SUPER CRITICAL POWER GENERATION - EXPERIENCE, ISSUES AND FUTURE CHALLENGES

A PRESENTATION BY:

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TODAY’S AGENDA

- Supercritical water steam cycle
- Boiler as key component of a supercritical unit
- Natural circulation to once-through boiler design
- Evaporator design and stability
- Water treatment.
- Material selection
- Problems that have nothing to do with supercritical technology
- Flexible operation
- Proper choice of fuel
WHAT SO “CRITICAL” ABOUT SUPER CRITICAL POWER GENERATION

A STARTER
WHAT IS “CRITICAL” ABOUT SUPER CRITICAL POWER GENERATION

“Supercritical ” is a thermodynamic expression describing the state of a substance where there is no clear distinction between the liquid and the gaseous phase (i.e. they are a homogenous fluid). Water reaches this state at a pressure above around 220 Kg Bar (225.56 Kg/cm^2) and Temperature = 374.15 C.

In addition, there is no surface tension in a supercritical fluid, as there is no liquid/gas phase boundary.
WHAT IS “CRITICAL” ABOUT SUPER CRITICAL POWER GENERATION

By changing the pressure and temperature of the fluid, the properties can be “tuned” to be more liquid- or more gas-like. Carbon dioxide and water are the most commonly used supercritical fluids, being used for decaffeination and power generation, respectively.
CHALLENGES FOR ADOPTION OF SUPER CRITICAL TECHNOLOGY

- Up to an operating pressure of around 190Kg Bar in the evaporator part of the boiler, the cycle is Sub-Critical. In this case a drum-type boiler is used because the steam needs to be separated from water in the drum of the boiler before it is superheated and led into the turbine.

- Above an operating pressure of 220Kg Bar in the evaporator part of the Boiler, the cycle is Supercritical. The cycle medium is a single phase fluid with homogeneous properties and there is no need to separate steam from water in a drum.

- Thus, the drum of the drum-type boiler which is very heavy and located on the top of the boiler can be eliminated.

- Once-through boilers are therefore used in supercritical cycles.

- Advanced Steel types must be used for components such as the boiler and the live steam and hot reheat steam piping that are in direct contact with steam under elevated conditions.
STEAM GENERATION IN NATURAL CIRCULATION & ONCE THROUGH BOILER
Concept of Once through Steam Generator
Circulation Systems

Drum Type

Once-through
**BOILER FOR SUPERCritical ONCE THROUGH POWER PLANT**

- Once through Boiler technology, which originated in Europe, has evolved into the most effective application for Super Critical Steam condition.
- There are no operational limitations due to once-through boilers compared to drum type boilers.
- In fact once-through boilers are better suited to frequent load variations than drum type boilers, since the drum is a component with a high wall thickness, requiring controlled heating. This limits the load change rate to 3% per minute, while once-through boilers can step-up the load by 5% per minute.
- This makes once-through boilers more suitable for fast startup as well as for transient conditions.
CHANGE FROM NATURAL CIRCULATION TO ONCE THROUGH IS MORE IMPORTANT THAN THE SWITCH FROM SUB-TO SUPER CRITICAL

<table>
<thead>
<tr>
<th>Natural circulation</th>
<th>once through</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NC Boiler</strong></td>
<td><strong>UP Boiler</strong></td>
</tr>
<tr>
<td>[Diagram of NC Boiler]</td>
<td>[Diagram of UP Boiler]</td>
</tr>
<tr>
<td>Steam</td>
<td>Feed Water</td>
</tr>
<tr>
<td>DRUM</td>
<td></td>
</tr>
<tr>
<td>Down Comer</td>
<td></td>
</tr>
<tr>
<td><strong>Vertical Type</strong></td>
<td><strong>Vertical Type</strong> (UP-UP Type)</td>
</tr>
<tr>
<td><strong>Sub-Critical</strong> (Constant or Sliding)</td>
<td><strong>Sub-Critical or Supercritical</strong> (Constant Pressure)</td>
</tr>
</tbody>
</table>

The change from natural circulation to once through is more important than the switch from sub- to supercritical.
**BOILER FOR SUPERCritical ONCE THROUGH POWER PLANT**

- Once-through boilers have been favored in many countries, for more than 30 years.

- They can be used up to a pressure of more than 300 Kg Bar without any change in the process engineering. Wall thicknesses of the tubes and headers however need to be designed to match the planned pressure level.

- Once-through boilers have been designed in both two-pass and tower type design, depending on the fuel requirements and the manufacturers‘ general practice.

- For the past 30 years, large once-through boilers have been built with a spiral shaped arrangement of the tubes in the evaporator zone.

- The latest designs of once-through boilers use a vertical tube arrangement.
BOILER CONCEPTS – SUPERCRITICAL BENSON TYPE
SUPERCRITICAL ONCE THROUGH POWER PLANT – TURBINE GENERATOR

The Turbine designs for a Super Critical plant are similar to the sub critical with the only special materials required for the casings and walls for withstanding high Temperatures and pressures.

- **High Pressure (HP) Turbine**: In order to cater for the higher steam parameters in supercritical cycles, materials with an elevated chromium content which yield higher material strength are selected.

- **Intermediate Pressure (IP) Turbine Section**: In supercritical cycles there is a trend to increase the temperature of the reheat steam that enters the IP turbine section in order to raise the cycle efficiency. As long as the reheat temperature is kept at 560 DEGC there is not much difference in the IP section of Sub critical and Super Critical plants.

- **Low Pressure (LP) Turbine Section**: The LP turbine sections in supercritical plants are not different from those in subcritical plants.
SUPER CRITICAL TECHNOLOGY – ISSUES, CHALLENGES, OPERATIONAL EXPERIENCES
CHALLENGES FOR ADOPTION OF SUERCritical TECHNOLOGY

- DNB (DEPARTURE FROM NUCLEATE BOILING) & DO (DRY OUT)
- DAMAGING THERMAL STRESSES ARISING OUT OF TEMPERATURE DIFFERENCE AT EVAPORATOR OUTLET
SPIRAL WALL DESIGN

Features:

- Reduced number of tubes with pitch.
- Increased mass flow.
- Mass flow rate can be chosen by number of parallel tubes.
SPIRAL WATER WALL, TUBING & HEAT FLUX
SPIRAL WATER WALL, TUBING & HEAT FLUX

Water Wall
Outlet
Fluid Temp.

Heat Flux

Vertical Type Water Wall
Spiral Type Water Wall
Each evaporator tube has to get the same water mass flow and similar heat input.

This complex scheme has to be optimized to reach good part load behaviour without extensive use of the circulating pump.

Evaporator stability at part load is of high importance.
ISSUES OF SUPERCRITICAL POWER GENERATION TECHNOLOGY, INITIAL

- High thermal stresses and fatigue cracking in the boiler sections of an SC plant and related higher maintenance costs
- Lower operational availability and reliability of steam turbines compared to sub-critical units.
- Main concerns were related to the ST control valve wear-and-tear, to the turbine blade thermal stress and solid particle erosion problems as well as to more complicated start-up procedures.
- SC units are also more sensitive to feed-water quality. Full-flow condensate polishing, therefore, is required to protect the turbine from stress corrosion Cracking.
ISSUES OF SUPERCