas) that is then upgraded (i.e., impurities like carbon dioxide are removed). Waste-to-energy is created when municipal solid waste is combusted and the heat from the resulting combustion converts water to steam, which is sent to a turbine to generate electricity and thermal heat. After this combustion process, remaining ash from waste is processed to remove particulate matter before being trucked to a landfill.



The above graph shows the relative GHG emissions of some typical sources of bio-mass compared to fossil fuel.

Carbon Capture and Sequestration Technology Development

There are several development happening to capture the carbon emission from flue gases and sequester CO2 or use the CO2 to make polymers that can replace crude oil which is conventional feedstock. Similar facility is operated by Mitsubishi Heavy Industries (MHI) Hiroshima R&D centre. This plant has boilers, dust separator, flue gas processing apparatuses, and the desulfurizing system of the wet limestone gypsum method (FGD). The CO2 recovery system is including a rinse tower to remove sulphur oxides present in the flue gas, a cooling tower to cool the flue gas, an absorbing tower to capture CO2 by “KS-1 solvent,” a water washing tower to recover solvent components accompanying the flue gas from the CO2 absorbing tower, and a regenerating tower to strip CO2 by heating the solvent absorbing CO2 with steam. The purity of the CO2 captured from the flue gas of the coal fired boilers is approx. 99.8 %-dry, which meets the requirement of 95% or higher in purity generally required for CO2EOR. When the concentration of sulphur oxides flowing into the CO2 recovery system is high, the accumulation of heat stable salt, particularly sulphate, increases to cause the deterioration of the solvent. To solve this problem, sulphur oxides must be pre-processed and removed on the downstream side of the CO2 recovery system beforehand.

Coal is one of the most abundant fossil fuels and thus has a long history of use, from heating to steel production to power generation. Though coal use is both reliable and inexpensive, it is also a major producer of carbon dioxide (CO2) emissions. Research into carbon capture and storage technologies, often termed "clean coal," has soared since implementation of the Clean Air Act, designed to regulate airborne contaminants. CRF scientists Chris Shaddix, Ethan Hecht and postdoc Manfred Geier, in collaboration with professors at the National University of Colombia and the University of Sydney, recently announced the results of their experimental and computational work showing how CO2 influences nitrogen oxide (NOx) formation, coal particle stream ignition, and char particle combustion in unexpected ways during the combustion process.

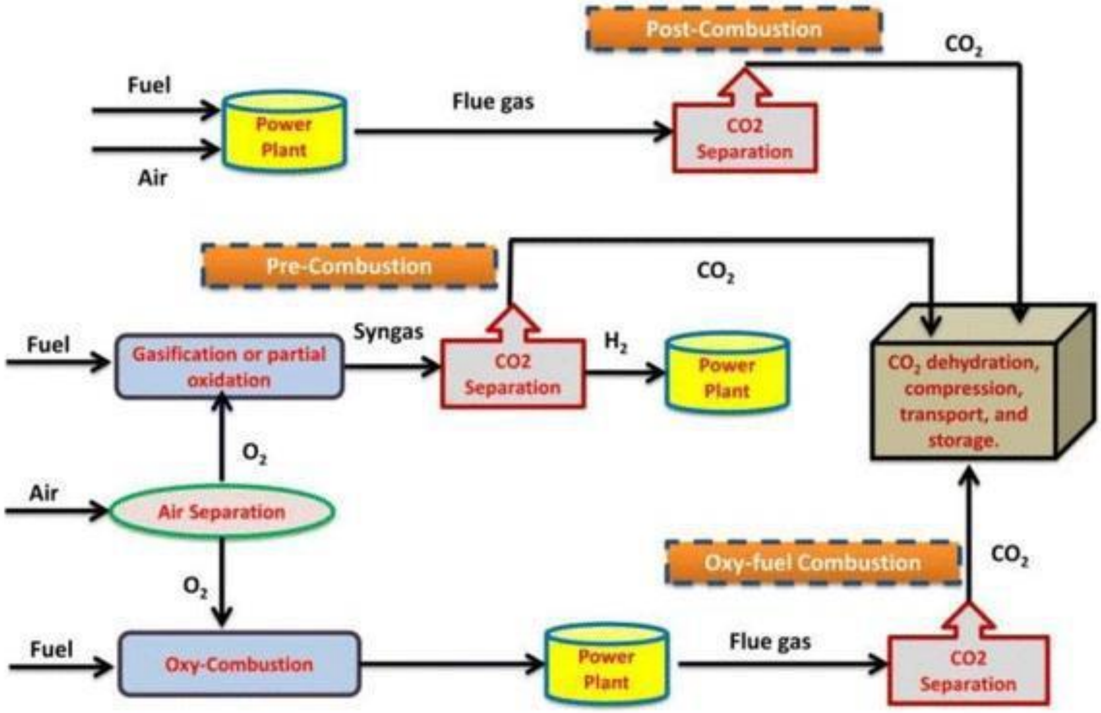
Over the past two years, improvements in the efficiency of traditional coal power plants have been made through the development of strong, nickel-based superalloys used for steam pipes in the combustion furnace. The development of these advanced steel alloys has allowed the steam turbine to operate at higher input temperatures and pressures, in which the steam is in a supercritical state. Thus, new "ultra-supercritical" coal power plants have recently been built throughout the world; these plants have thermal efficiencies of 44%, compared to the 32% average efficiency of U.S. coal power plants (which were built 35 years ago). This level of efficiency gain corresponds to a 27% reduction in CO2emissions (and, indeed, of all pollutant emissions) from the coal power plant.

In the US, the conversion approaches constitute two of the three basic routes for fossil fuel carbon capture, namely the 'oxy-combustion' and 'pre-combustion' routes shown in Figure 3. Recent cost estimates suggest that implementation of any of these approaches to carbon capture would add 40-50% to the cost of electricity relative to a new supercritical coal boiler without carbon capture, and would reduce the plant-wide thermal efficiency back down to nearly 32%.

While CCS technology can significantly mitigate anthropogenic GHG emissions, CCS installations are expected to impose new water stresses due to additional water requirements for chemical and physical processes to capture and separate CO2. In addition to these processes, the parasitic loads imposed by carbon capture on power plants will reduce their efficiency and thus require more water for cooling the plant. Groundwater contamination due to CO2 leakage during geologic sequestration is an additional concern when adapting CCS into power plants.

A review of recent studies highlights three main challenges that would impact water sustainability due to CCS installation:

- water requirements needed for different stages of CCS,
- changes in groundwater quality due to carbon leakage into geologic formations
- opportunities for using desalinated brine from saline sequestration aquifers to provide new freshwater sources and offset the CCS-induced water stresses.



CCS technology is a viable mitigation option for reducing GHG emissions in fossil-fuel power plants. There are three main components of the CCS process: capturing CO2 arising from the combustion of fossil fuels, transporting CO2 to the storage site, and storing CO2 for a long period of time, rather than being emitted to the atmosphere.

The three common technologies for CO2 capture in CCS systems are the following: postcombustion capture, pre-combustion capture, and oxy-fuel capture. In post-combustion capture, CO2 is separated from the flue gases before they are discharged to the atmosphere. The most commercially common method, amine scrubbing, is based on using amine gas treating to remove CO2 by aqueous solutions of amines. The CO2 removed from the amine solvent is then dried and compressed to reduce its volume before being transported to a safe storage site. The pre-combustion capture of CO2 is based on the ability to gasify all types of fossil fuels with oxygen or air and/or steam to produce a synthesis gas (syngas) or fuel gas composed of carbon monoxide and hydrogen. Additional water (steam) is then added and the mixture is passed through a series of catalyst beds for the water–gas shift reaction to approach equilibrium, after which CO2 can be separated to leave a hydrogen-rich fuel gas. This hydrogen can be sent to a turbine to produce electricity or used in hydrogen fuel cells of transportation vehicles. Although the energy requirements in pre-combustion capture systems may be of the order of half that required in post-combustion capture, the precombustion process requires more water for the water–gas shift reaction. In the oxy-fuel capture, pure oxygen is used for combustion instead of air and gives a flue gas mixture of mainly CO2 and condensable water vapor, which can be separated and cleaned relatively easily during the compression process.

Conclusion

Transitioning to low carbon economy is a reality globally and is necessary to mitigate the risks that are arising from the Climate Change. India also has taken aggressive targets reduce the GHG emissions by 2030, we all need to plan for this transitional journey. This is visible in all walks of life, whether it is renewable power of electric vehicles or alternative fuels, or preference of consumers for low GHG emission products.

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LATEST TECHNOLOGY & REMEDIAL MEASURES FOR ASH DEPOSITION PROBLEMS

By Mr Pramod P. Kate
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Name: Pramod P Kate
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Designation: Boiler Technical Consultant
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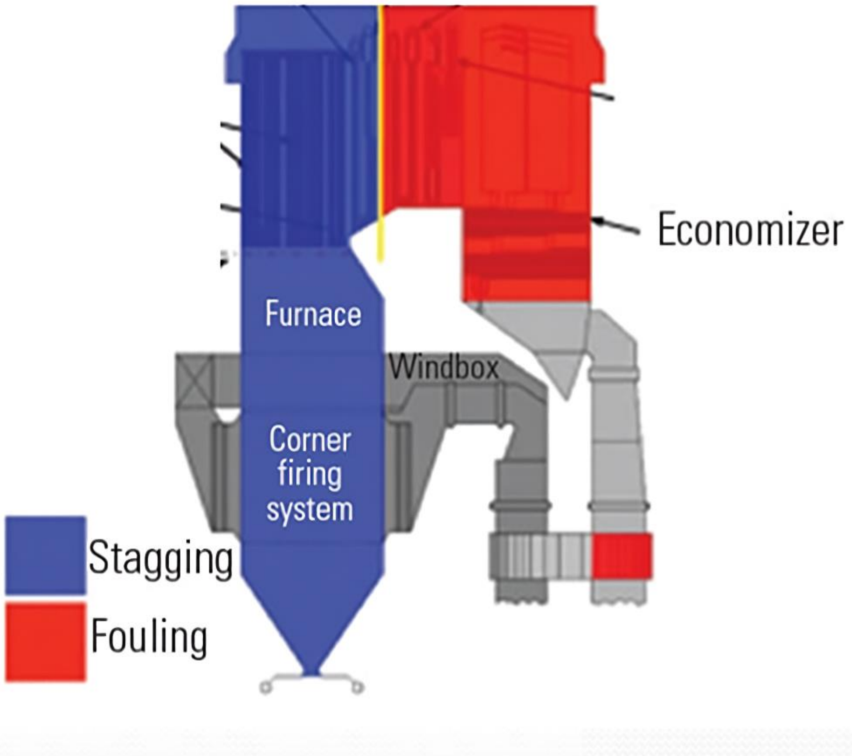
36 years of experience of Boiler Pressure Parts, Coal Mills, Air Preheaters, ESP'S Fans and various boiler auxiliaries and mountings. Successfully completed 12+ Consulting / Training Assignments in last 12 months

- 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 reduction in Generation Loss due to Boiler Tube Leakages (BTL) (less than 2%)
- Member of Committee for Studying Unchar Accident & giving guidelines & directions for safe working of boilers at Maharashtra State
- Member of Board of Examination of Boiler Proficiency Examination conducted by Office of Steam Boiler, Maharashtra State

Ash deposition problem in conventional coal fired / fuel oil fired / FBC boilers including mechanisms, latest technologies, and remedial measures.



Ash Deposition - Fouling & Slagging

Introduction

Uneven ash deposition on fireside steam generating surfaces of boilers may lead to alarming disturbances in circulation. The situation aggravates with higher steam generating parameters i. e. temperature and pressure.

For once through super critical pressure boilers, ash deposits on waterwalls of the furnace bring about a large amount of temperature maldistribution. Large aggregate of slags detached from furnace waterwall can cause mechanical breakage of waterwall tubes at the furnace bottom.

Fly ash clogs convective gas duct with the effect that greater resistance is imparted to the motion of flue gas. This may result in a loss of steam generating capacity as high as 50% from the rated value. Fly ash deposits on convective heat transfer surfaces build up additional thermal resistance and lead to a loss of boiler efficiency.

Process

The inorganic impurities in fuel like Sodium, Sulphur and vanadium are responsible for ash deposition problem in boilers. Fuels used for steam generation contain a large variety of impurities in the form of inorganic material apart from the organic material that provides the heat energy. During combustion, these impurities undergo changes in their chemical form by combining with other constituents in the combustion regime. The effect of such combined materials being formed will be different at different sections of boiler starting from the furnace to the air pre-heaters.

At the beginning of deposition process, when the tube is clean, only vapours of KCl, K_2SO_4, NaCl, Na_2SO_4 and fine particles of Al_2O_3 & SiO_2 will accumulate on the surface in a sticky condition. The deposit surface temperature goes up when the thickness of the deposit increases. Consequently, a molten film on the outer part of the deposit can flow down the side and form drops at the bottom of the deposit. Finally, these drops detach the tube when the surface tension is no longer capable of supporting the weight of the drops.

Classification of Ash Slags

When pulverized solid fuels are burnt, a part of mineral impurities in the fuel, are melted. Depending on their melting point, viscosity, and thermal conductivity the ash particles adhere to external surface of tubes leading to slag formation.

Ash slags can be classified as

- LOW FUSIBLE ASH
    - Contains compounds like NaCl, Na_2SO_4, $CaCl_2$, $MgCl_2$, $Al_2(SO_4)_3$
    - Melting Point 700-900˚C
- MEDIUM FUSIBLE ASH
    - Contains compounds like Na_2SIO_3, K_2SO_4, FeS
    - Melting Point 900-1100˚C
- HIGH FUSIBLE ASH
    - Contains compounds like CaO, MgO, Al_2O_3, Fe_2O_3
    - Melting Point 1600-1800 ˚C

There is another convenient way to classify ash deposit. Depending on bonding characteristics of ash particles and mechanical strength of deposited layer, ash deposits are classified into

- Loose Deposit
  Loose deposits are the deposits that form without chemical reactions and contain no sticky component in the matrix.
- Bonded Deposit
  Bonded deposit is denser layer of slag firmly bonded to heat transfer surfaces. At higher flue gas temperature, most of the ash particles suspended in the flue gas remain in plastic stage and form sticky mass on outer surface of waterwall and superheater tubes.
  It quickly grows in thickness by arresting fly ash particles from flue gas and subsequently such physico-chemical processes may occur to strengthen the bond.
  Bonded deposits are mainly encountered in solid fuel fired boilers. They also known to occur in oil fired boilers if fuel oil contains mineral components as sodium, vanadium, calcium and magnesium.

Factors Responsible for Formation of Ash Deposit

Principle factors responsible for formation of bonded ash deposits are

- Mineral matter present in the fuel
- Behavioural pattern of mineral constituents of fuel
- Furnace temperature
- Heating rate
- Time of exposure of mineral matter of fuel to high temperature
- Flue gas composition
- Temperature of flue gas, fly ash and heating surfaces in those zones where formation of ash deposits is more likely
- Physico-chemical processes taking place inside the deposited mass of ash

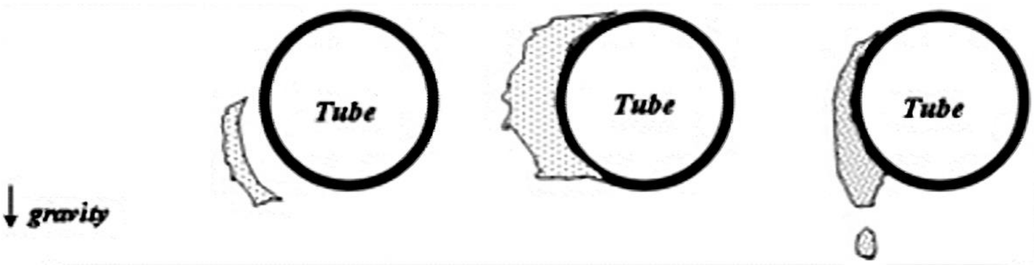
Fusibility of Ash

Fusibility of ash is determined by the amount of different metal oxides and silica present in ash. These metal oxides (CaO, MgO, Fe_2O_3) form eutectics with silica (SiO_2). Usually, ash produced by most solid fuels contain metal oxides in the range of 5 to 40 %. Higher percentage of metal oxides lower the melting point of eutectic giving rise to low melting ash. Al_2O3+ SiO_2 content higher than 80 % tends to increase the melting point of ash, which therefore becomes high melting. Mechanical strength of primary ash deposit has effect on slagging of heat exchange surface of boiler.

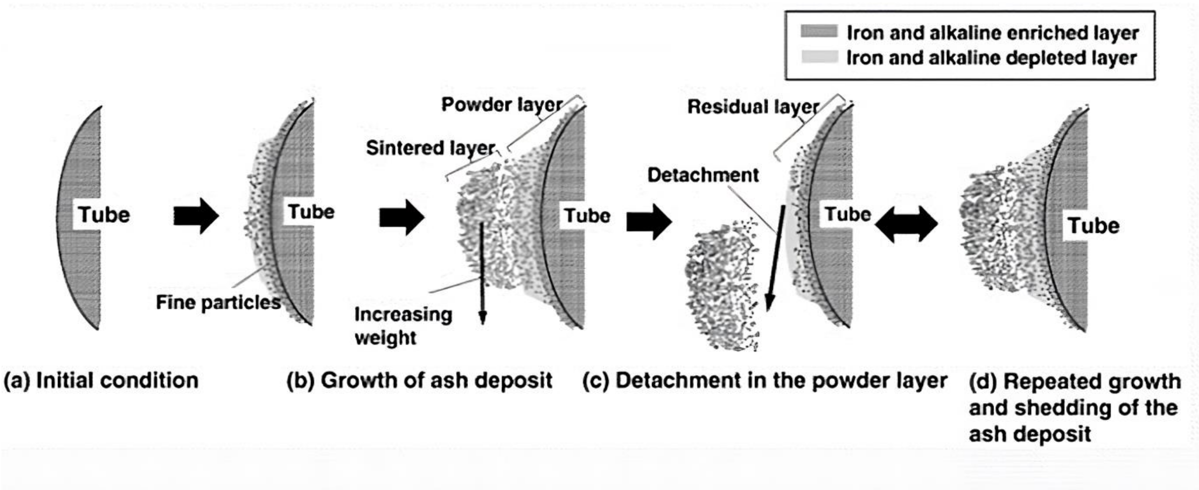
Strength of Deposit

The mechanical strength of ash particles is determined by their compressive strength. On the basis of different compressive strengths, the ash deposits can be divided into

- LOOSE DEPOSIT
  Compressive Strength < 1 MN / M^2
- DENSE DEPOSIT:
  Compressive Strength 1 to 3 MN /M^2
- STRONG DEPOSIT
  Compressive Strength 3-7 MN /M^2
- VERY STRONG DEPOSIT
  Compressive strength >7 MN/M^2
  I MN= 101971.62 Kgf
  I MN/SQ.M=IO Kgf /cm^2



Deposit characteristic	Weak deposit (low strength value)	Strong deposit (high strength value)	Low-melting-point deposit
Shedding characteristic	Debonding	No debonding	Melting and flow



Mechanisms of Ash Deposition

- Generally, the following five main mechanisms contribute for ash deposition.
- Condensation
- Thermophoresis
- Brownian diffusion
- Inertial Impaction
- Chemical reaction

Condensation

Condensation is the mechanism by which vapours are collected on a surface cooler than local gas. It happens either heterogeneously on tube surface or homogeneously on surface. The inner layer is formed due to the condensation of low melting ash from flue gases on tube surface as a thicky sticky film that arrests the high melting fine ash particles falling on it.

Saturated with fine ash particles, the molten slag on tube surface solidifies to form primary dense layer of slag firmly bonded on tube surface. The temperature of outer surface of primary layer then gradually increases and inhibits further condensation of low melting ash from flue gas.

Therefore, further deposits of high melting ash particle on the rough outer surface of primary layer become loosely held and they form secondary layer.

Thermophoresis

Thermophoresis is a force generated by the temperature gradient between the hot gas and the cold wall affecting the particulate movement towards the cold wall. This phenomenon observed in mixtures of mobile particles where the different particle types exhibit different responses to the force of a temperature gradient. It is caused by the temperature gradient so that movement of fluid molecules in the hot zone and high energy levels in this region, displaces the nano particles towards the cold region.

This force transmits gas-borne particles of size less than 10 micrometres to 30 micrometres towards the lower temperature regions, such as radiant section of the boiler. Thermophoresis is also referred as Thermo migration, Thermo diffusion or Soret effect. Soret number is the ratio of temperature difference to the concentration. The rate of change of temperature with displacement in given direction as with increase of height gives database for studying thermophoresis effect.

Brownian Diffusion

Brownian diffusion is the characteristic random wiggling motion of small particles resulting from constant bombardment by surrounding gas molecules. This pattern of motion typically consists of random fluctuations in a particle position inside a fluid sub domain, followed by a relocation to another sub-domain.

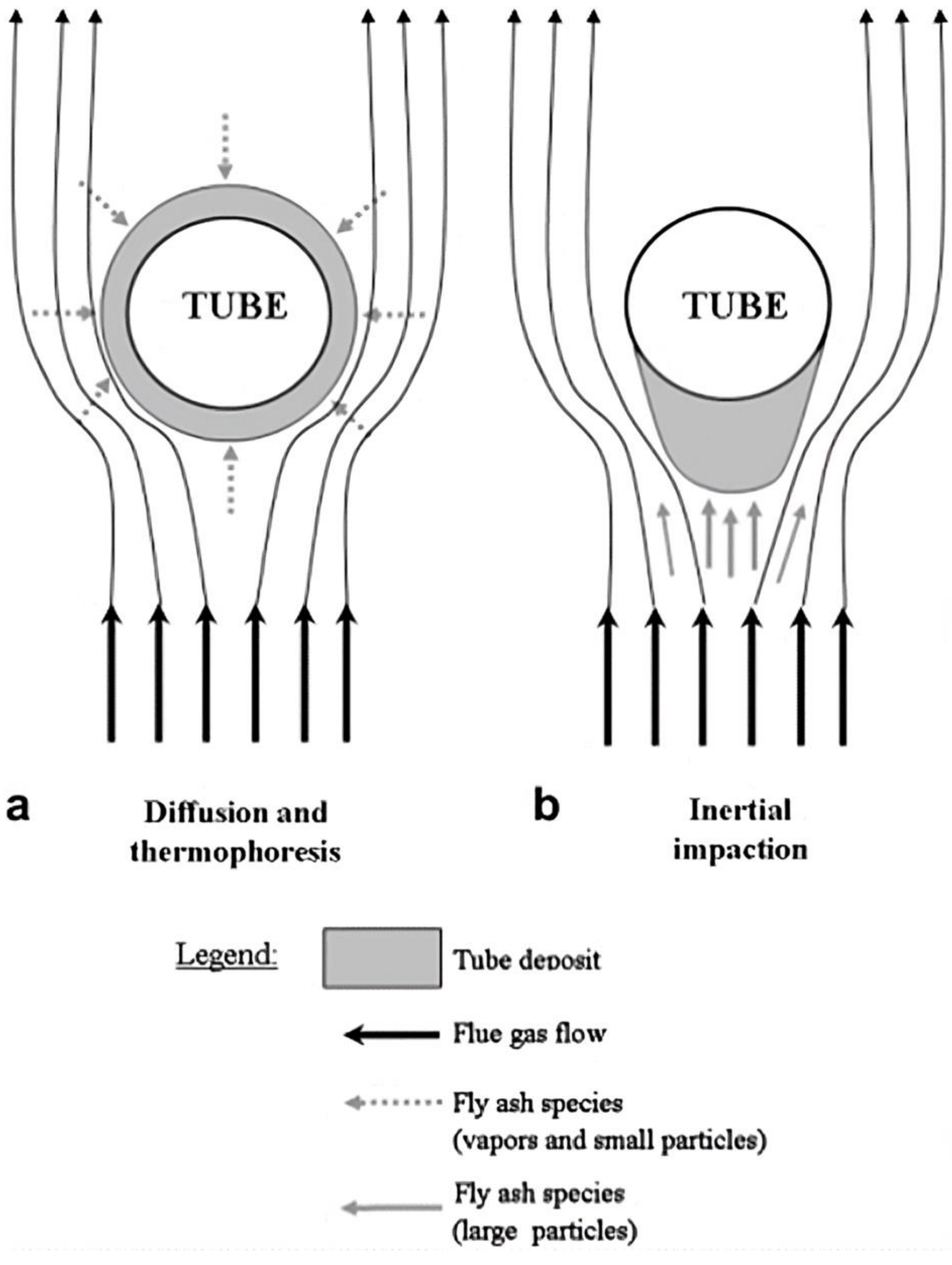
It is dominant particle deposition mechanism for small particles over short distances. Brownian coefficient depends on Boltzmann's constant (1.38x10-23J/K). Larger the value of this coefficient the more rapid is the mass transfer from regions of high to low temperatures.

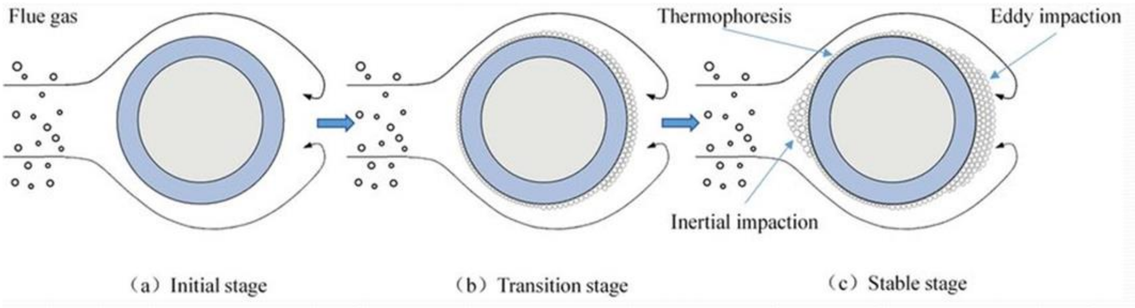
Impaction

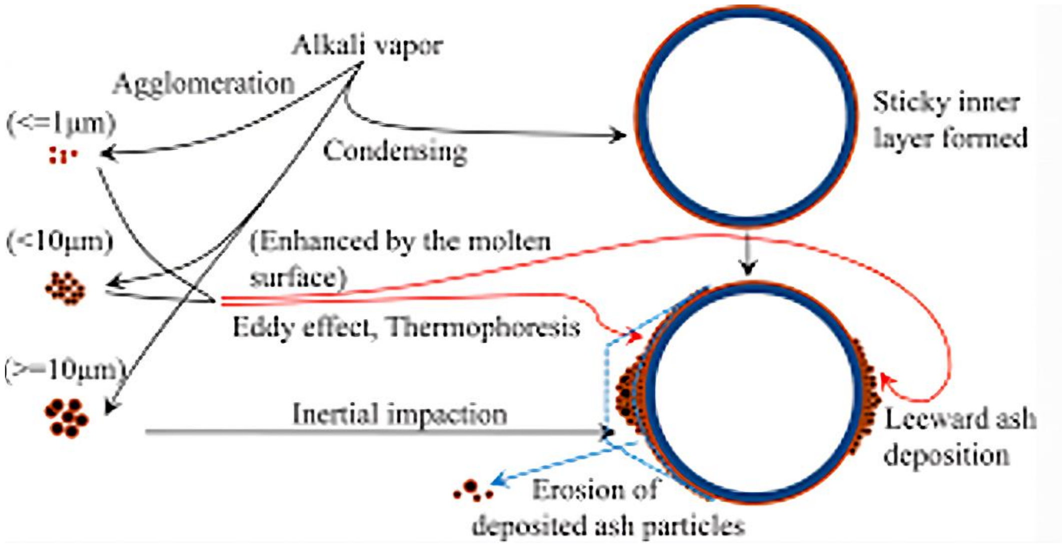
Inertial impaction is the mode of transport for large particles to heat exchange surfaces. The particles subjected to inertial impaction are usually greater than 5-10 micrometre in size.

To impact a force, the large particles must have enough inertial momentum to overcome the drag force of the gas flow on the particles. Smaller particles will tend to succumb to the drag effect and follow the streamlines.

Eddy impaction is another important transport mechanism. It acts on particles in the range of 1—10 micrometre and those susceptible to diffusion and thermophoresis. These particles do not have enough inertia to impact on front side of the tube. However, they may accumulate on back side of the tube.


TUBE
TUBE
a
Diffusion and thermophoresis
b
Inertial impaction
Legend:
Tube deposit
Flue gas flow
Fly ash species
(vapors and small particles)
Fly ash species
(large particles)





Chemical Reaction

The flue gases are cooled in the vicinity of the tube's boundary layer, thus the vapors KCl, K_2SO_4, NaCl & Na_2SO_4 diffuse towards the cooling surfaces and condense on it, causing a sticky layer on the surface. The presence of this sticky layer is then essential for solid particles to be captured on tube surface.

The deposit outer surface temperature increases as its thickness so at certain temperature, higher than saturation temperature of condensable species the condensation process stops. The mechanism by which ash can be accumulated in a deposit is completely by chemical reactions. These reactions include the heterogeneous reactions of gases with species in the deposit.

The most significant chemical reactions with respect to deposit formation are

- Sulphidation
- Alkali Absorption
- Oxidation

Formation of Compounds

Compounds that have been recognized as having the potential to form in deposits and cause fire side corrosion of tube surfaces include.

- PYRO-SULPHATE $Na_2S_2O_7$, $K_2S_2O_7$
- ALKALI-IRON TRI-SULPHATE $Na_2Fe\ (SO_4)_3$, $K_2Fe\ (SO_4)_3$
- MIXED SULPHATES Na_2SO_4, K_2SO_4

In considering the possibilities for such compounds to form in deposits, it is essential to assess the melting point of the compounds and the conditions necessary for their formation.

A. Flue gas temp. 1000-1650
   Furnace water wall
   Sodium/Potassium pyrosulphates
B. Flue gas temp. 650-1000
   Superheater tubes
   Alkali Iron Trisulphates
C. Flue gas temp. 150-370
   Economiser tubes
   Mixed Sulphate/ phosphorous pentoxide rich deposits

Sulfidation

Sulfidation proceeds via following stages

1) Na & K in the coal become oxides.
   - $4Na + O_2 = 2Na_2O$
   - $4K + O_2 = 2K_2O$
2) Sulphur in the coal becomes SO_2
   - $S + O_2 = SO_2$
3) SO_2 becomes SO_3
   - $2SO_2 + O_2 = 2SO_3$
4) $Na_2O + 2SO_3 = Na_2S_2O_7$
   - $K_2O + 2SO_3 = K_2S_2O_7$
5) Carbon deposits within ash either by Unburned coal
   - $2CO = CO_2 + C$
6) Sulfidation by either
   - $SO_3 + 3C + Fe = FeS + 3CO$
   - $SO_3 + 9C + Fe_2O_3 = FeS + 9CO$

Conditions For Sulfidation

The temperature of tube surface must be high enough so that mixtures of $Na_2S_2O_7$ & $K_2S_2O_7$ exit in molten state. The exact temperature depends on relative amounts of Na & k in coal. Carbon from unburned coal is unlikely to be sufficiently active to set up reducing environment at these tube metal deposit interface. The decomposition of CO would give a finer, more uniform and perhaps a more active form of carbon within deposit matrix.

Hydrogen Sulphide / Vanadium

Hydrogen sulphide is main component in furnace gases, responsible for ash deposition. It proceeds via following steps

- H2S +Fe =Fes +H2
- FeS +2O2 =FeSO4

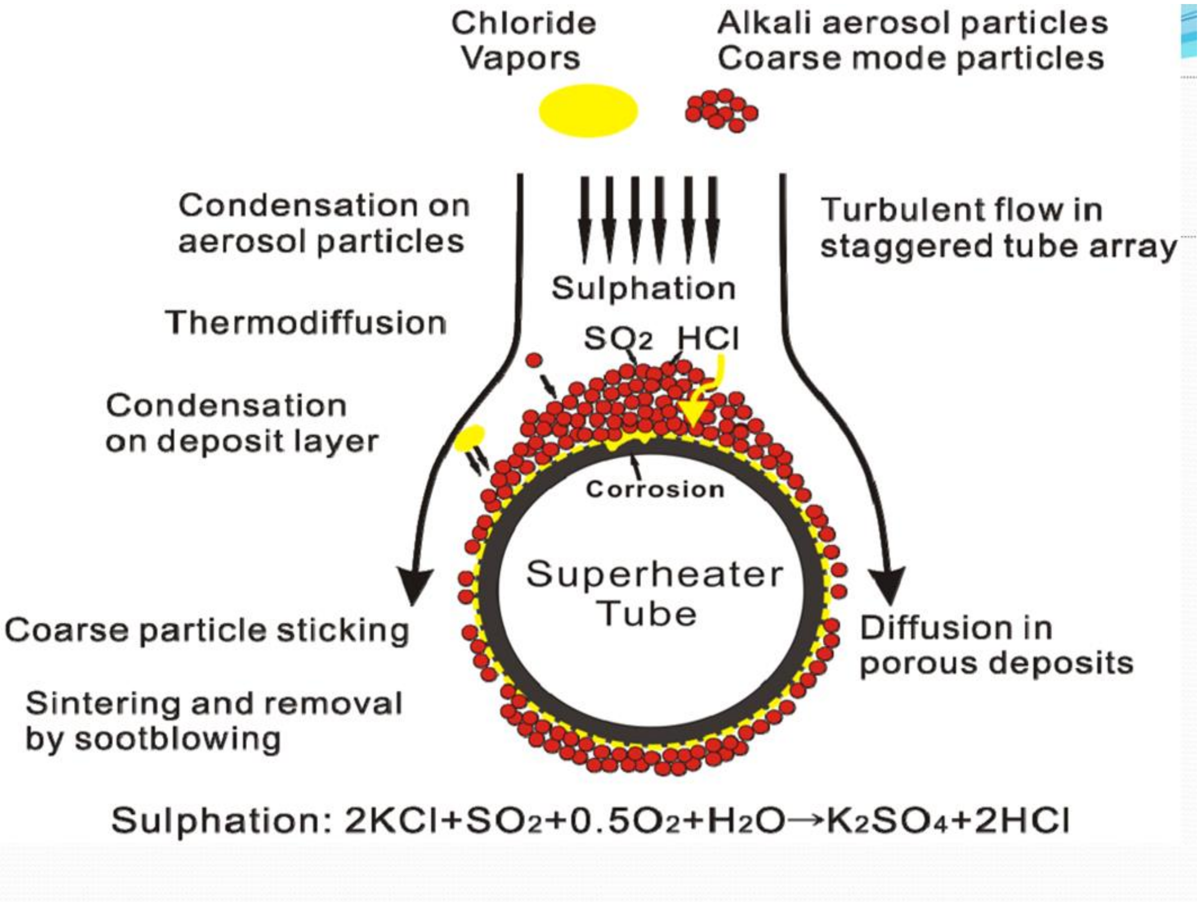
The ferrous sulphate ($FeSO_4$) layer produced on tube wall surface flakes off due to erosion exposing fresh tube metal to further ash deposition. Vanadium corrosion refers to the attack of superheater tubes by the vapors of vanadium pentoxide formed in flue gases.

If fuel contains sodium, the flue gases will contain, among other, sodium vanadate ($Na_2OV_2O_5$), a low fusing compound (M.P. 600^oC) forming a thin film of liquid on superheater tube surface at 610-620^oC. This film attacks carbon, low alloyed and austenitic steels. The corrosivity of V_2O_5 increases in combination with sodium pyrosulfate $Na_2S_2O_7$.

Sulphation

It is a kind of sintering that may occur in the furnace if there is an unfavourable mineral composition in the fuel. If CaO content in the ash is more than 40% and if SO_2 is present in the flue gas, the process of sintering may start on loosely deposited layer formed on heating surfaces. This results in the growth of dense/ strongly bonded slag deposit on tube surfaces of water wall, platens and superheaters.

$CaO+SO_2+1/2\ O_2 = CaSO_4$



Ash Deposition in Fuel Oil Fired Boiler

- Fuel oils burnt in boilers are characterized by low ash content (0.07 - 0.15%), whereas some of them are rich in Sulphur (3 - 3.5%).
- Ash of fuel oil contains an assortment of mineral fractions-mainly the compounds of Ca, Mg, Na, Si, V & Fe.
- These specific mineral impurities together with a high content of Sulphur led to ash deposition.

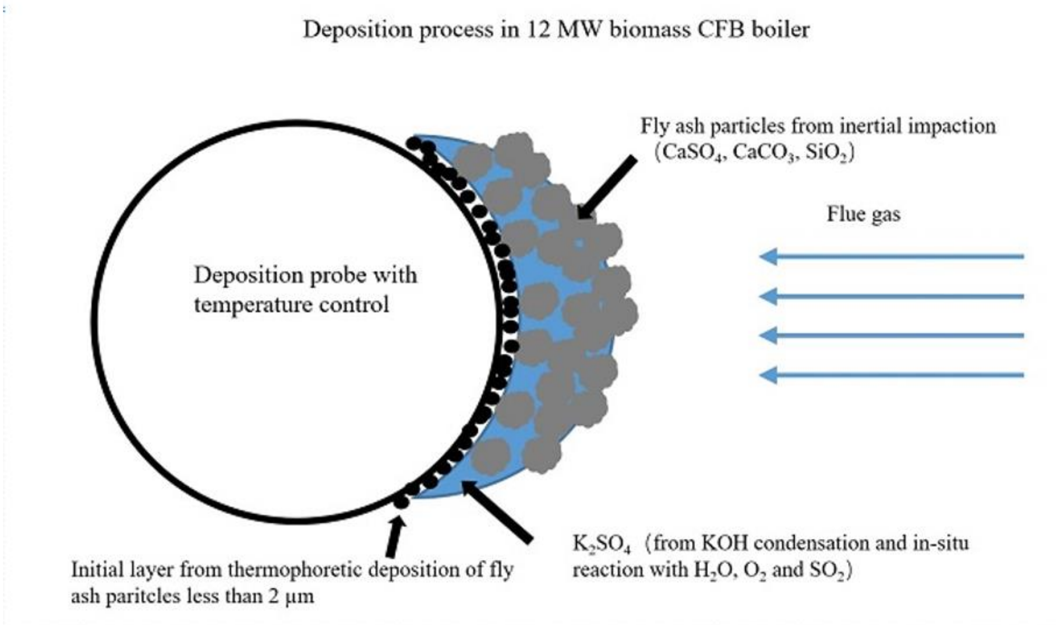
- When fuel oil is burned, the combustion products contain all sorts of vanadium oxides i.e., VO, V_2O_3, V_2O_4 and V_2O_5.
- Higher valent oxides have lower melting point and hence more harmful from the point of fouling.
- Fouling of waterwall tubes in the form of sticky deposit begins at temperature above 815K. This sticky film of sodium vanadates ($5Na_2O.V_2O_4.11V_2O_5$) attracts fly ash particles.
- With the increase of surface temperature, the layer becomes more plastic and capable of retaining higher load of fusible fractions of fly ash
- As a result, the overall process leads to the formation of strong bonded deposit.
- Na/V ratio plays a very important role in determining the characteristics of deposited ash in fuel oil fired burners. With the increase of this ratio in ash, its sticky property increases. It is found to be maximum when this ratio is in the range of 3.7 - 9.5.

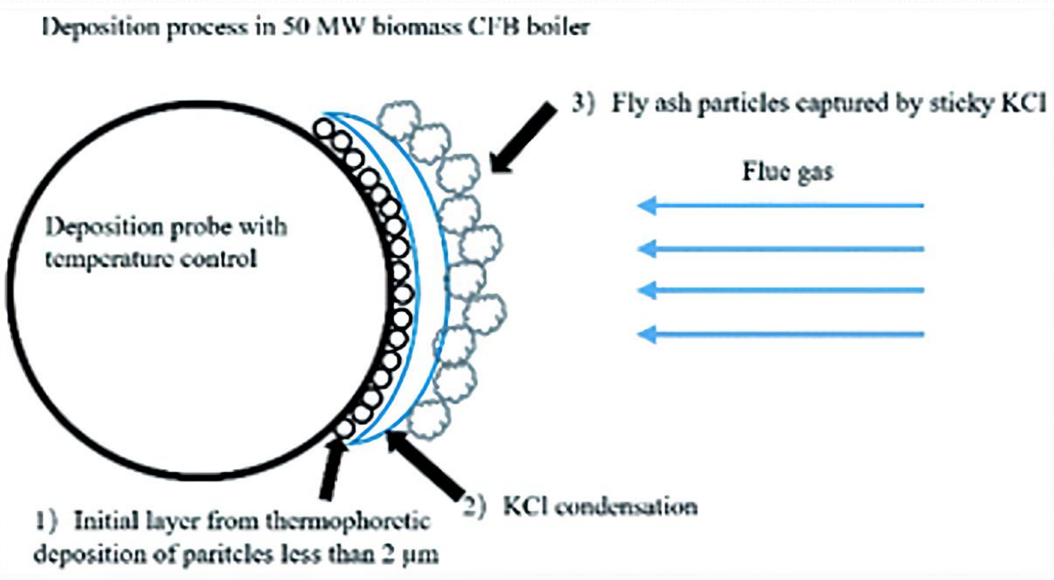
Ash Deposition in FBC Boilers

- In fluidized bed combustion solid fuels reduced to 1-6 mm size can be successfully burnt in fluidized state over a grate at the bottom of which combustion air is blown off.
- The velocity of air is so controlled that the fuel particles are lifted off and are reciprocated in the vertical flame.
- The finer and partially burn coal particles are carried to the upper layer of fluidized bed, whereupon their flow velocity decreases, and they undergo complete combustion.
- Thickness of such bed varies from 0.5 M to 1 M & temp. around 800-1000˚C.
- The specific characteristic of fluidized bed is that it expands in volume by 1.5 - 2 times during operation
- Boiler tubes are placed in the form of inline or staggered tube bundles arranged in and above the bulk of fluidized bed.
- Fluidized bed boilers can be categorized into 2 main groups.
  1. Atmospheric fluidized bed boiler
  2. Pressurized fluidized bed boiler.
- A.F.B. Boilers are of 2 types
  1. Atmospheric Bubbling Bed Boiler
  2. Atmospheric Circulating Bed Boiler
- AFB Boilers can be sub divided into
  1. Bubbling bed with inbed tube

2. Bubbling bed without inbed tube
3. Circulating fluidized bed with external heat exchanger
4. Circulating fluidized bed without external heat exchanger

- Bubbling bed boilers has inbed evaporator tubes and superheater tubes
- Fluidizing velocity of air is fundamental distinguishing feature of fluidized bed combustion process.
- Bubbling beds have lower fluidization velocities i.e., 1.2 M/S to 3.6 M/S.
- CFB have higher velocities i.e., 3.6M/S to 9 M/S





Degree of Fouling

- Degree of fouling depends on
  1. Time of exposure of tube surface
  2. Size composition of ash particle
  3. Flue gas flow velocity
  4. mode of layout
- As the exposure time increases, fouling coefficient also increases.
- Finer particles causing more intensive fouling than coarse particles
- Lower the flue gas velocity, thicker is deposition.
- Mode of lay out is staggered, then thickness of slag deposit is more. If it is in line, then thickness of deposit is less

Effect of Gas Flow Velocity on Degree of Fouling

- The degree of fouling is determined by the thickness of loose deposits comprising chiefly of medium fractions (10-30 micrometre)
- Ash particles in this range continuously settle on the tube surface while ash particles in the coarse range (>30micrometer) continuously destroy the layer on collision.
- Ultimately the final thickness of deposited loose layer is governed by dynamic equilibrium between these two processes.
- As the flow velocity of flue gas increases, the kinetic energy of ash particles increases &with the rise destructive effect of coarse particles in proportion to the third power of velocity.
- Therefore, the net result is that the thickness of loose deposits on tube surface decreases.

Effect of Arrangement of Tubes in Furnace on Degree of Fouling

- The tube fouling depends not only on type of tube arrangement (staggered/in-line) but also on the longitudinal pitch of bunches.
- Under the conditions of identical gas velocity and tube diameter, the fouling coefficient for in line tubes is about 2 to 3.5 times that for staggered tubes.
- It is not advisable to operate pulverized coal fired water-tube boiler at gas velocity as low as 3-4 m/s as the degree of fouling of fire side heating multiplies with fall of flue gas velocity and it increases significantly. Nominal gas velocity at rated load should be 5-6 m/s

Effect on Heat Transfer Coefficient

The overall heat transfer coefficient is reduced by loose deposit of ash particles.

Thermal Conductivity = QL/A Δ T

Where,

Q = Amount of heat transferred through material in Joules/second

L = Distance between two planes

A =Area of surface in m^2

Thermal Conductivity =W.M/M^2.Kelvin

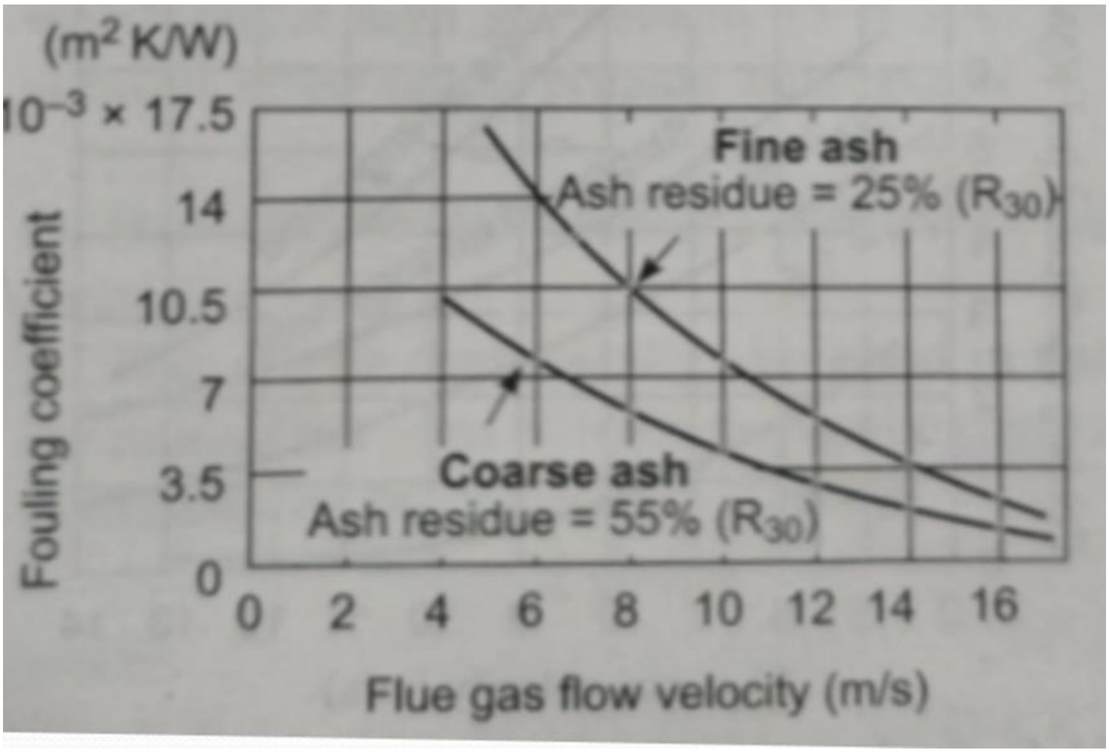
=W/M Kelvin

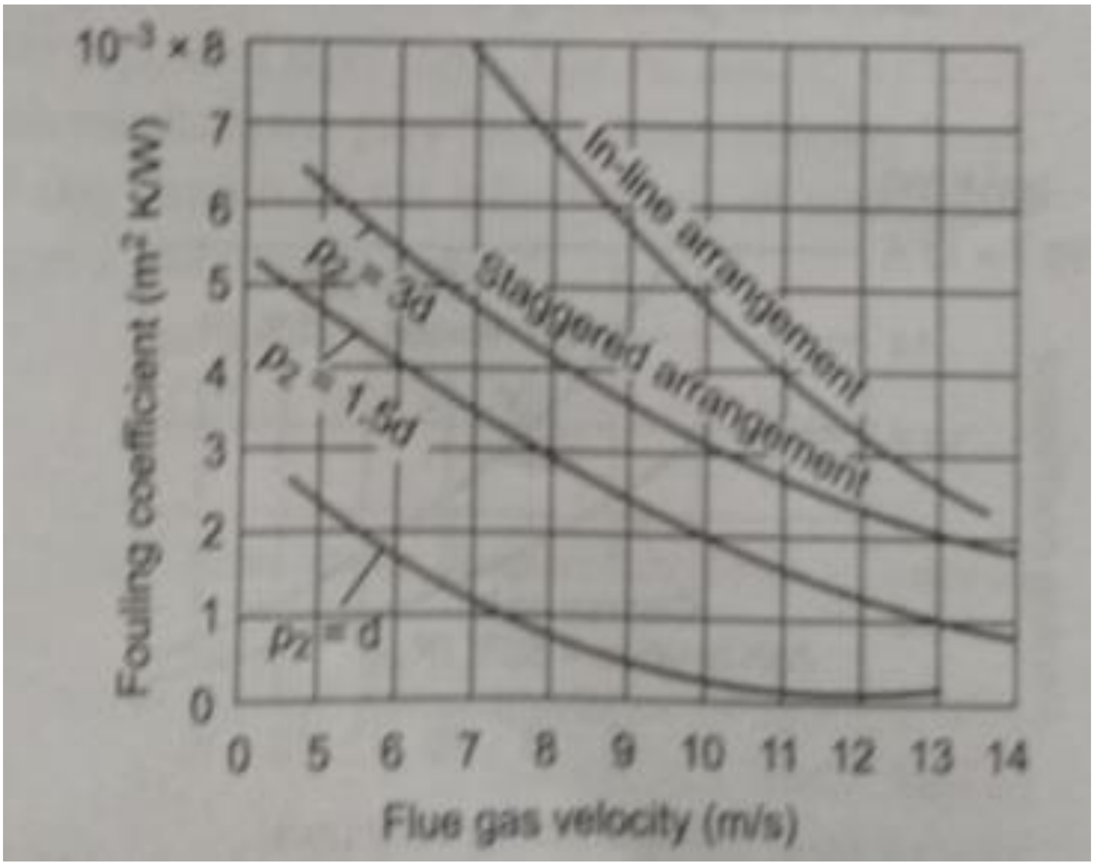
Fouling Coefficient =Thickness of slag/conductivity of slag

=m.mk/w

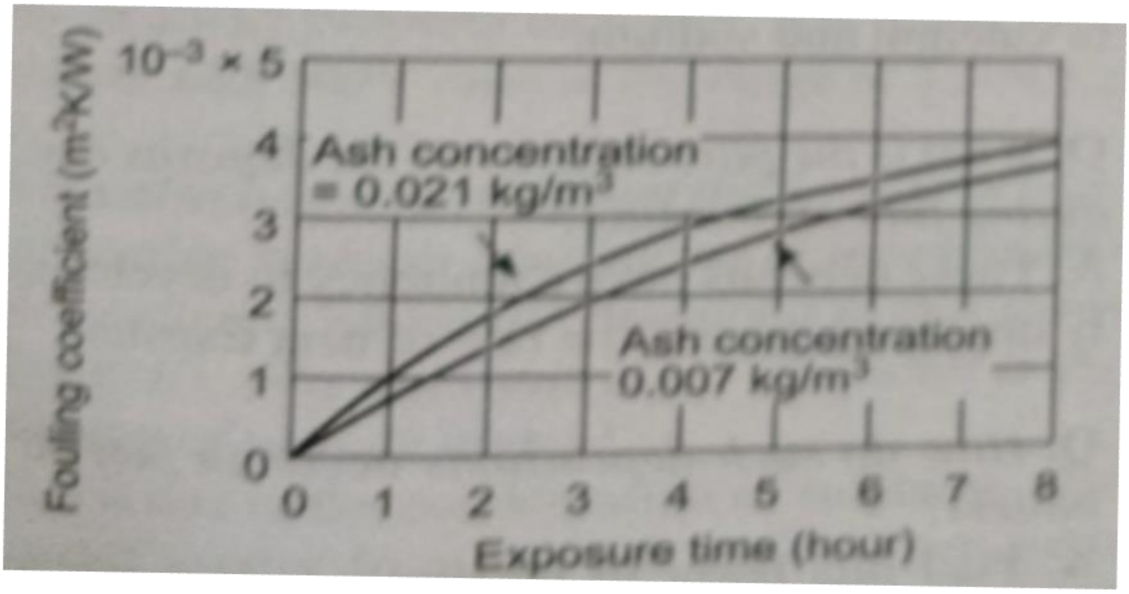
=m^2k/ w

Flue Gas Velocity vs Fouling Coefficient





Fouling Coefficient vs Exposure Time



Effect of Coal on Deposit

Sudden change in heat flux as those caused by using coals of varying CV results in higher scale deposition and consequently higher metal temperature and higher oxide growth on steam side leading to exfoliation. For the same flow of coal, the coals with higher GCV will give higher heat flux compared to coals with lower GCV, so whenever, imported coal is used the boiler tubes are subjected to higher heat flux compared to lower heat flux from Indian coals.

Reverse occurs during changeover from imported to Indian coals. In either case boiler tubes are subjected to change in heat flux causing additional stresses on internal oxides and external scales which spall off paving way for further oxidation/fouling.

Imported coals are softer coals and are rich in alkali and alkaline earth metals which have tendency to soften during combustion process. These softened materials form a thin film over the tube surface where subsequently they react with Sulphur compounds to form pyrosulphates. The slagging and fouling tendency of such coals is higher. On the other hand, Indian coals have high silica, alumina, which are abrasive in nature and are responsible for higher erosion.

In either case some ash is deposited over boiler tube surface (external surface) this results in high heat being experienced by the tube metal. Internal steam side metal temperature is affected which changes the steam oxidation of boiler tubes (S.H. &R.H. tubes are more prone to this phenomenon)

During start up and shut down processes the oxide film which may be having multiple layers, are subjected to differential coefficients of thermal expansion resulting in spalling /exfoliation of oxide layer and exposing fresh tube surface to further oxidation.

Technologies Available for Prevention of Deposition Problem in Boiler

Ash behaviour prediction tool

- There are some ash behavior prediction tools like Ash pro (SM) used to assess the slagging and fouling situations in coal fired boilers, integrating boiler computational fluid dynamic (CFD) simulations with ash behavior models including ash formation, deposition, deposit growth and strength development.
- These prediction results are very important to assess the overall performance of power plants including fuel quality, ash properties, fouling, slagging etc.

- The characterization of ash is extremely important to predict the mineral transformation in coal particles during combustion, that controls characteristics of resulting ash particles.
- Computer Controlled Scanning Electron Microscopy (CCSEM) and Scanning Electron Microscopy Point Count (SEMPC) methods are available today to fully characterize ash with respect to ash deposition process.
- As a result, direct comparison can be made between coal minerology and that observed in ash sample.
- This is of fundamental importance as it provides the data base from which the relevant ash-deposition models can be constructed.
- Thus, it is possible to establish the effect of coal preparation (grinding, pulverizing and cleaning) and combustion conditions on the size and minerology of ash particles.

Ash Deposit Characteristics

- Fine, light coloured, reflective, thin layered depositing at W.W. at all types of boilers and dense and molten slag deposit covering patches or entire W.W. area at p. c. fired boilers.
- Sticky ash rimming around the burners (called eyebrows) or accumulating on W.W. near Burner
- Highly fused, very porous slag with bubbly appearance (termed vesicular) depositing at 2-3 m above Burner.
- Sandstone like feathered fouling deposits on front edge of the tube of R.H.
- Alternating light grey and brown or red deposit at primary S.H. / R.H.
- White to reddish brown depositing at L.T.S.H. / ECO.
- Very fine light brown or grey ash depositing at A.P.H.

C.C.S.E.M. AND S.E.M.P.C.

- S.E.M.P.C. involves the systematic micro probe analysis of over 240 points within a suitable prepared sample.
- C.C.S.E.M. analysis of ash sample establishes an estimate on size distribution of major species.
- S.E.M.P.C. data is used to establish the amount of liquid phase available in the sample.
- Factors which control probability of deposit initiation are
  a. Size, shape & momentum of ash particle

b. Temperature
c. Amount of liquid phase on surface of particle
d. Base/Acid ratio of liquid phase
e. Viscosity & surface tension of liquid phase
f. Structure & nature of metal surface

Method of Analysis

- The viscosity of various phases is computed by particle basis and data is presented in the form of population Histograms called viscosity distribution.
- Viscosity is then calculated at a given temperature.
- Usually, the gas temperature in the region of surface of the target is taken for calculations.
- By studying the data one can establish a scale or relative degree of sticking probability of the targeted surfaces.
- Ash with a high population of low viscosity liquid phases will have a tendency to form a deposit on metal surface than ash with bulk of amorphous phases with high viscosities.
- Clearly it is the proportion of liquid phase and its viscosity in the ash particles that plays the primary role in ash build up on the tubes.
- Coals which form ashes with smaller size particles, lower amount of surface liquid phases have low probability of sticking on the targeted surfaces as initial layer.
- From CCSEM and SEMPC analysis we get the size distribution of the ash particles, the phase distribution, viscosity and the chemical composition of the liquid phases on a particle-by-particle basis.
- Use of this data can be made to gain some insight into the degree or relative degree of sintering the ash particles will undergo within the deposit and that will enable us to assess the degree to which the surface of the deposit will become the dominant factor in the rate of growth.
- It is convenient to review the complex process with respect to measurable parameters.
- We can use the data from CCSEM and SEMPC analysis to access the extent to which a captive liquid phase will form and hence the rate of growth.

Micro Beam Technology

- Micro beam Technologies Inc (MTI) provides advance quantitative information on the impurities in fuels, ash behaviour and determining and predicting the effect of ash on power system performance using computer-controlled scanning electron microscopy (CCSEM).

- MTI processes also identify problematic deposits, slagging and fouling.
- This predicted information is very useful in reduction of abrasion & erosion, slag flow problems, convective pass fouling, ash resistivity and deposit strength.

Heat Flux Meters

- Heat flux meters can be used to study thermal absorption diagnostics in boilers as a part of the boiler- monitoring systems.
- These sensors can be installed at power plants by a supplier of soot blowing system though it is difficult to quantify the energy saving obtained from the development and application of such a sensor.
- Continuous fouling formation on heat transfer surfaces is a great problem in existing conventional coal fired utility boilers.
- A cost effective way to minimize this difficulty is the continuous monitoring of fouling tendencies in boiler as a tool of operation.

Targeted In Furnace Injection (TIFI) Technology

- Chemicals are injected into the flue gas system after mixing with water and air.
- Magnesium hydroxide slurry diluted with water and then atomized with air is the most common application of TIFI technology.
- This mixture is sprayed into the furnace at computer determined ports that allow for complete coverage of problem areas.
- These cause a chemical reaction with existing deposits and affect their physical crystal characteristics.
- This chemical treatment program is successfully applied for inhibition and reduction of slag formation in the superheater, reheater and furnace wall sections.
- This technology is used in western USA coal fired utility boiler to control slagging. fouling and tube cracking.
- This technology involves different forms of fluid dynamics modelling.

Pulse Detonation Wave Technology

- This technology is based mainly on a supersonic combustion process.
- Shock wave is propagated forward due to energy released in a reaction zone behind it, where an ignited fuel/ oxidizer mixture burns and releases energy.

- The significant characteristics of the pulse detonation technology are high temperature, high velocity and high-pressure waves producing direct impact, thermal stresses, high reflection and wave reverberations and exceptionally high shearing capacity to remove slag and fouling deposits
- P.D.E. (pulse detonation engines) are very effective for producing detonation wave (strong wave) for removing ash deposition without damaging the boiler.
- P.D.E. is powered by an electric motor and injection valves feed the combustible fluid into the ignition section. Instruments mounted on different sections of the devise are necessary to check the performance of the engine. These instruments include pressure transducers, thermocouples and thin film gauges.
- Researchers have found that softer slags are removed more easily with multiple waves. Slag on the top of tube generally breaks up into smaller pieces when exposed to wave, while the slag on the side of the tube and in the webbing shears off.

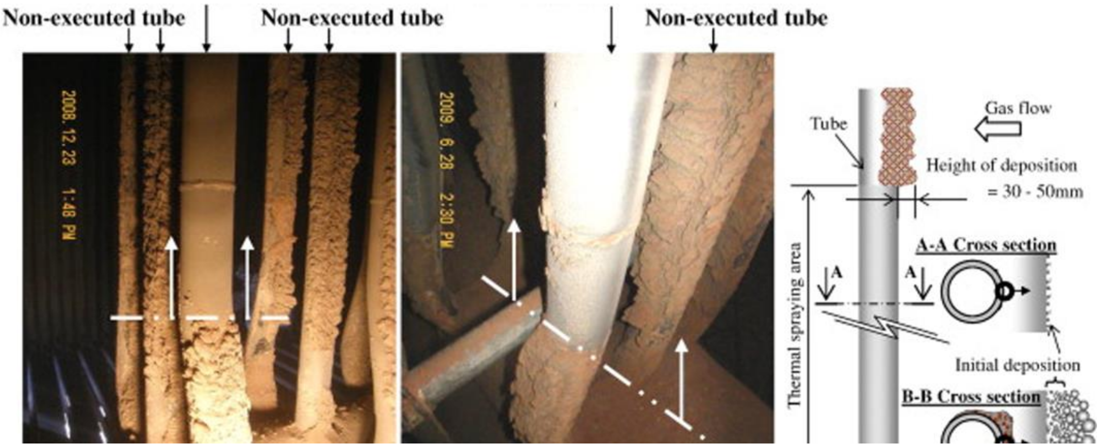
Internal Cameras

- Internal cameras (3.9 micrometre band) can be used to monitor the fouling problem.
- Special infrared cameras for this purpose are designed to scan the fouling by filtering the light from the boiler. This allows the camera to see through the flames to the walls by blocking the appropriate wavelengths.
- These types of cameras are hand held thus must be used through viewpoints.
- Internal cameras can be installed in areas that are prone to ash build up or can be installed in adequate numbers to cover the all relevant areas of boiler.
- If rotatable cameras are used, they will also be able to see multiple places of the boiler.

Location / Phenomenon / Counter Measures

A. S.H.& R.H.

External	Internal	Phenomenon	Counter Measures
High Temp. Corrosion	Steam Oxidation	• Corrosion by low molten coal • Alkali Iron Sulphate • Oxidation caused by steam	• Thermal spray • High chromium material • Composite tube • Additives



B. Furnace Water Wall

Sulfidation corrosion

Phenomenon	Counter Measures
• Corrosion loss caused by hydrogen sulphide in • Reducing atmosphere combustion gas and iron • sulphide in deposit ash	• Improvement in combustion efficiency • Thermal Spray • Clad Welding

C. Burners

Oxidation, Sulfidation

Phenomenon	Counter Measures
• Oxidation /Sulfidation at high temperature (>1800°F)	• Heat resistance material

D. Economiser

Low Temperature Corrosion

Phenomenon	Counter Measures
• Sulfuric Acid Dew Point Corrosion	• High Cold End Metal Temperature • Corrosion Resistance Material

E. CFB BOILERS

- It has been possible to battle out ash deposition problem in the most aggressive environment of CFB with the advent of new spray processes, such as Electric –Arc Wire and HVOF (High Velocity Oxygen Fuel) and improved coating materials like
- Iron – based alloy containing 30 % Cr
- Low carbon steel similar to the material in the existing weld overlay

- The goal of weld overlay is ultimately to improve the properties of the base metal and cladding is a process where different tougher material is applied than the base metal.
- Many CFBs have an external heat exchanger which helps to compensate the changes in load conditions and fuel properties for controlling heat absorption rate in the furnace.

UPKEEP AND MAINTENANCE OF SAFETY VALVES

By Mr. Rajesh Palkar, Mr. Narayan Katyare,
Mr. Narayana Prabhu, Fainger Leser

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32 + Years of experience. Specialist in Application Engineering, Safety relief valve construction, Sizing & Selection, Product Management.

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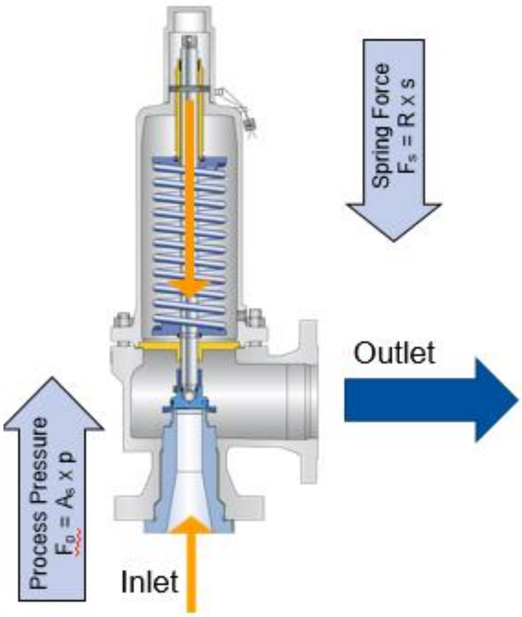
Designation: Engineering Manager
Education: Mechanical Engineer
15 + Years of experience. Specialist in Safety Valve design, Technology Transfer, New Product Development, Product Certification, Codes & Standards

Name: Narayana Prabhu
Organisation: Fainger Leser
Designation: Quality Manager
Education: Mechanical Engineer
17 + Years of experience. Specialist in Quality Management System, Testing & Inspections, Repair & Maintenance, Trouble shooting, Quality Control.

Basics of safety valves

- **Why a Safety Valve?**
  The Safety Valves assure proper function of pressurized system and processes like steam boilers, vessels and pumps. Thereby the primary purpose is fulfilled to protect life, property and environment against undesired overpressure.

- **What is a Safety Valve?**
  A Safety Valve is characterized by rapid opening or pop action, or by opening in proportion to the increase in pressure over the opening pressure.
- **Function of a Safety Valve**
  The downward force through the spring is applied on the disc and it keeps safety valve closed. This is the normal and safe operating conditions. When the force below the disc exceeds downward force (i.e., when working pressure crosses set pressure) the safety valve will open. It opens fully within permitted overpressure and discharges rated capacity. As the flow takes place, there would be pressure drop and the valve will close down slowly.



Types of safety valves

- The safety valves are generally of “Full nozzle” type and sizes ranging from 1 inlet to 8” inlet.
- The low-capacity relief valves are of “Modified nozzle” type and are generally of smaller sizes i.e., ¾” x 1”.

Applications in boiler industry

- The package boiler is provided with two safety valves on drum.
- The high pressure/capacity boiler is provided with two valves on drum and one on Super heater. There would be one relief valve of min. 2” inlet on economizer.
- The pressure reducing station would have one safety valve installed on downstream side (next to the first isolation valve).
- There would be safety valves installed on process side and also relief valves on hot/cooling water line.
- The other applications could be for installation on Soot blower, Deaerator, Turbine exhaust, shell & tube side of the heaters etc.

IBR regulations applicable

- Regulation 290 – Chest (Valve Body)
- Regulation 291 – Safety valves in General
- Regulation 292 – Types of safety valves (Ordinary, high and full lift)
- Regulation 293 – sizing and selection of safety valves for saturated steam (Eqn. 78) and superheated steam (Eqn. 79).
- Regulation 294 – Overpressure for safety valves
- Regulation 295 – Pressure drop (blowdown)
- Regulation 296 – Mountings of safety valves
- Regulation 297 to 314 covers Openings in shell, Discharge Passage, design, construction, materials and dimensions safety valves.
- Appendix-L of IBR 1950 - Type test certification for computation of C constant under the witness of IBR Inspecting authority.

Installation guidelines

General Notes

Safety Valves are high quality devices which should be handled with great care. To ensure proper performance, all parts are made with precision. Casual handling of valve in workshops, stores, during transportation or installation could cause leakage or possibly permanent damage.

The seating surfaces are machined, lapped and polished with high precision to ensure required tightness. Even though the surfaces are extremely hard, the seat can still be damaged. By all means, care should be taken to prevent dust, foreign particles etc. from entering valve during transportation, installation and operation.

All safety valves are thoroughly tested and sealed. The purpose of sealing is to ensure that pressure setting is not disturbed by any unauthorized persons. For new installations, if there is any performance related issues, it should be reported to manufacturer so that immediate solution or to depute service person can be considered. It is highly recommended that the seal is kept intact.

When installing safety valves with threaded connections use only gaskets or metal seal washers. Sealing materials such as PTFE tape should not be used as this type of material can break off and enter the valve causing it to leak.

If valves with open bonnets and/or levers are to be re-painted after dispatch from the factory, care must be taken to protect sliding parts. Otherwise, correct operation may be affected.

Transport Protection

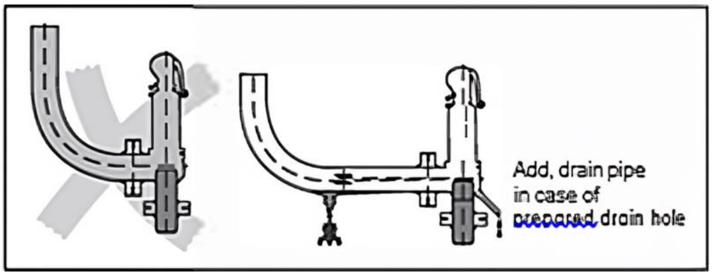
The inlet and outlet of safety valves are protected during transportation with plastic caps. These caps should only be removed just before installing the valve.

Installation / Assembly

Safety valves should be installed with bonnet VERTICALLY UPRIGHT. Furthermore, it should be mounted in such a way that no inadmissible static, dynamic or thermal loads can be transmitted to the valve due to up and downstream pipe work.

Draining of Condensate

To prevent dirt and all kinds of impurities from safety valve, the drainage of discharge pipe must be done via discharge pipe. Therefore, LESER safety valves are generally not provided with drain holes. According to rules, a drain hole of sufficient size must be incorporated at the lowest point of pipe work. In all cases the discharge pipe must first slope in a downwards direction and fitted with a suitable size drain hole before any bends are connected (refer to the sketch below).



Exception: In special cases an optional drain hole may be recommended in valve body as it may be that pipe work drainage cannot be guaranteed at a lower point than the valve. The standard drain hole which will then be supplied by manufacturer is with ¼” BSP or ½” BSP threads depending on valve size.

Insulation

In case insulation is provided for the pressure relief valve, the bonnet must be kept free to avoid unacceptable heating up of the spring.

Inlet Pipe

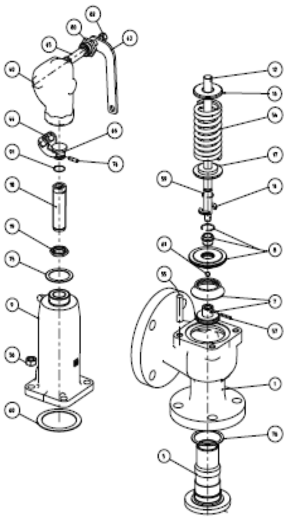
The inlet pipe for safety valves should be as short as possible and should be so arranged that when valve is in its fully open position, the pressure drop must not exceed 3% of set pressure. If calculation results in a pressure drop is higher than 3%, then inlet pipe size must be enlarged.

Dismantling and Assembly Instructions

a. Loosen the existing lead seal.
b. Press the lever (43) towards the middle until it reaches the stop so that the lifting fork (44) no longer holds the spindle cap (46).
c. Loosen and remove the lever cover (40).
d. Loosen spindle cap (46) from spindle (12), remove securing ring (91) and pin (74).
e. Loosen the lock nut (19) of the adjusting screw (18).
f. Turn the adjusting screw (18) anticlockwise to remove the spring tension.
g. Remove the hexagonal nuts (56) from the flange of the bonnet (9).
h. Lift off the bonnet (9).
i. Remove the upper spring plate (16).
j. Lift off the spring (54) and remove lower spring plate (17) and split ring (14).
k. Remove spindle (12) with guide (8) and disc (7).
l. Carefully clean seat (5) and disc (7), and if required body internals.
m. Refit spindle (12) with guide (8) and disc (7).

n. Fit the split ring (14) into spindle groove and retain with the securing ring (59); slip on lower spring plate (17) to locate on split ring (14).
o. Replace spring (54).
p. Slip on the upper spring plate (16) onto the spindle (12).
q. Align adjusting screw (18), and bonnet (9), over the spindle (12) and refit.
r. Fit and tighten the hexagonal nuts (56).
s. Load the spring (54) to obtain required set pressure. Clockwise rotation of adjusting screw (18) increases pressure. Anticlockwise rotation of screw (18) reduces pressure.

Exploded View
Valve Type 441 IC



POS. NO.	DESCRIPTION
1	BODY
5	NOZZLE
7	DISC + LIFTING AID
8	SPINDLE GUIDE + INSERT + SECURING RING
9	BONNET
12	SPINDLE
14	SPLIT RING
16	LOWER SPRING PATE
17	UPPER SPRING PATE
18	ADJUSTING SCREW
19	LOCK NUT
40	LIFTING DEVICE H4
43	LEVER
44	LIFTING FORK
45	LEVER-SHAFT
46	SPINDLE CAP
54	SPRING
55	STUD
56	NUT
57	ROLL PIN
59	SECURING RING FOR SPLIT RING
60	GASKET FOR GUIDE
61	BALL
74	PIN FOR SPINDLE CAP
75	GASKET FOR CAP
76	GASKET FOR NOZZLE
80	GLAND
82	HEX NUT
91	SECURING RING FOR SPINDLE CAP

t. Tighten the lock nut (19) onto the adjusting screw (18).
u. Refit and secure spindle cap (46) by pin (74) and securing ring (91).
v. Screw-on the lever cover (40).
w. Pull the lever (43) towards the middle so that the lifting fork (44) is pushed under the spindle cap (46).
x. Test spindle will lift correctly by pulling lever.
y. Seal the valve.

Trouble Shooting

Prior to shipment, all safety valves go through quality check for functional parameter at the manufacturing facility as per customer specification. Valves which pass the test as per internal procedure as well as applicable code and standards, it will be further moved to shipment else the valves will be retested to achieve the specific result.

The possible complaints related to safety valves are as follows:

A. Safety Valve opens before or after the specified pressure:
All safety valves are passed for its functional parameter prior to shipment. This specified problem may occur due to various reasons such as

a. Disturbance of setting due to misalignment during transportation.
b. Disturbance of setting due to improper handling in transportation or at site.
c. High impact on safety valve due to mishandling.
d. Galling effect between seats of nozzle & disc due to long storage period.

For any of the complaints above, the valve needs to be opened with the help of manual lifting lever once or twice above the specified pressure. This is to restore valve realignment. Then the testing can be conducted to observe actual opening of safety valve. If the complaint is still not resolved by above method, then it shall be reported to the manufacturer.

B. Safety Valve Leakage

All safety valves have been tested for its tightness at the manufacturer end. The testing shall be according to API 527 standard. The specific problem may occur due to various reasons such as:

a. Presence of dust particles due to improper storage or removal of caps.
b. Damage of seating surface due to foreign particles present inside the piping.
c. Damage of seat due to initial flushing of system after installation of safety valve.

This complaint may be analysed by dismantling safety valve with the help of manufacturer. Generally, the nozzle and disc may need lapping and polishing in order to achieve required flatness. At the same time, guiding surface of guide and spindle may also be cleaned with soft tissue paper to remove dust/foreign particles.

C. Safety Valve excess vibration during discharge

Safety valve may show signs of vibration during discharge and it would be mainly due to:

a. Selection of oversized valve (higher discharge capacity)

b. Inappropriate outlet piping construction

If there is a reasonably higher gap between steam discharge and valve flow capacity, there is a possibility of chattering which can result in to vibration. Then the selection parameter needs to be cross verified or referred to the manufacturer to suggest suitable size valve to eliminate vibration.

If the installed discharge piping construction is inappropriate (i.e., too long with multiple bends), it can create resistance to discharged medium and develop back pressure. This can result in to vibration. To avoid such complaint, care to be taken during the design and installation of discharge pipe construction.

D. Boiler pressure building up even during Safety valve full discharge:

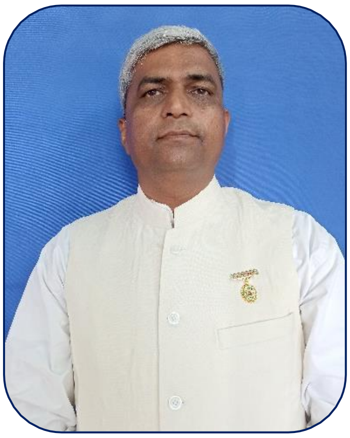
The complaint could be of safety valve discharges fully to its rated capacity; however, pressure continue to raise in the boiler. This situation may occur if the installed valve is not in line with capacity requirements. In such cases, the valve selection needs to be first looked in to. Then check discharge capacity shown in Attachment 8 of IBR Form IIIC and compare it with boiler capacity. If it is matching, then the issue may be taken up with manufacturer for their reconfirmation on valve performance.

E. Safety valve is not reclosing within specified limits of IBR 1950:

There are seldom complaints about valves not reclosing within permitted limits below set pressure. In such cases, the valve size and flow diameter need to be checked to correlate with IBR regulation requirements. IBR does permit 10% blowdown for safety valves having flow diameter ≤ 32mm. If the installed valve is within above range, up to 10% blowdown shall be acceptable. If the valve size is having flow diameter ≥ 32mm, the permitted blowdown shall be 5%. In such cases, it shall be referred to manufacturer.

USE OF SOLAR THERMAL ENERGY IN BOILERS

By Dr. B.K. Jayasimha Rathod
India One Solar Thermal Power Plant



Name: Dr B K Jayasimha Rathod
Organisation: India One Solar thermal Power Plant
Designation: CEO

Practicing Rajayoga Meditation and Value base lifestyle from last 30 years. CEO and Co-PI of “India One” Solar Thermal Power Plant, R&D project under MNRE and German Govt. With Indigenously developed 60 Sq. meter fixed focus Solar reflectors and Innovative Thermal storage for round the clock operation.

2019 Honorary Doctorate by National Virtual University for Peace and Education Bengaluru.

2014-2017 Director MNRE UNDP-GEF Training centre of CST awareness, Govt. Of India. Group head for finalizing BIS standards for concentrating type Technology. Govt. of India. Member Editorial Board Sun focus magazine by UNIDO – MNRE Govt. of India. Steering committee member, Anchor Institute of Solar Energy, Govt. of Gujarat.

2007-2010 Co-Inventor of 50 SQM & 60 SQM parabolic reflector

2007-2009 Product Development Head at Thermax Ltd. Pune Solar Division

2001-2007 Established and worked as CEO of Supreme Rays Systems Pune; Designing and executing solar projects in various applications Throughout India.

2003 Project In-Charge of the first solar steam system for industrial Application at Global Hospital & Research Centre in Mt Abu, solar for sterilization and laundry use.

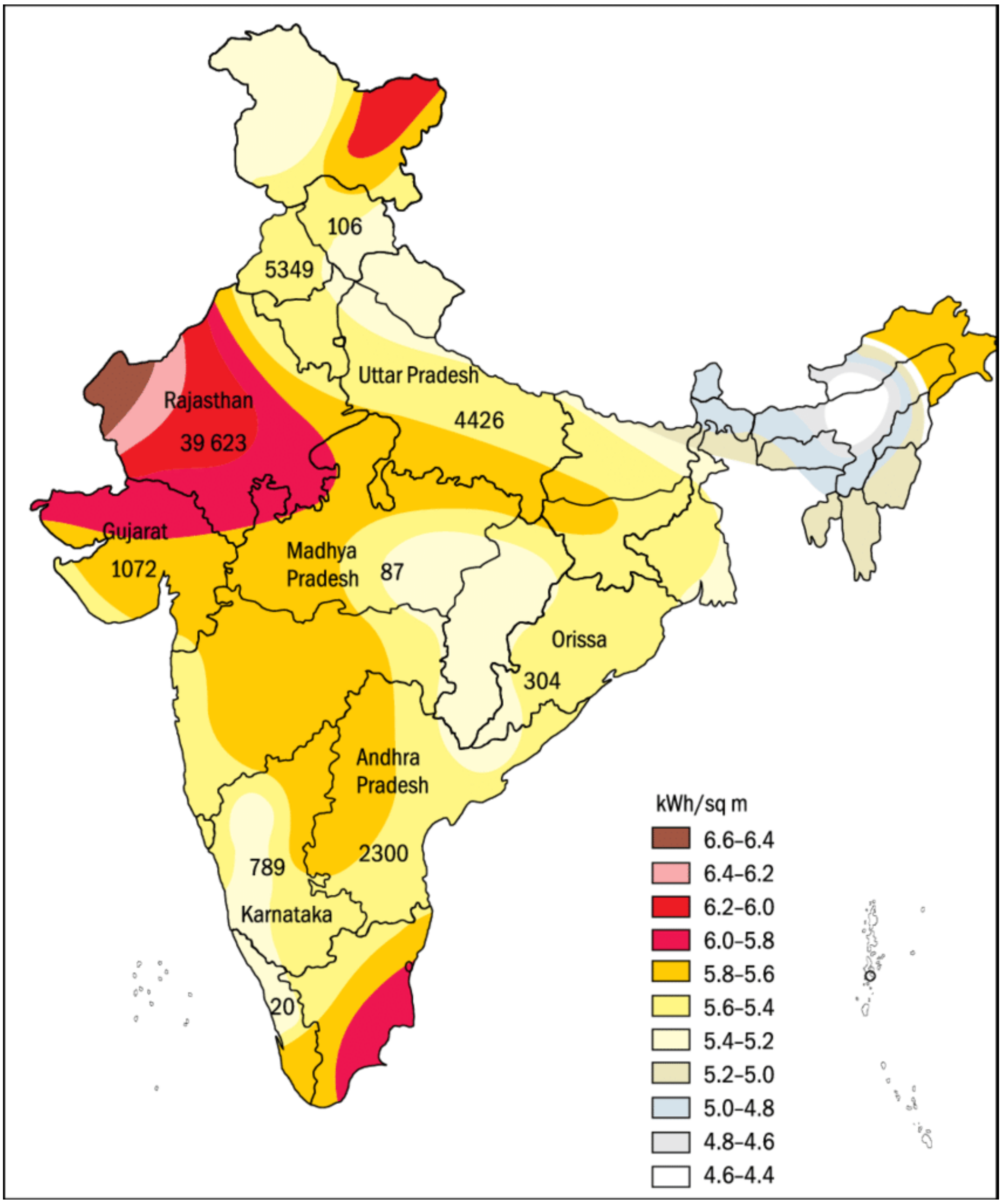
2001 Co-Investigator for R&D project sponsored by MNRE of India for development of 16 SQM paraboloid reflector with a variety of receivers for optimum thermal output.

1998 Project In-Charge for the world largest solar steam cooking: designing, installation & commissioning at the Headquarters of Brahma Kumari’s World Spiritual University (BKWSU) in Shantivan, Abu Road, India

1995 Successfully executed the first solar steam cooking system at BKWSU Academy for Better World, Gyan Sarovar in Mt

Renewable Energy in India

- About 5000 trillion kWh/year energy is incident over India's Land
- Most parts receiving 4 – 7 kWh/m2/day
- Highest annual global radiation is received in Rajasthan (5.5 – 6.8 kWh/m2/day) and Northern Gujarat
- 250 – 300 clear and sunny days in a year
- Most of the India has solar insolation above 1800 kWh/m2/day



CST potential for various Industrial heat applications

The key industrial sectors with high heat demand are:

- food processing
- textile
- paper
- hotels, ashrams, residential schools
- hospitals
- transport equipment
- metal and plastic treatment
- chemical & pharmaceutical
- space heating and cooling
- automobile industry – components washing
- cold storage for agricultural products etc.

Market Potential

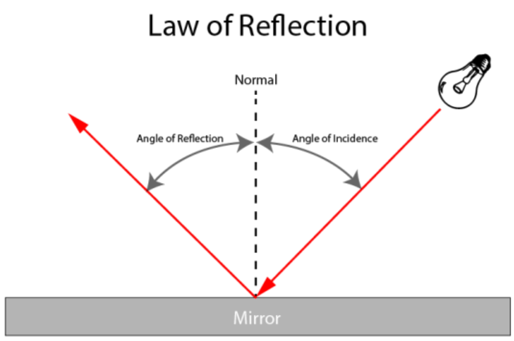
Industrial sector	Process	Temperature level [°C]
Food and beverages	drying	30 – 90
	washing	40 – 80
	pasteurising	80 – 110
Textile industry	washing	40 – 80
	bleaching	60 – 100
Machinery industry	cleaning	40 – 80
Chemical industry including pharmaceutical	boiling	95 – 105
	distilling	110 – 300
All sectors	pre-heating of boiler feed water	30 – 100

The areas of applications, include:

- cleaning, drying, evaporation and distillation
- Sterilization, Laundry.
- pasteurization, cooking
- melting, painting, and surface treatment

The Laws of Reflection

- The angle of incidence equals the angle of reflection
- The incident ray, the reflected ray and the normal are all in the same plane

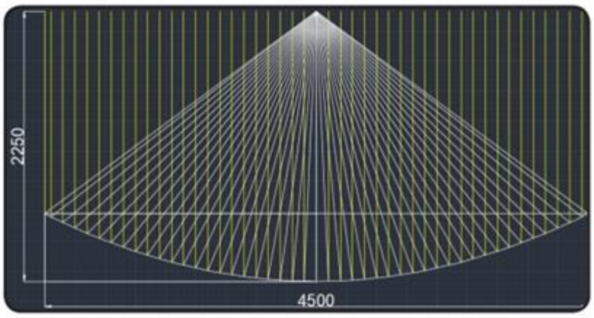


Solar Thermal Energy Generating Devices

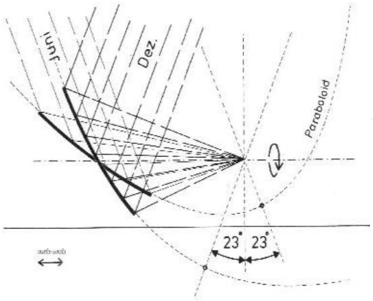
1. Passive devices for low temperature generations such as Flat plate collectors, Vacuum tube collectors, CPC
2. Concentrators for medium and high temperature generations

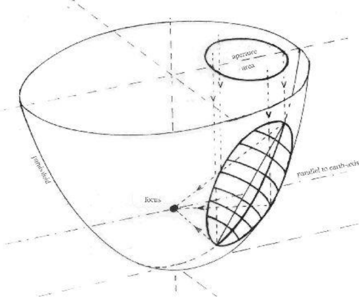
- Point focus concentrators
    - Parabolic dish moving focus
    - Parabolic dish static focus
    - Heliostats
- Linear focus concentrators
    - Parabolic trough
    - CLFR.

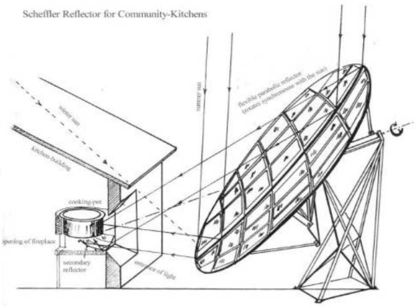
Parabolic Dish with dual axis tracking mechanism with moving focus.



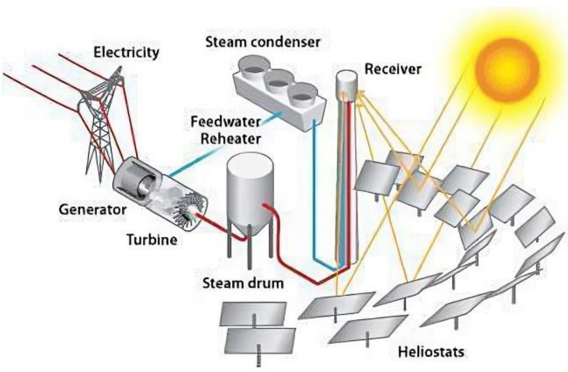
Scheffler Reflector: Parabolic Reflector with fixed focus





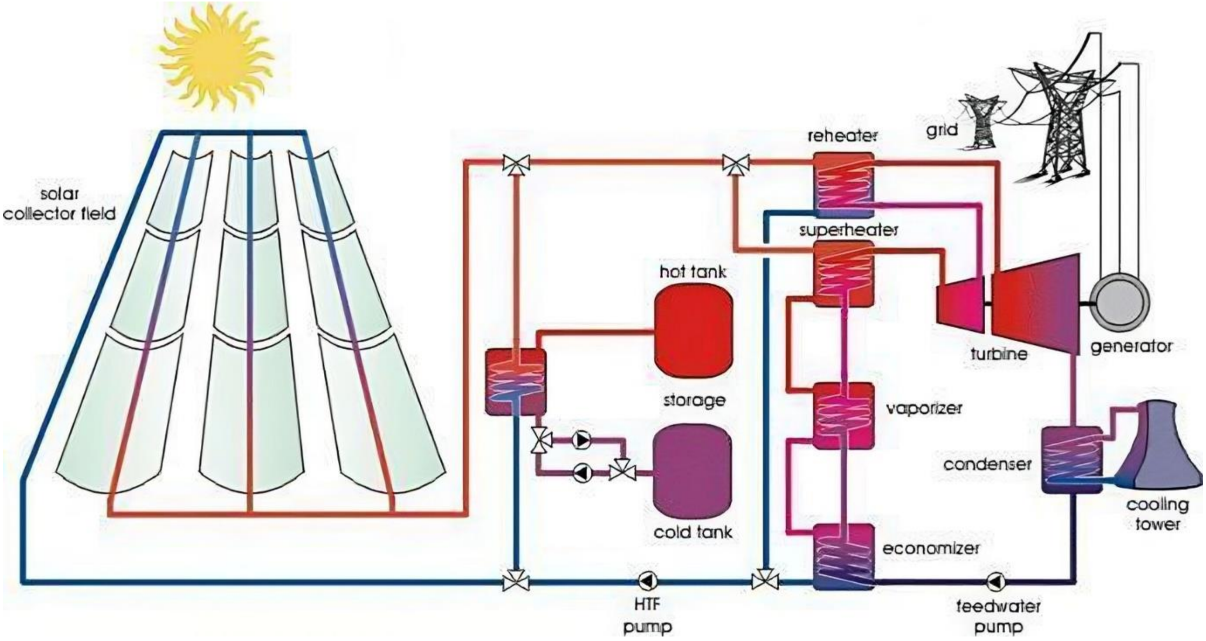


Known CSP technologies: Heliostat with solar tower



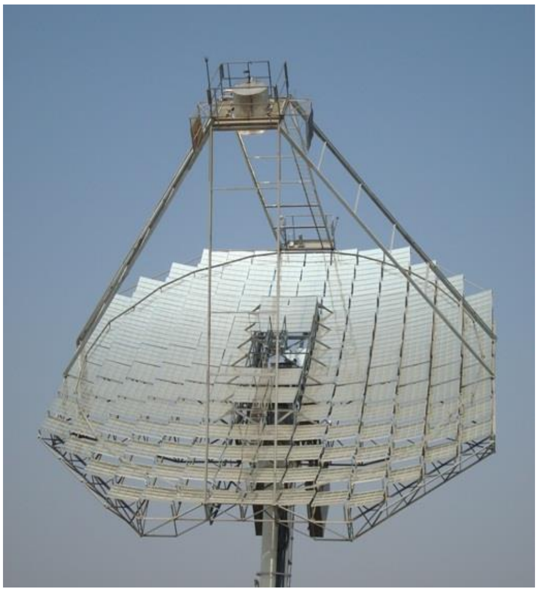
PS10 (10 MW) and PS20 (20 MW) Solar Power Plant, Seville, Spain

Known CSP technologies: Parabolic Trough



Andasol 150-megawatt (MW) concentrated solar power station, Andalusia, Spain

Fresnel Parabolic Concentrators

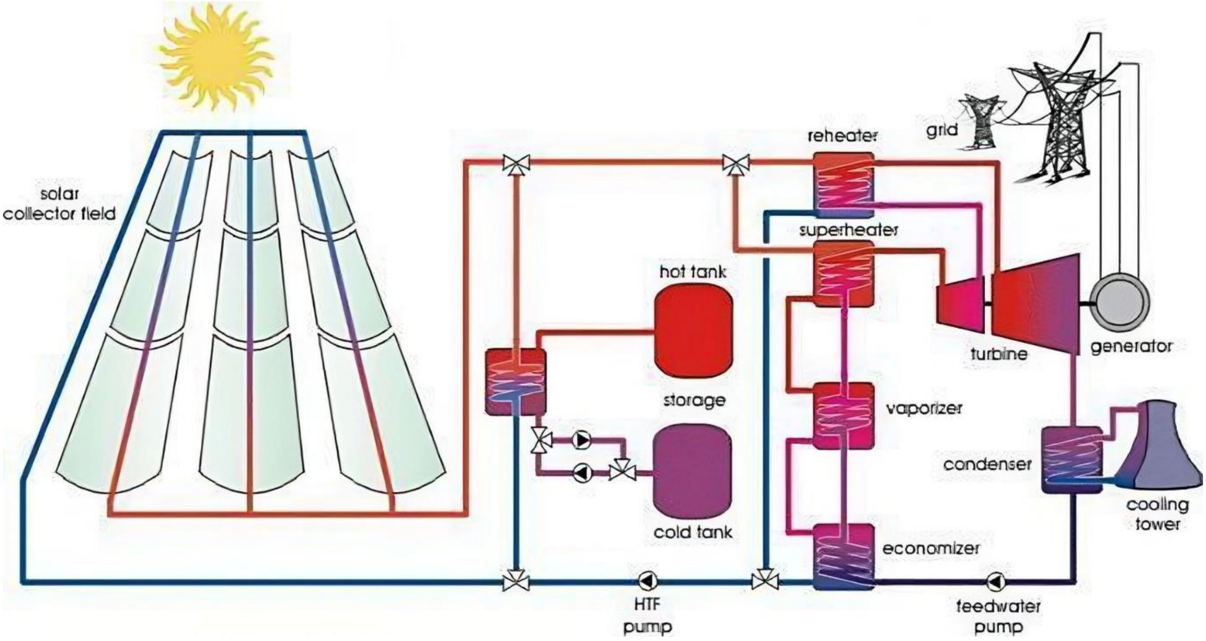


- It uses solar grade mirrors for reflection
- Automatic dual axis tracking system
- Receiver is placed at the focus of the Reflector
- This technology can achieve temperature up to 300°C
- various media / thermal storage like steam, thermic oil, hot air as well as pressurized water can be used.
- Various applications like:
    - Comfort cooling
    - Milk Pasteurization
    - Effluent evaporation etc

Linear Fresnel Reflector Concentrator

- Reflecting material could be highly polished reflecting metal / metalized plastic / reflecting mirrors
- Single axis automatic tracking system
- Linear focus that runs axially above reflectors
- Can be mounted in horizontal E-W or also in N-S direction
- Suitable for applications with temperature up to 180°C
- Various applications like:
    - Distilling
    - Boiling
    - Evaporation

Known CSP technologies: CLFR with linear focus



Linear Fresnel Demos

Plataforma Solar Almeria, Spain

(MAN/SPG)

Calasparra, Spain

(Novatec)

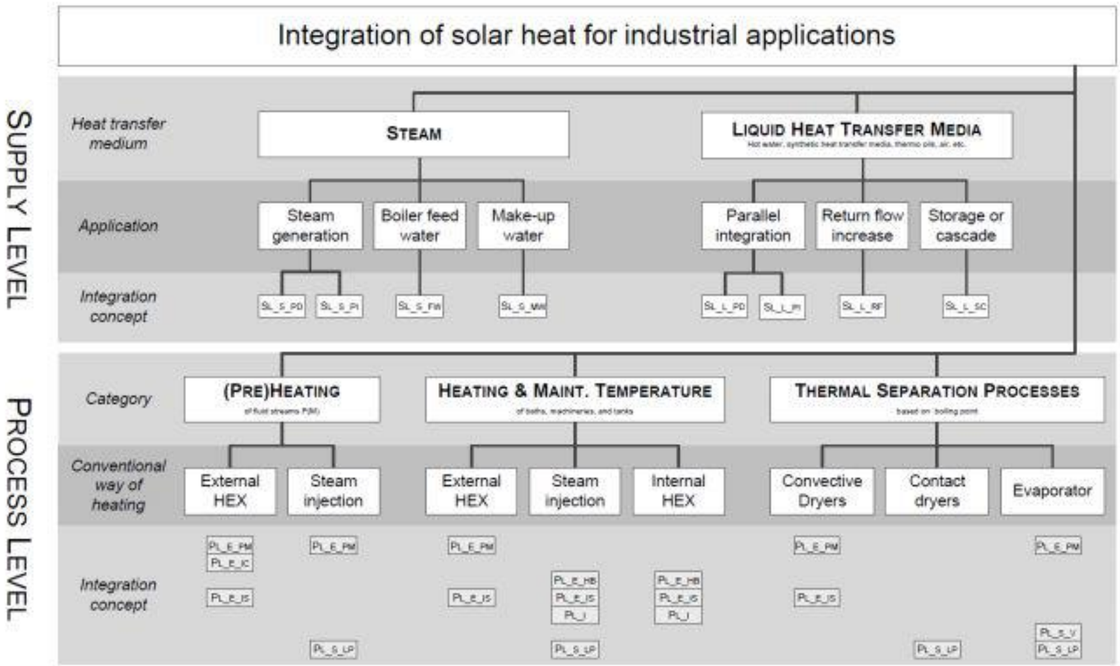


Figure 14: Classification of the heating systems of industries, along with their conventional heating system as well as a possible integration concepts [9].

Direct Steam Generation at supply level

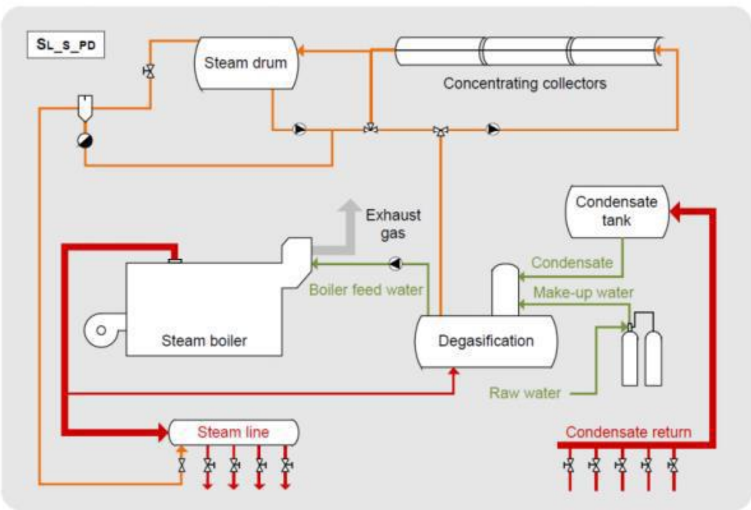


Figure 15: Integration of direct solar steam generation at supply level (SL_S_PD). Water is partially evaporated in the solar collector loop and fed to the steam drum, where the steam is separated from the produced water steam mixture. The steam is subsequently fed to the steam line, when a sufficient pressure is obtained in the steam drum [9].

Indirect Steam Generation at supply level

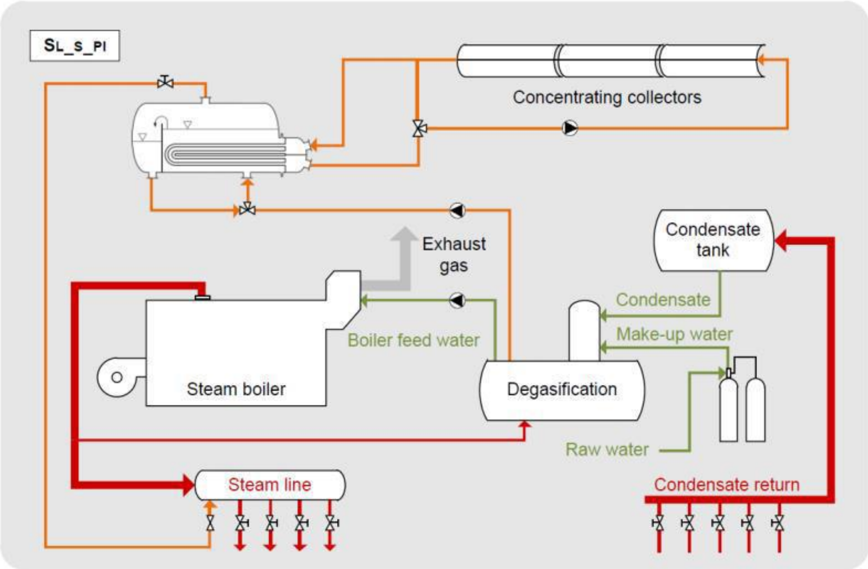


Figure 16: Integration of indirect solar steam generation at supply level (SP_S_PI). Concentrating solar collectors, with heat transfer media typically being pressurized water or thermal oil, are evaporating water indirectly in a kettle type reboiler. The evaporated water is subsequently fed to the steam line when a sufficient pressure is obtained [9].

Solar Heating of Boiler Feed water

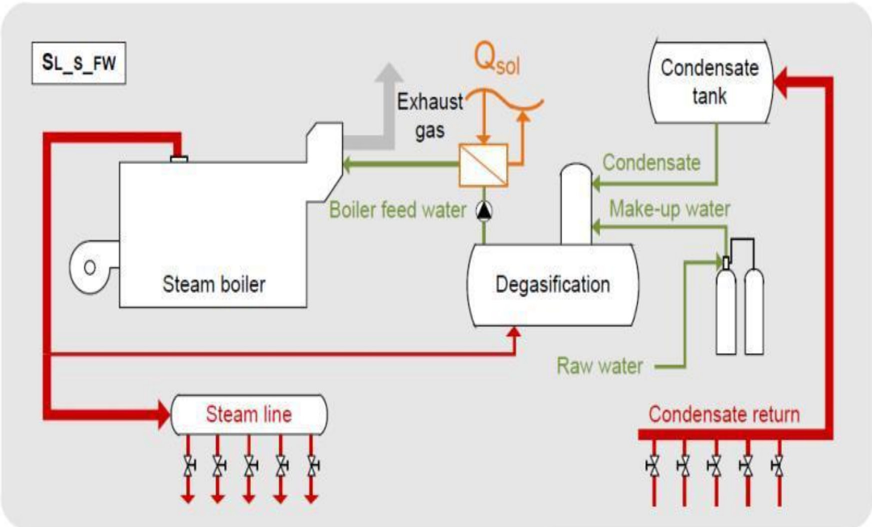


Figure 17: Integration of solar heating of boiler feedwater (SL_S_FW). The typical degasification temperature is 105°C. It is preferable to heat the feedwater prior to the boiler. This can be done either with the utilization of an economizer, a solar system, or a combination of both [9].

Solar Heating of Boiler Make up water

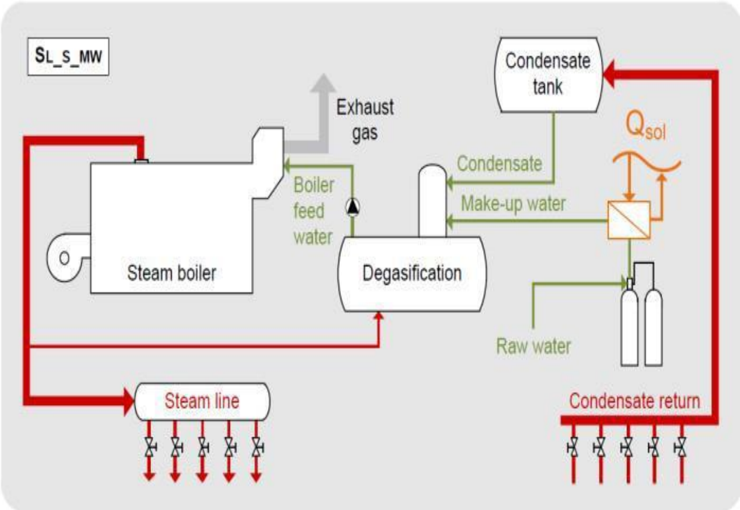


Figure 18: Integration of solar heating of make-up water (SL_S_MW). Make-up water can be preheated prior to entering the degasser, where a temperature of approximately 105°C is required [9].

Parallel Solar System for Hot water

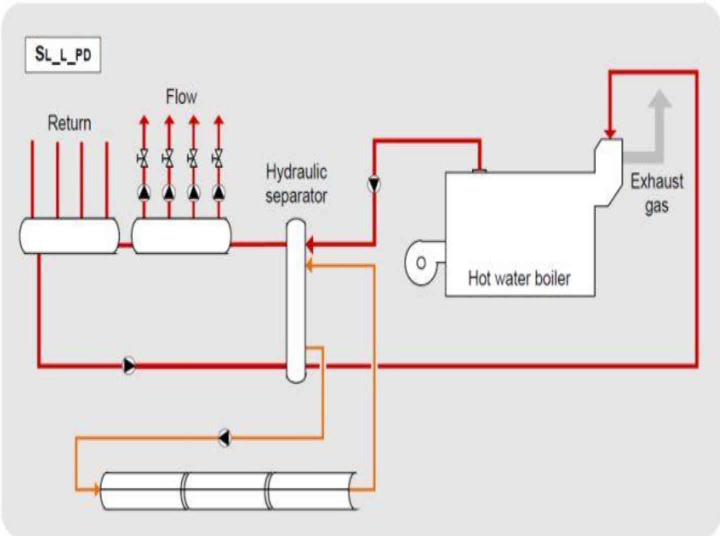


Figure 19: Parallel integration of a solar system to a hot water system (SL_L_PD). Return water is partially redirected through the solar heating system and fed back to the supply line. It is of great importance that the solar control system ensures that sufficient temperature is reached [9].

Indirect Solar Boost for Hot water

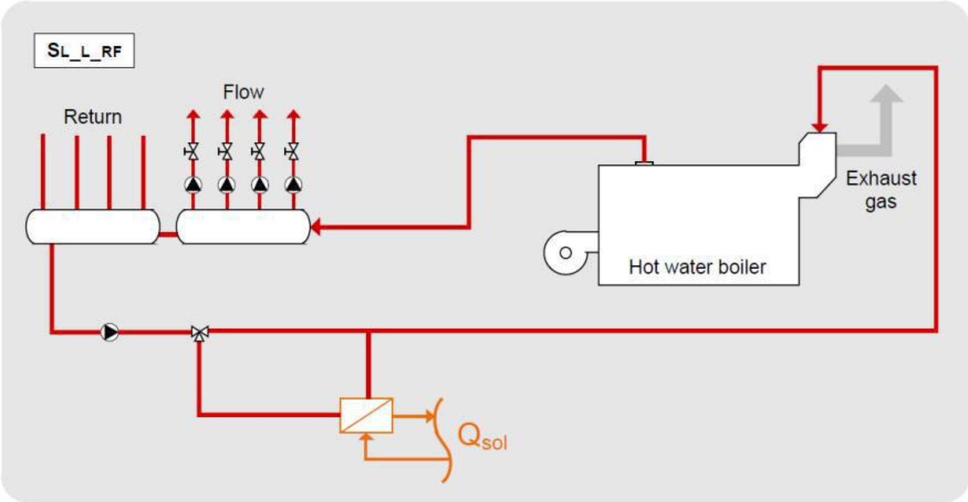


Figure 20: Preheating of return line prior to the boiler (SL_L_RF). No fixed set temperature is required in such a system [9].

Thermal Storage in hot water

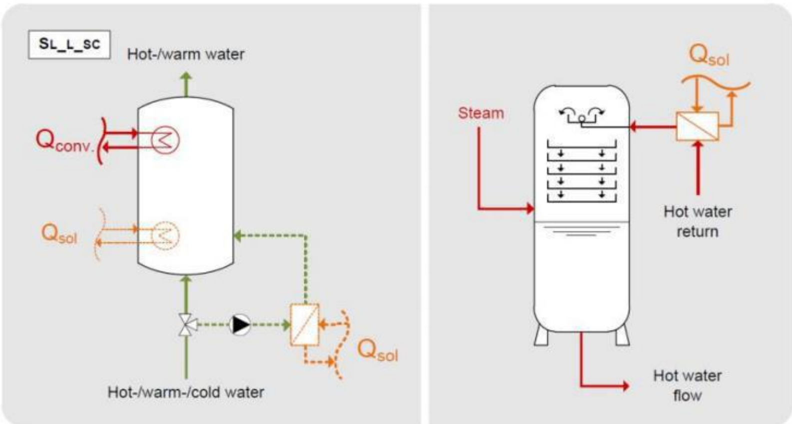


Figure 21: Schematic illustration of various integration concepts for solar heating of storages or cascades (SL_L_SC). STE can be supplied both directly and indirectly, depending on the requirements on the system [9].

Heating Product/process through Indirect solar heating (Heat Exchanger)

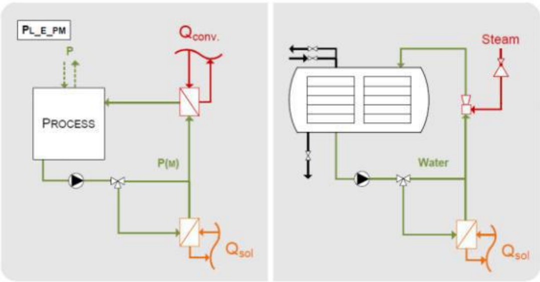


Figure 22: Left: Schematic illustration depicting the general integration of solar heating of product or process media with an external HEX (PL_E_PM). Right: The same integration concept realized for a sterilization process with autoclave [9].

Solar heating of intermediate hot water circuit in process application

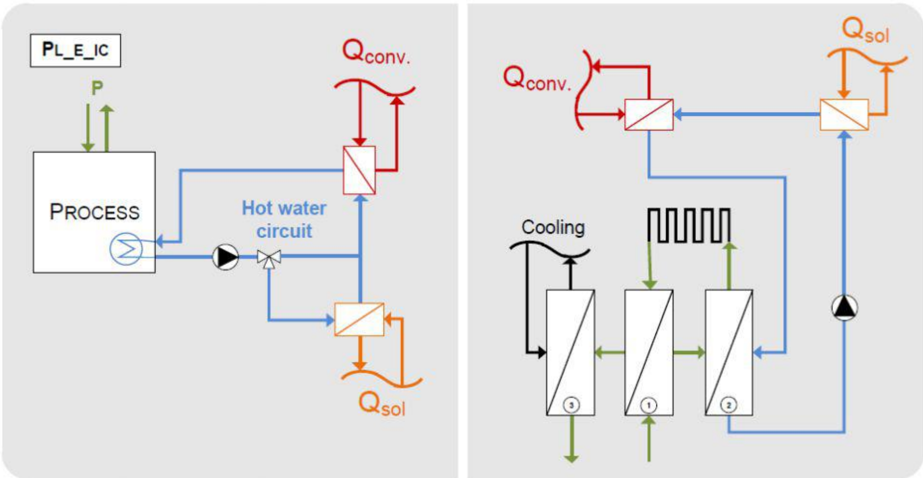


Figure 23: Schematic illustrations depicting solar heating of an intermediate hot water circuit with external HEX (PL_E_IC). Left: General integration concept. Right: Pasteurization process with multi zone plate HEX and external heating zone [9].

Indirect Solar heating of Bath, Machinery or Tanks (through Heat Exchangers)

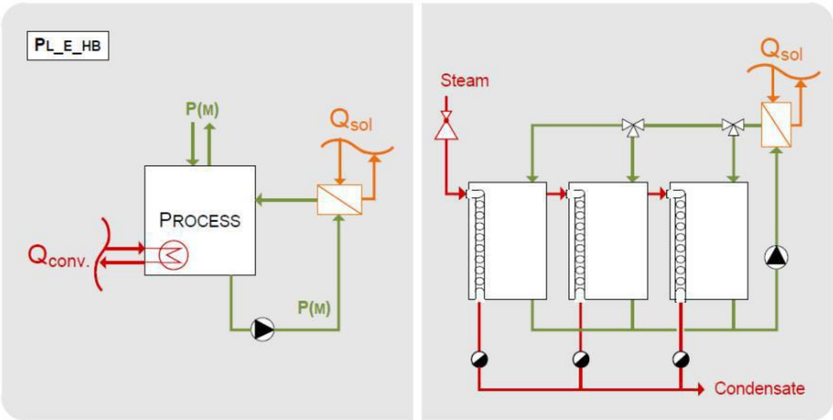


Figure 24: Left: General integration concept for solar heating of bath, machinery, or tank with an external HEX (PL_E_HB). Right: Schematic illustration depicted for the same integration concept, realized for electro plating process heating with internal plate coils [9].

Process level solar heating through internal heat exchangers

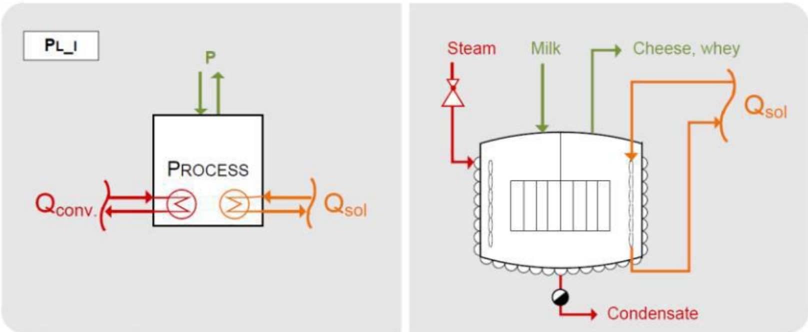


Figure 26: Left: General integration concept for solar heating with an internal HEX (PL_I). Right: Integration of a solar heated dimple plate HEX in parallel with the existing conventional heating jacket, for cheese production in a curd vessel [9].

Evolution of Process Heat Applications in India

Fixed focus, automatically tracked Scheffler dishes

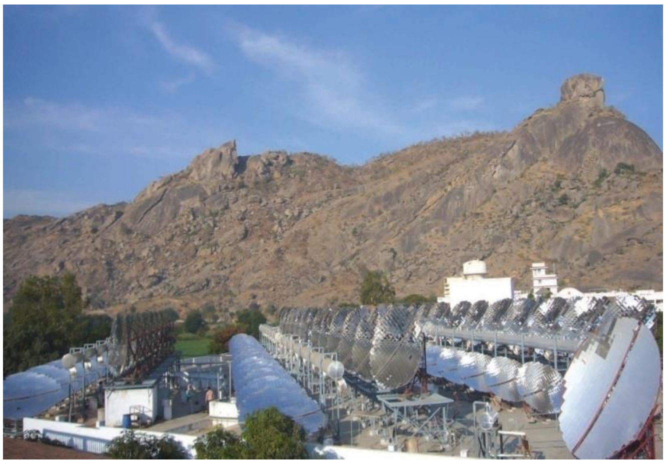
Beginning

- In 1997, paraboloid concentrators for institutional cooking were installed at the BK Gyan Sarovar Academy for a Better World in Mt Abu, Rajasthan, India.
- System consists of 24 pieces of 7.5 SQM paraboloid concentrators, with an output of 650 kg steam per day and it is used for cooking 2000 meals a day. It is the oldest system working in this application in the world.

Unique Features of the system

- Pressurized water for steam generation
- Steam generation into an accumulator
- Static focus due to centralized daily tracking system introduced for the 1st time ever

Technology refinement



In 1999, the world's largest solar kitchen was constructed in Brahma Kumaris Shantivan campus.

- 84 parabolic concentrators of 10 SQM generate 3500 kg steam and 38 000 meals per day
- The system has been running smoothly for all those years and it has been recognized by the MNRE thus is eligible for 50% grant of total cost.

Improvements and Unique Features of the system:

- High reflecting glass iso aluminium foil
- Direct steam generation by thermo syphoning principle with less parasitic load
- Buffer storage of 2 hours with high pressurized hot water

Thanks to the simplicity in steam generation and operations, this project set the trend in process heat application throughout India. MNRE established supporting policy of capital investment subsidy.

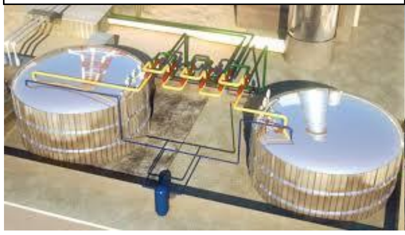
Since then, many other projects have been executed, building on this technology (10 SQM; 12 .6 SQM; 16 SQM). Since 2000 many new manufacturers have emerged.





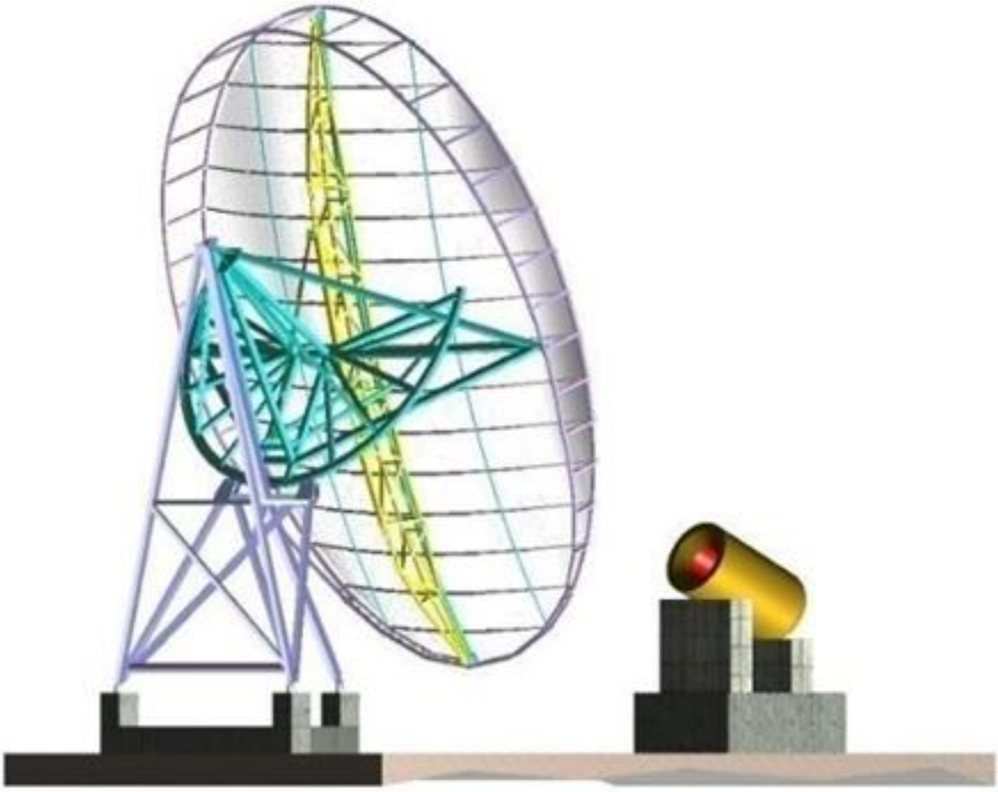
7.5 SQM Reflector	**10 SQM Reflector**	**12.6 SQM Reflector**	**12.6 SQM Reflector**	**16SQM Paraboloid Reflector**
- BK Gyan Sarovar, academy for better World Mt Abu - Installed by WRST in 1997 - 24 paraboloid reflectors - Total 650 kg steam generation for 2000 meals per day - Oldest system working in this technology	- Brahmakumaris, Shantivan campus, Abu Road - Installed by WRST in 1999 - 84 paraboloid reflectors - Total 3500 kg steam generation for 38000 meals per day	- The Global Hospital and Research Centre Mt Abu - Installed by WRST in 2003 - 10 paraoboloid reflectors - Total 900 kg steam - generation: • 300 kg steam for sterilizer (2 -3 shifts per day); • 300 kg steam for laundry • 300 kg steam for food cooking (600 meals per day);	- Om Shanti Retreat Center, near Delhi - Installed by WRST in 2006 - 28 paraoboloid reflectors - Total 800 kg steam generation for 5000 meals a day	- R&D by WRST, Abu Rd in 2006 - R&D sponsored by MNRE

Various available thermal storage options for CST based Technologies

Molten salt Potassium Nitrate & Sodium Nitrate	Steam accumulators	Concrete as thermal storage
		

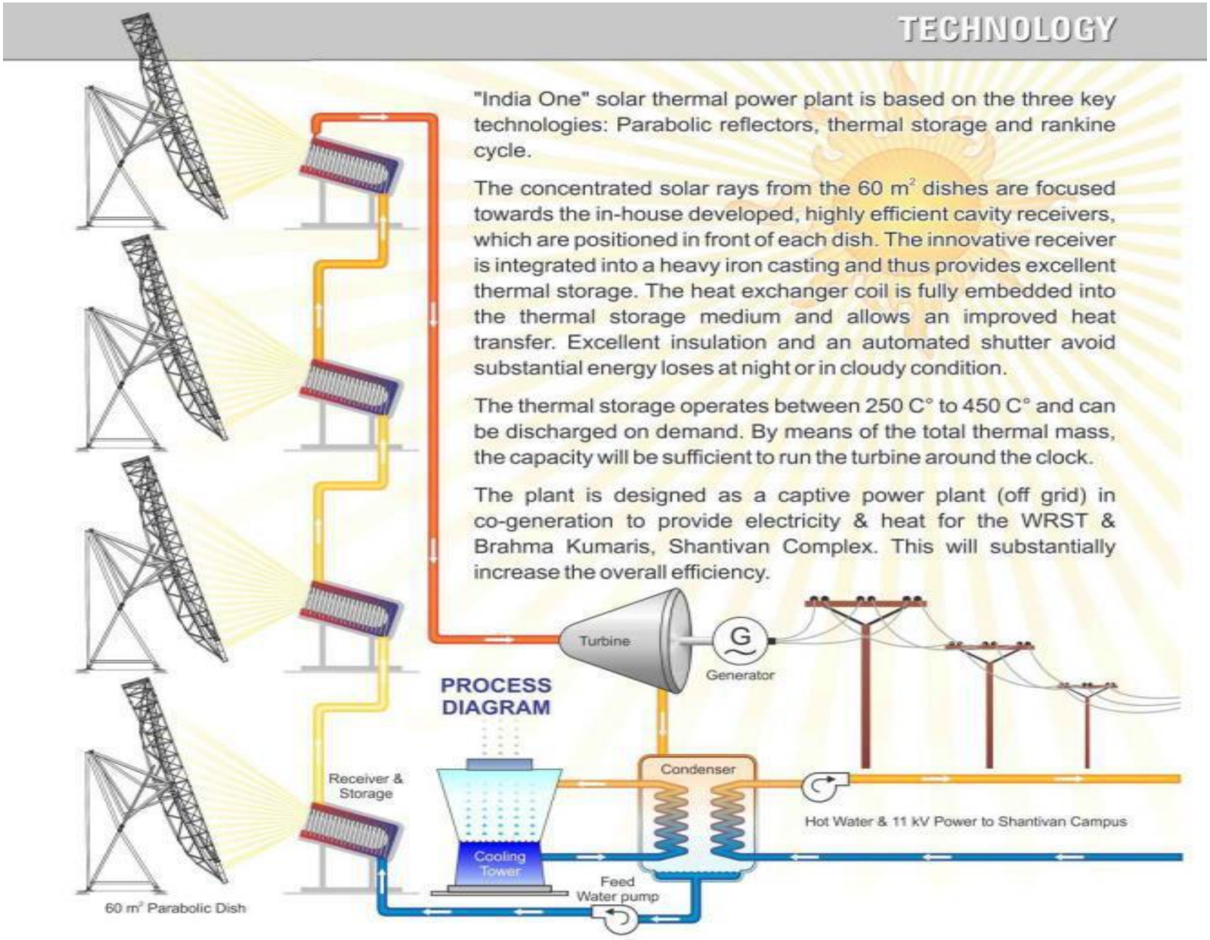
Latest development: 60 m2 Paraboloidal Reflectors

India One solar thermal Power plant with cogeneration at Abu Road



Key R&D achievements

Flexible Parabola	Space frame design	Reflective surface	Reflector Output
Three parabola's for different seasons	Structural optimization @ 50 kgs/m2	In house developed curved mirrors	@ 3.25 kWhrs/m2/day of thermal energy
Static focus, with concentration ratio 350:1	Indigenous fabrication & capacity building	Solar grade mirror with 93% reflectivity	Reflector efficiency @ 70% at focus
Automatic dual axis tracking mechanism	Local material & spare parts	Special glue for curving & exterior application	Static focus concentration temp @ 1200°C to 1400°C



Receiver Output Testing & Results

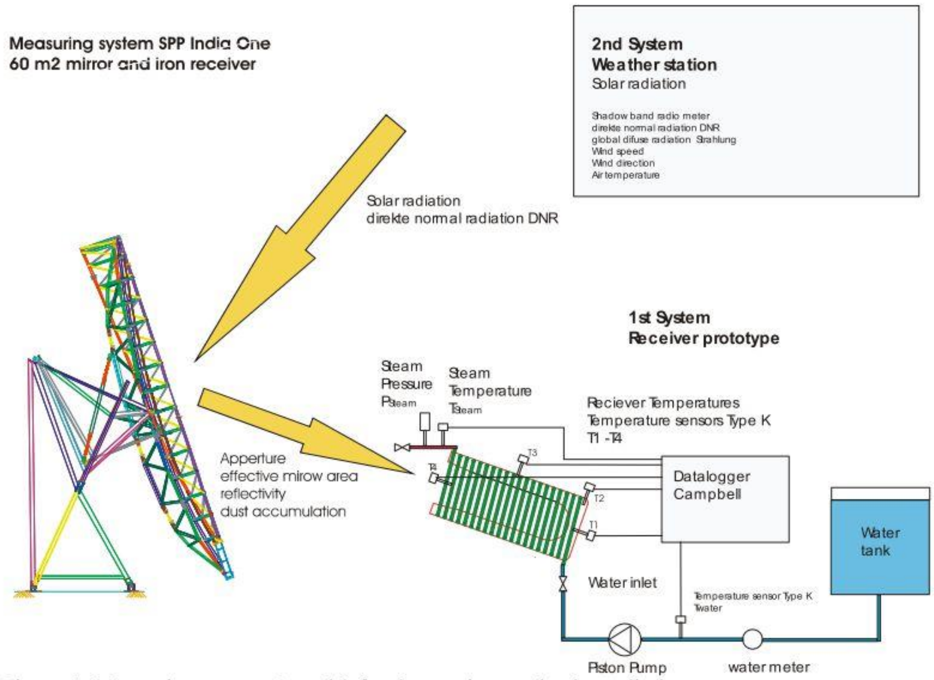
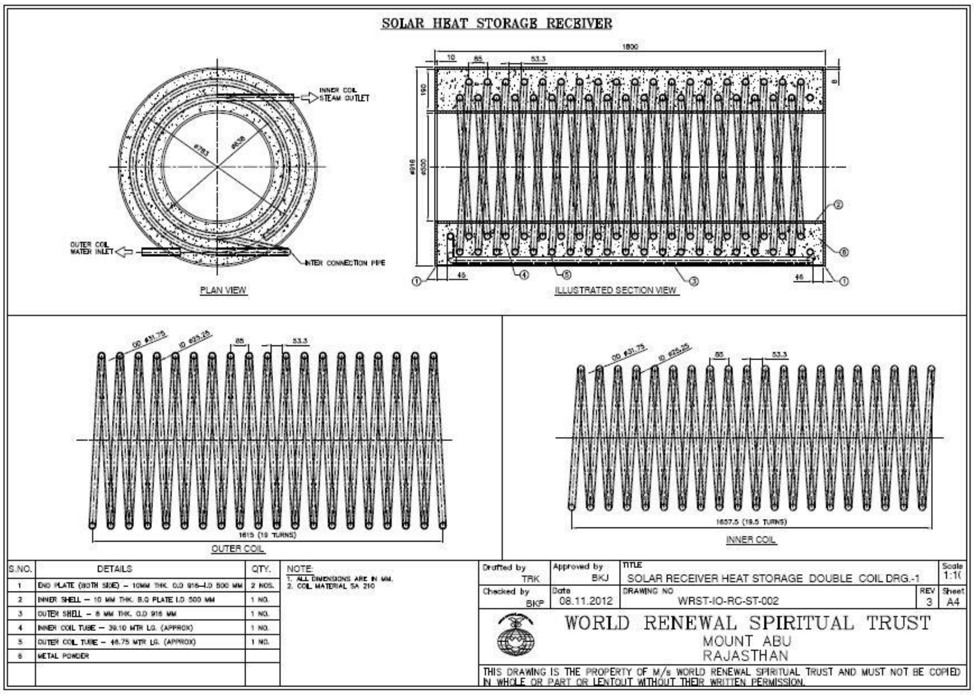
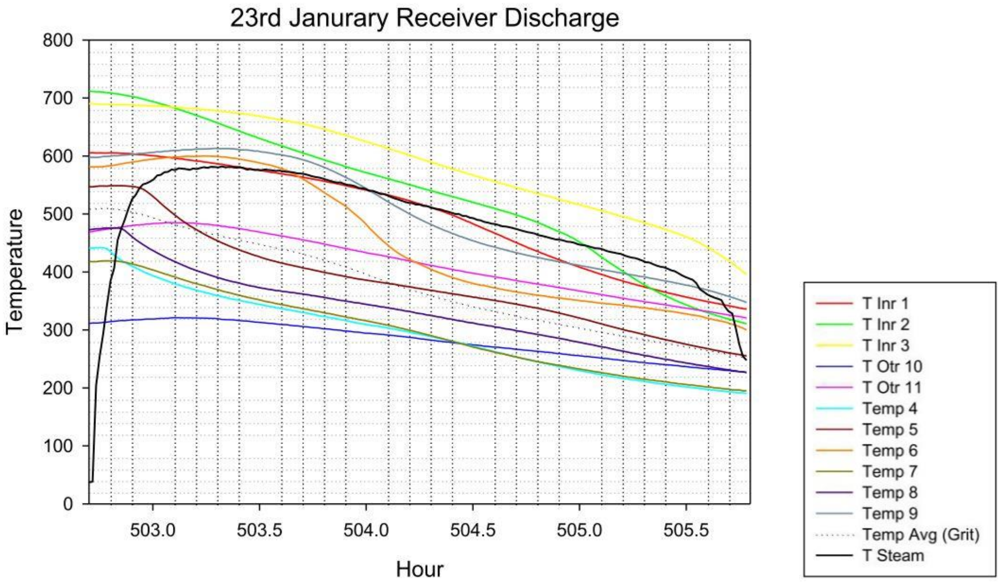


Figure 1. Measuring system 1 and 2 for the receiver and solar radiation





Parameters	**22nd Jan 2013**	**23rd Jan 2013**
Water Speed (Hz)	20	20
Water (lts)	190.34	196.78
Dis. Duration (Mins)	174	179
Grit Avg Temp (before Discharge) (°C)	504.95	510.07
Avg T_{steam} (°C)	477.19	491.57
Enthalpy (h) (kJ/kg)	3401.69	3434.2
(CALCULATED) Total Energy Stored (Kwh)	349.26	352.80
(CALCULATED) Energy Extracted (Kwh)	179.85	187.72

Various advantages of “India One” Technology:

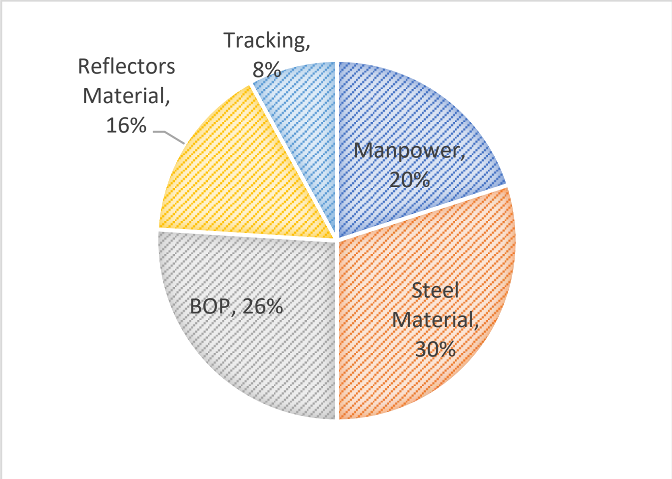
- Direct steam generation
  - No heat transfer fluid required
  - Less parasitic loads for heat transfer to generate steam
  - Due to static focus, no movement in high pressure joints resulting less O&M
  - No auxiliary heating system required
- Thermal storage
  - Decentralized thermal storage system
  - @ 130 kWhrs of thermal discharge per receiver per day
  - Operational flexibility
  - Variable flow discharge on demand
- Steam Parameters
- @ 252°C to 450°C steam generation @ 42 bar pressure
- @ 8000 kgs of steam production per hour for 24 hours
- Turbine efficiency @ 18 %to 20%

Cost of Thermal Energy Generation

1. With electric power: to generate 1 kWhr thermal is approximate Rs. 7.00 X 1.1 = Rs.7.7/ kWhr
2. With HSD: to generate 1 kWhr thermal is approximate Rs.5.55/- per kWhr
3. Thermal energy delivered by most of the CST technology is from 3 to 3.5 kWhr/day
4. Assuming per sqm rate of CST technology is Rs.20,000 to Rs.25,000 per sqm
5. Central financial assistance = Rs.6000 per sqm
6. Payback period with 'CFA' help @ 3 to 3.5 years

Cost analysis of typical 16m2 fixed focus double axis tracking Parabolic Reflector

A. Cost per Sq.m @ Rs.20,000
B. CFA per Sq.m = Rs.6,000
C. Total Investment (A-B) / m2 @ Rs. 14,600
D. Cost savings per year = Rs.60,000 to Rs.80,000
E. Payback period @ 3 to 4 years with CFA



DIGITISATION OF THE BOILER HOUSE AND STEAM SYSTEM

By Mr. Yash Sahajpal
Forbes Marshall

Name: Yashasvi Sahajpal
Organisation: Forbes Marshal
Designation: Digital Leadership Team

Yashasvi Sahajpal is a Business Leader with a background in marketing, sales and R&D. He has over 22 years of experience in product development, driving initiatives and launching and establishing businesses. Yashasvi is presently a part of Leadership Team for Digital Initiatives at Forbes Marshall, India's leading Process and Energy Efficiency firm.

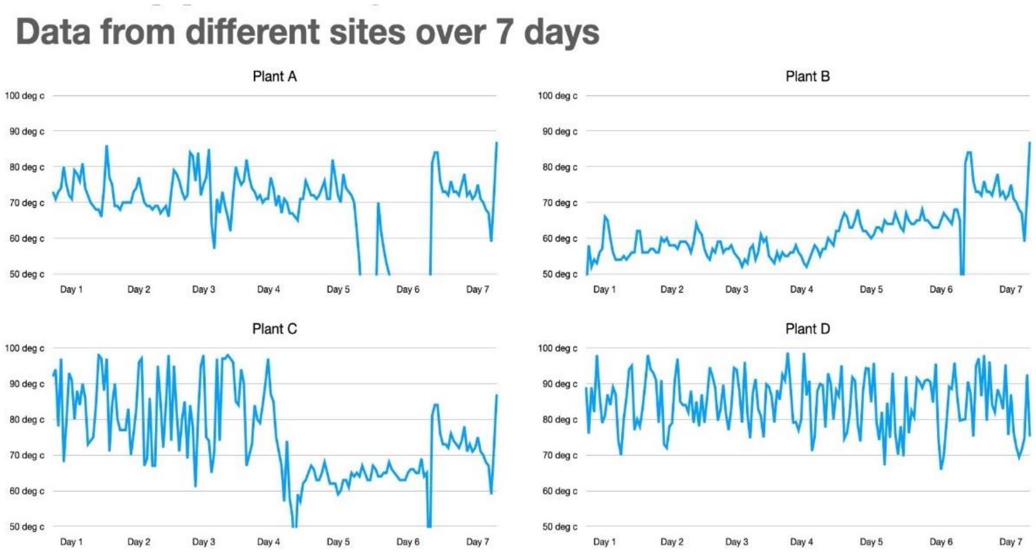
Forbes Marshall helps Industry build and sustain highly efficient plants by reducing waste, optimising process and energy efficiency, and complying with regulatory requirements. Forbes Marshall has consistently ranked as a Great Place to Work, and is a growing multinational with Indian roots.

Yasahasvi has a keen interest in, and is responsible for developing and establishing digital technologies, tools and services based ecosystem for improving process plant KPIs. He is focused on deriving value for customers through monitoring and improvements. His other areas of work involve establishing sales process, marketing tools and digital marketing.

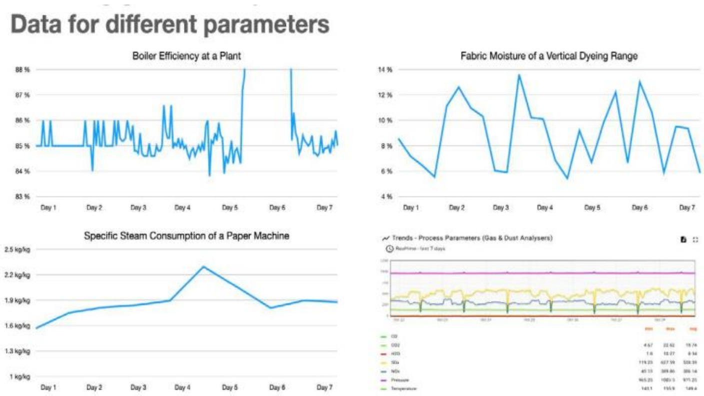
Yashasvi has done his BE in Instrumentation and holds a Post Graduate Degree in Business Management, specialising in Marketing.

Deploying Data to enhance performance

Conventionally, all plant KPIs are monitored as and looked at as static numbers. Digitally connected sites have shown that parameters and KPIs are not really static, but vary, not only day to day, but hour to hour and in fact minute to minute. This image below illustrates the variation of a simple parameter like feed water temperature of boilers in different plants.



Such variation is not confined to a single parameter, but holds true for various parameters. The adjoining image shows different parameters and KPIs like boiler efficiency, moisture in a product, specific steam consumption of a process and emissions from a boiler stack to be varying significantly



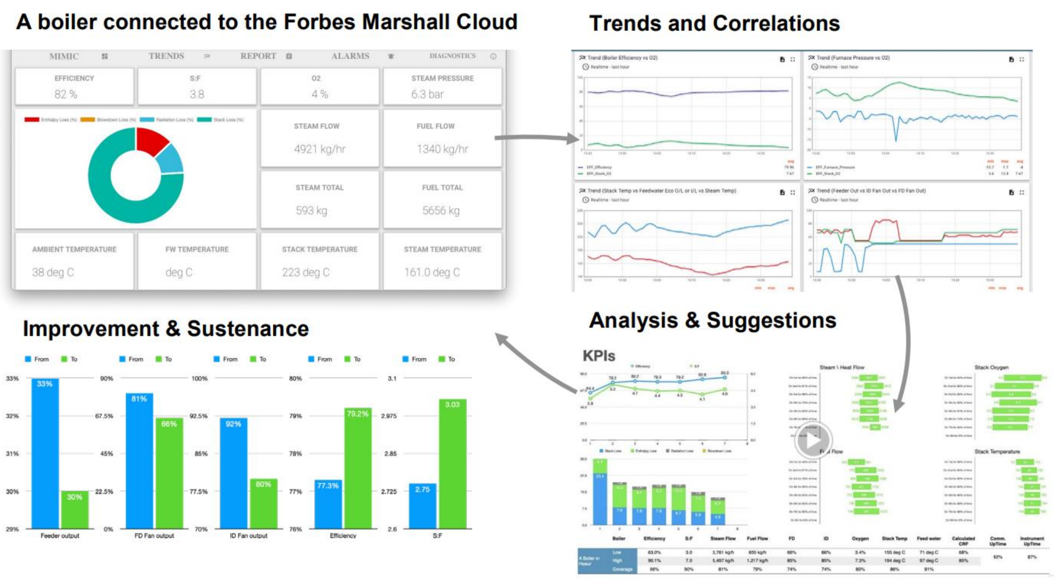
The variance is a problem and an opportunity to optimise and improve. Traditionally, most of measurements and logs have been either manually collected in the plant or stored locally in spreadsheets and SCADA softwares. Digitising the most important and relevant parameters enables continuous monitoring, advanced analysis and predictions. This helps plants improve and on their own with their internal teams.

Having connected hundreds of plants and thousands of parameters to our cloud, we have seen that domain and process experts add tremendous value to plant improvement and sustenance by correlating this data with their intrinsic knowledge.

Learnings from one plant can also be leveraged to bring about improvement to many other plants, and vice versa, bring experiences from many plants to your plant.

Using digital tools backed by decades of knowledge, Forbes Marshall brings tremendous value to the table. Not only does Forbes Marshall have capability to digitise parameters and KPIs, but also the expertise to analyse the data, revert to plant personnel with actions for improvement, and provide a complete product and solutions basket to support the plant through its journey, right from uptime and improvement to sustenance.

As a case in point, consider this example. A boiler connected to our cloud showed that the steam load on the boiler was varying weekly and seasonally, depending on the production demands. The efficiency and steam to fuel ratio were varying as the operating set points of the boiler were set for only one load condition. Looking at this data, we were able to find the most apt operating points for different loading conditions. Making these corrections on the boiler resulted in performance improvement. Subsequently, over a period of time, we were able to rectify problems as soon as they cropped up (as we were monitoring online!), and ensure sustained performance.



Similar to this example of boiler efficiency, all plant KPIs have similar characteristics and opportunities to improve. Digital connectivity of devices enables monitoring on a continuous basis by subject matter experts who can use statical tools, their experience and knowledge to come up with optimum performance points. Digital, hence, plays multiple roles of providing visibility (and triggering basic corrections), information on uptime of equipment (and possibly prediction of failure) and possibilities of improvement and sustenance.

OPERATION PHILOSOPHY OF GTG-HRSG AND ENERGY SAVINGS THROUGH COMBINED CYCLE

By Mr. Raju Ismulwar, Mr. Suman Kumar, Mr. Ayush Gupta
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Designation: Dy. Manager (Production)
Education: BE - Mech.

RCF at glance

Rashtriya Chemicals and Fertilizers Limited is a leading fertilizers and chemicals manufacturing company with about 75% of its equity held by the Government of India. Company has been accorded the coveted “Mini Chemicals. Ratna” status in 1997. RCF manufactures Urea, Complex Fertilizers, Bio-fertilizers, Micro-nutrients, 100 % water soluble fertilizers, soil conditioners and a wide range of Industrial

We have Two operating units,

1. Trombay in Mumbai
2. Thal, Raigad District

Steam Generation Group of Plants

- Boilers Section
- Water Treatment Plant
- GTG-HRSG Section

Steam Generation Plant Boiler Section

- Boiler Make : M/s BHEL, Trichi
- Capacity : 3 x 170 TPH
- Heating Surface Area : 4225 m²
- Type: Natural Circulation, Water Tube, Tangential Fired, Dry Bottom, Outdoor, Industrial Boiler
- Fuel used : Associated Gas
- Operation Parameter :
    - Steam Outlet Temperature: 510 º C ±10
    - Steam Outlet Pressure: 105 kg/cm²

Water Treatment Plant

Capacity

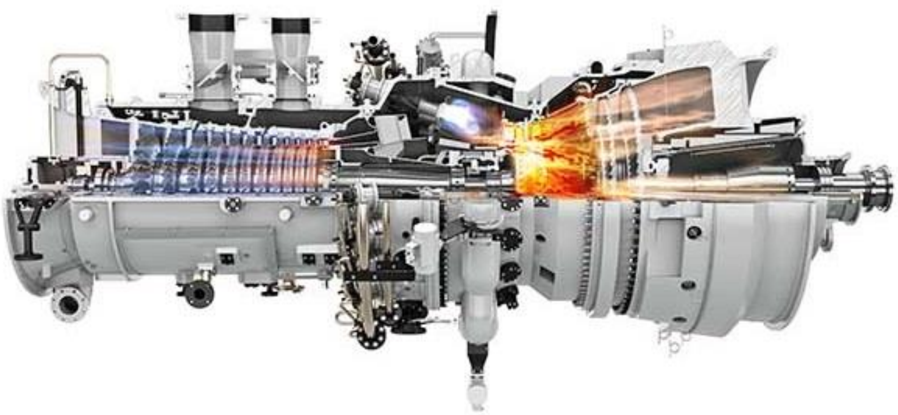
- WTP-0 : 50M^3/hr.
- WTP-1 : 200M^3/hr.
- WTP-2 : 350M^3/hr.

Heat Recovery Steam Generator (HRSG)

- Boiler Make : Thermax Ltd.
- Capacity : 2 x 65 TPH
- Heating Surface Area : $5307 m^2$
- Type: Natural Circulation, Water Tube, Supplementary Fired, Single Drum, Outdoor Steam Generator.
- Fuel Used : Natural Gas
- Operation Parameter :
    - Steam Outlet Temperature: 513 º C ±10
    - Steam Outlet Pressure: 108 kg/cm^2

Gas Turbine Generators

- Make: Siemens (Sweden).
- Capacity: 2 x 25 MW
- Type: Gas turbine with Electric Generator
- Fuel: Natural Gas



GTG – HRSG Project For Energy Reduction

- Target energy reduction by 0.3 Gcal/ MT of Urea
- HRSG will support existing steam network of RCF Tr. Unit up to 130 TPH
- GTG – HRSG Commercial Operation started on 23.07.2022 in RCF Trombay Unit

GTG	HRSG
A gas turbine is a combustion engine that can convert natural gas or other liquid fuels to mechanical energy. This energy then drives a generator that produces electrical energy.	HRSG is an energy recovery heat exchanger that recovers heat from a hot flue gas stream. It produces steam that can be used in a process (Cogeneration) or used to drive a steam turbine (combined Cycle).
	

Major Equipment's of HRSG

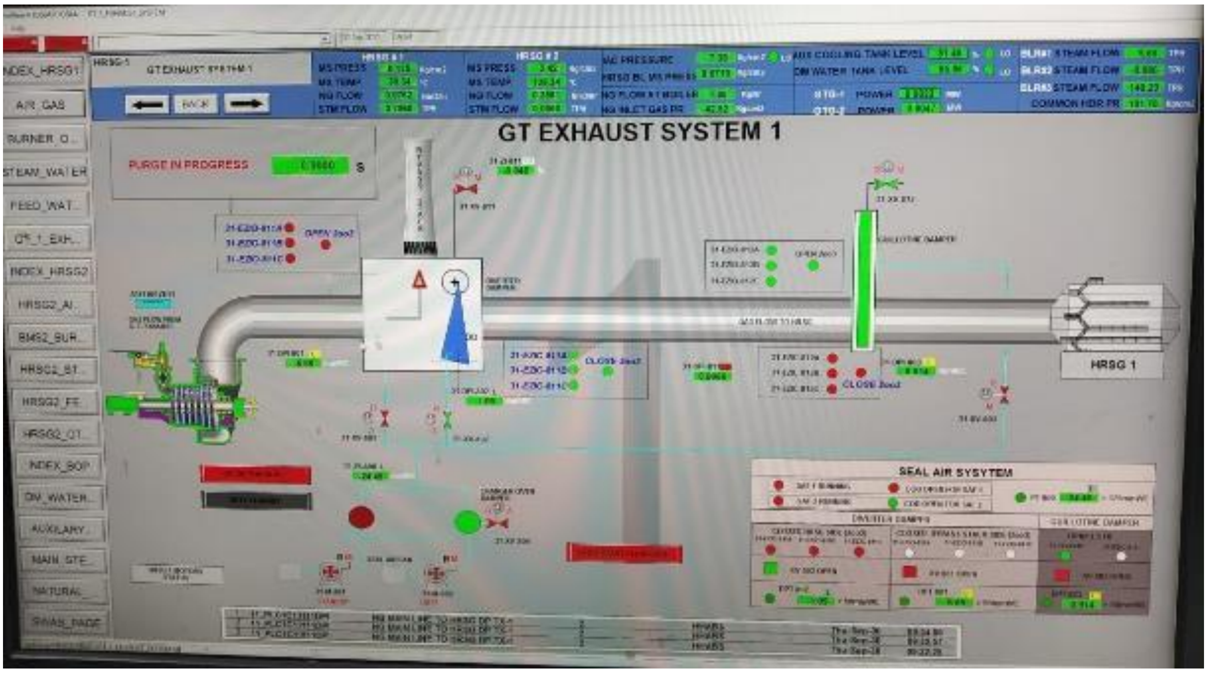
- Steam Drum
- Evaporator
- Economiser
- Condensate Preheater (CPH)
- Superheaters
- Fresh Air Fan (FAF)
- Boiler Feed Pump

HRSG Mode of Operations

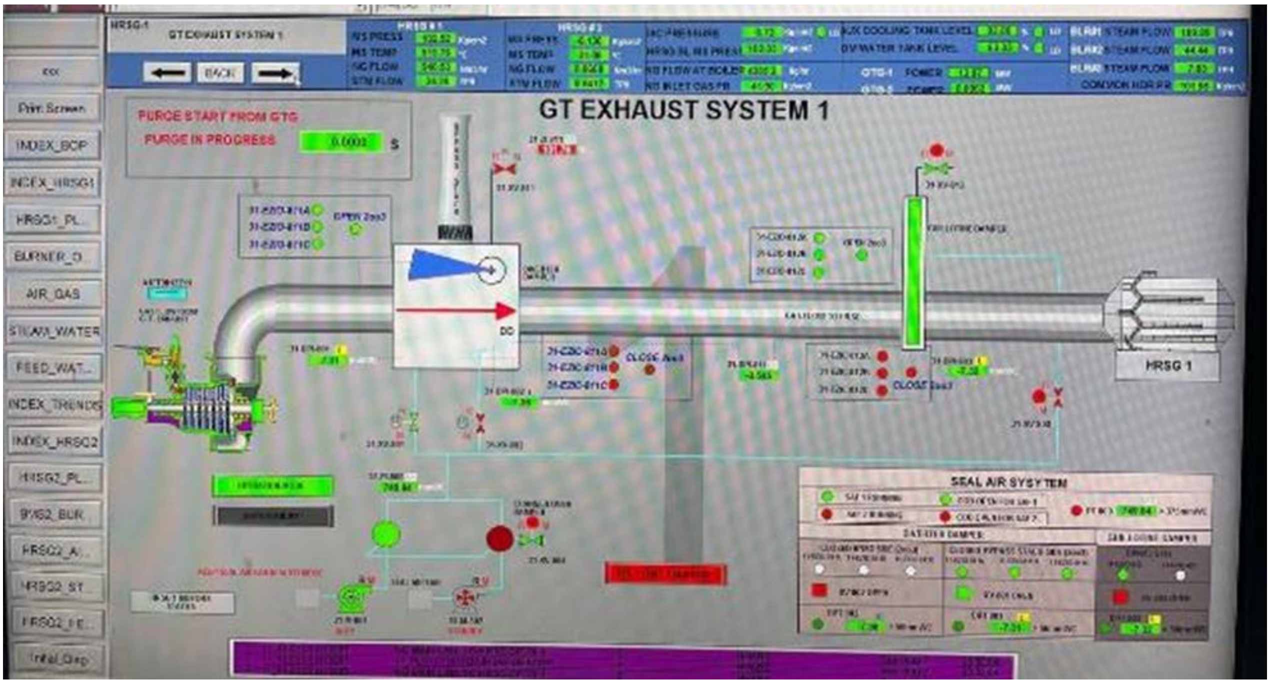
HRSG can be operate in two Modes:

1. Fresh Air Firing (FAF) Mode
2. Turbine Exhaust Gas (TEG) Mode

Mode	Supplementary firing	Maximum Load
Fresh Air Firing (FAF) Mode	With firing	65 TPH
Turbine Exhaust Gas (TEG) Mode	Only with GTG (@25MW) & no Supplementary firing	37.5 TPH
Turbine Exhaust Gas (TEG) Mode	With GTG & Supplementary firing	65 TPH

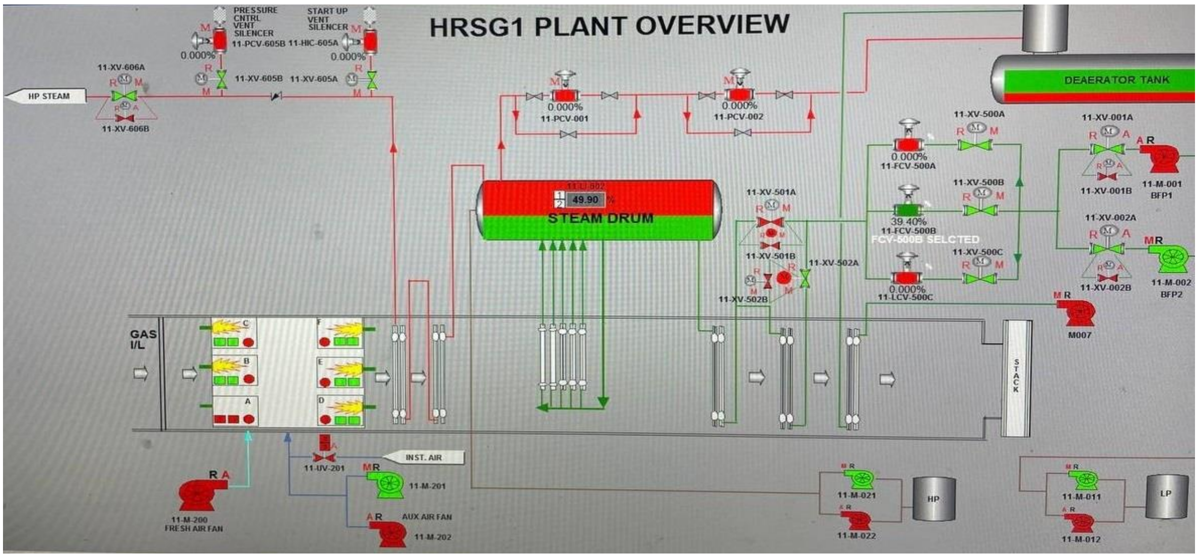


Fresh Air Firing (FAF) Mode



Turbine Exhaust Gas (TEG) Mode

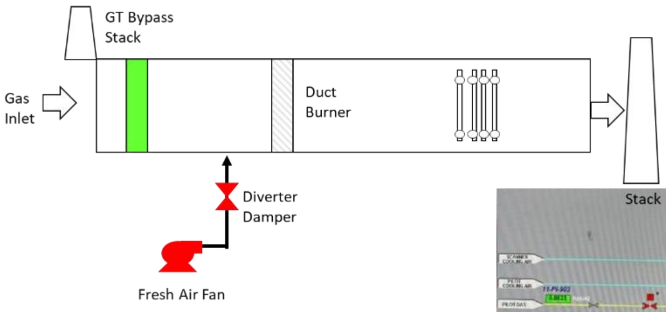
Water and Steam Circuit

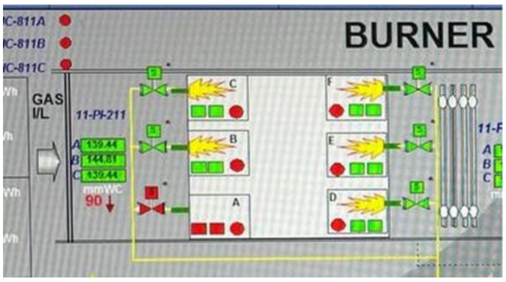


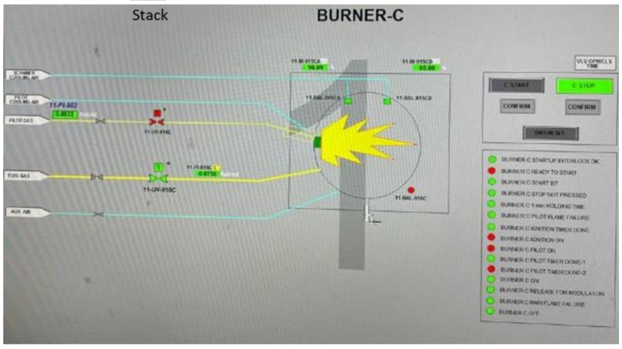
Fuel Firing System

- Fuel firing system consists of
    - Gas Burners (Duct Burner)
    - Pilot Burners
    - Spark Type Gas Igniter
    - Flame Scanner And
    - Remote/ DCS Burner Control Panel &
    - Local Burner Control Panel (02 Nos.).
- Total pilot burners: 06
- Total Main burners: 06 (03 on LHS & 03 on RHS).

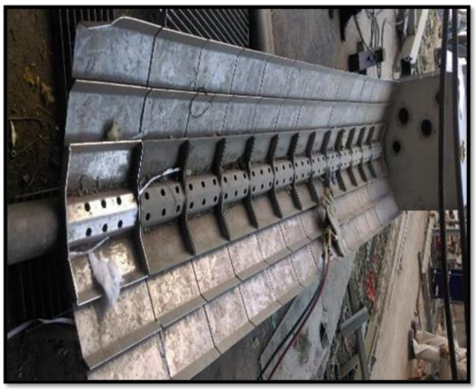
Burner arrangement in HRSG

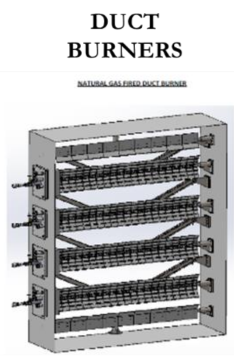






HRSG Duct Burners





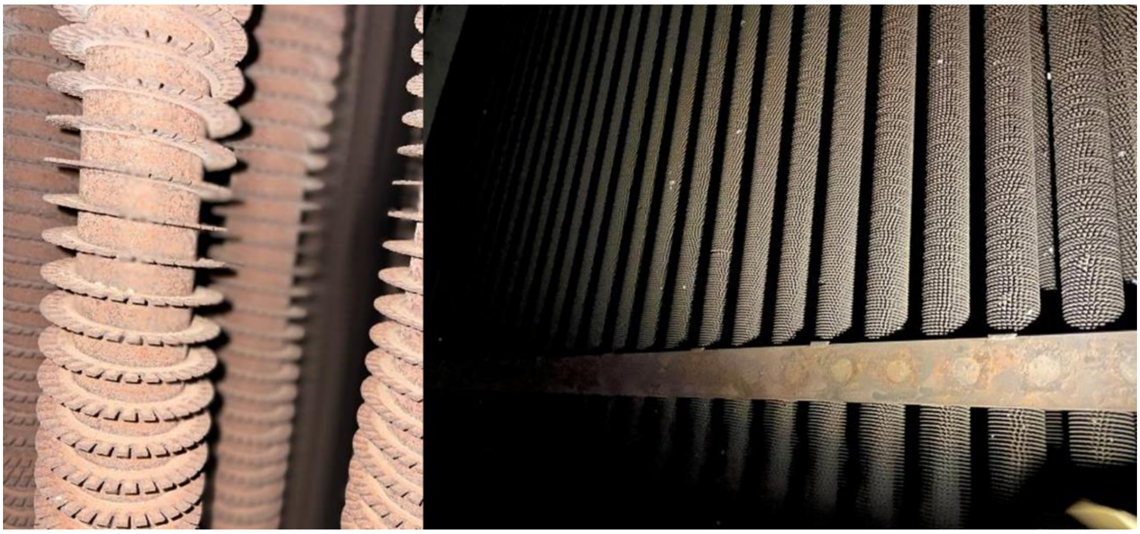
PYRO Blocks

It is used for furnace refractory

Harp Installation

HRSG Harp

Finned Tubes in HRSG



HRSG HARP detail

Equipment	Harp no.	No. of Rows	No. of tubes per row
Condensate Pre Heater (CPH)	1	3	34
	2	2	34
Economizer	1	4	34
	2	4	34
	3	3	34
	4	2	34
	5	2	34
Evaporator	1	4	34
	2	4	34
	3	3	34
	4	2	34
Primary Super Heater (PSH)	1	2	28
	2	2	28
	3	2	28
Secondary Super Heater (SSH)	1	2	28
	2	2	28
	3	2	28

Equipment Details

Boiler Feed Pumps

- Pump Make: Sulzer
- Motor Make: ABB
- There are two boiler feed pump (2x100%) provided & they are horizontal, multistage & centrifugal type.
- Pump discharge pr.: 137.15 kg/ cm^2
- Pump discharge flow: 85 m^3/ hr.
- NPSH Required for the pump: 11 m

Blow Down System

- The blow down system consists of blow down vessels to which both intermittent and continuous blow down lines is connected.
- The IBD tank is provided with a quenching water connection to discharge the blow down water at an acceptable temperature.

Dosing System

- Dosing system consists of skid mounted HP (Tri sodium phosphate) , LP (Hydrazine, Ammonia) & morpholine dosing systems.
- Each one of it is provided with a mixing cum metering tank, motorized agitators, and 2 x100% dosing pumps.
- HP dosing will be done in steam drum whereas LP dosing will be done at FST outlet i.e., in BFP suction line & morpholine dosing will be done in make-up water line to deaerator at Booster pump suction
- The dosing pumps are of positive displacement plunger type of variable stroke.

Cooling Tower

PARAMETERS	UNIT	DETAILS
Water Flow Rate	Cu. M / hr.	560
Cells	Nos.	280 x 2 cell + 280 as Stand by cell
Hot Water Temperature	° C	44
Cold Water Temperature	° C	34
Wet Bulb Temperature	° C	29
Cooling Tower Fan	Nos.	03
CW pumps	Nos.	04

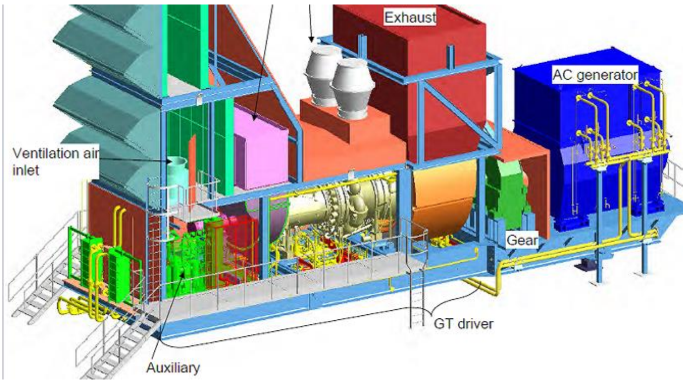
Air And Flue Gas System

- The air and flue gas system comprises of forced draft system and it consist of one (1) no. 100 % MCR capacity motor driven forced draft fan with inlet guide vane control.
- FD Fan Details:
  Flow Volume: 346731 m^3/hr
  Fan Speed: 980
  Power Consumption: 490 kW

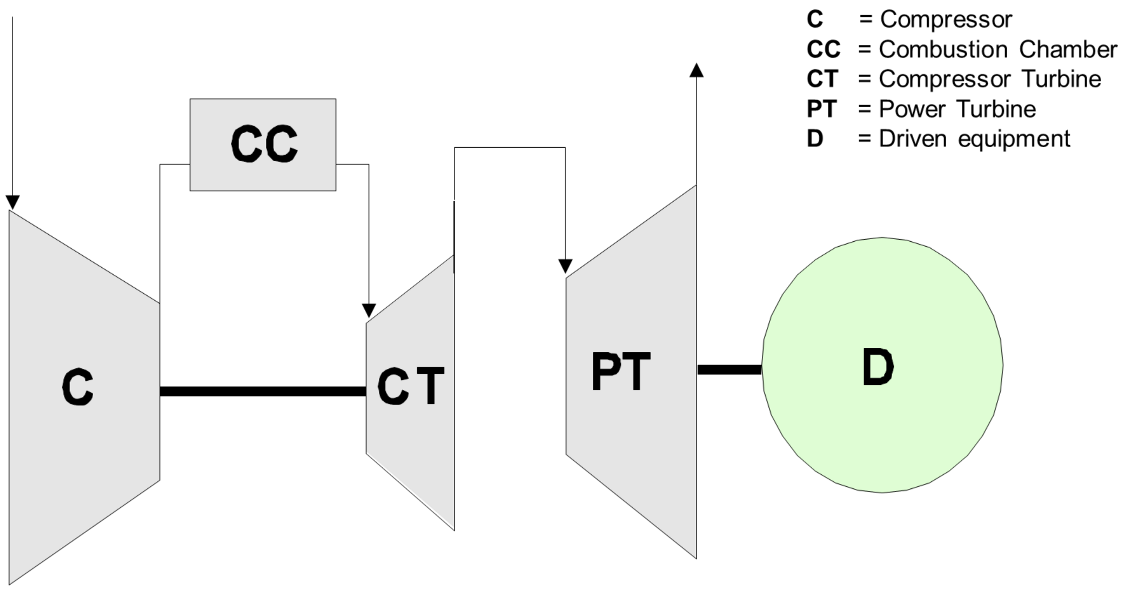
Gas Turbine SGT 700

- Gas Turbine Generator: 2 x 25 MW
- Model: SGT 700 (Siemens)
- Capacity: 25 MWH
- The SGT 700 gas turbine operates in an open cycle mode with axial air and gas flow through the turbine. It cab be divided into two main sections:
  - The Gas generator;
  - The power turbine

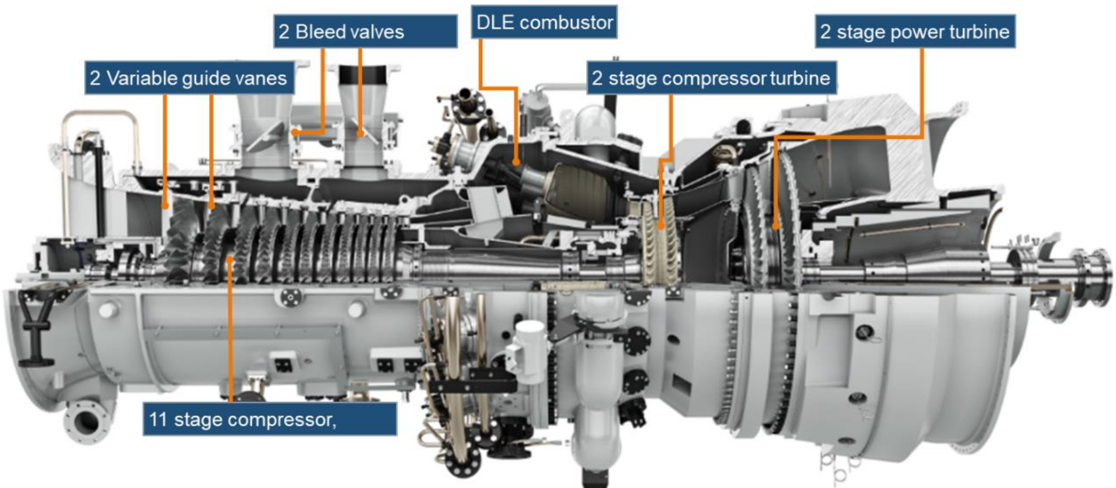
- The two shafts are not mechanically interconnected, so the gas generator speed is determined by the output of the unit, which allows a wider control range at sustained efficiency.
- The gas generator comprises the compressor, the combustion chamber and the compressor turbine. Power turbine is connected to generator by reduction gear.



Gas turbine - Two shafts type (SGT-700)



SGT-700 core engine design



Combustion
- Annular combustor
- Robust Dual Fuel DLE system
- Fuel and Operational Flexible
- Low gas pressure requirement
- High exhaust energy giving excellent cogen / CC characteristics

Maintainability
- 24 h swap concept
- Modular design
- Hot Section Inspections and Overhaul onsite or offsite

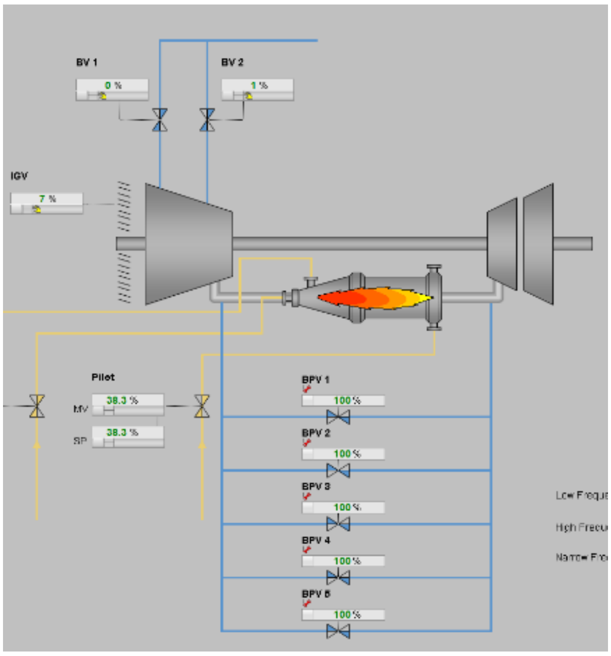
Simple and robust
- Dual shaft suitable for both Power Generation and Mechanical drive
- Tilting pad type bearings utilizing mineral oil
- All welded compressor rotor
- Bolted 2-stage turbine

3 Stage Suction Air filters in GTG

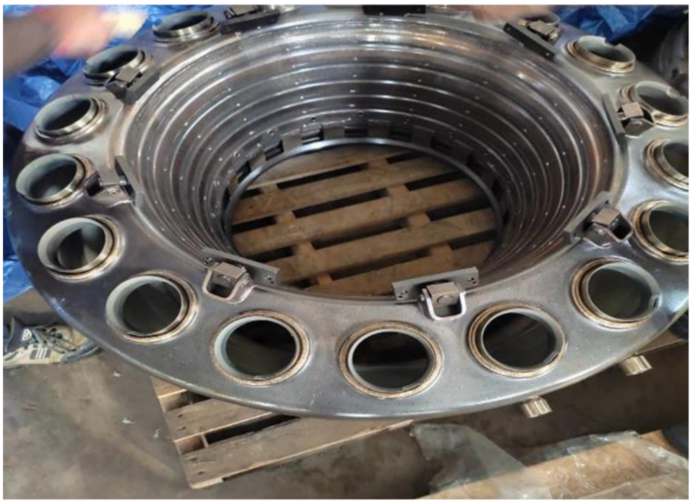
- Pre filter M6
- Intermediate F9
- Final Filter E12

Combustion System

- The variable dilution air system (Bypass System) is used in all SGT-700 gas turbines for gaseous fuel operation.
- The system provides a controlled by-pass of air to the combustor exit thus decreasing the airflow through the burners.
- When less air is led into the burners the flame temperature will raise and cause a better burn out of CO.



Combustor



GTG Igniter

The Compressor Washing System

Two types of compressor washing can be performed, Offline or Online washing.

The idea of washing is to keep the first stages of the compressor clean and in that way keep the compressor flow capacity.

GTG – HRSG TIME LINE

Mile Stone	Date
Zero Date	18.04.2018
GTG # 1 first firing	*22.01.2021*
GTG # 1 first synchronization	*01.02.2021*
GTG # 1 load test @ 6 MW, 12 MW (25%, 50%)	*06.02.2021*
GTG # 1 load test @ 12 MW, 18 MW (50%, 100%)	*08.02.2021*
GTG # 1 load test @ 28.5 MW	*09.02.2021*
GTG # 1 load test @ 28.5 MW	*12.02.2021*
GTG – HRSG# 1 & 2 Operability test	*02.09.2021 to 05.09.2021*
GTG – HRSG# 2 Reliability test run (RRT) & capability test	*08.09.2021 to 22.09.2021*
GTG – HRSG# 1 Reliability test run (RRT) & capability test	*11.09.2021 to 25.09.2021*
GTG – HRSG# 2 Performance guarantee test (PGT)	*04.10.2021 to 09.10.2021*
GTG – HRSG# 1 Performance guarantee test (PGT)	*14.10.2021 to 19.10.2021*
Performance Acceptance Certificate	23.07.2022

Commissioning Milestones

- COMPLETED
- UPS and MCC charging
- Auxiliary Cooling Water System
- DM Water Distribution System
- Fire Fighting System
- Package AC commissioning
- DCS Charging
- Natural Gas charging
- HRSG#1 & HRSG#2 Safety valve floating
- HRSG#1 & HRSG#2 open cycle commissioning
- GTES#1 & 2 Commissioning
- Operational & Commissioning Test
- Reliability Run Test
- PG test including Capability Test
- PAC issued to Thermax on 22.07.2022

Present Status

GTG-HRSG units are in commercial operation.

OFFICE LOCATIONS

MUMBAI OFFICE

Directorate of Steam Boiler, Kamgar Bhavan, 7th floor, C-20,
E Block, Opp. Reserve Bank, BKC, Bandra (E), Mumbai - 400051.
Phone: 022-26571201 / 1304 / 1352
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Phone: 0217 - 2317 015.
E-mail: jtdirsb.solapur@maharashtra.gov.in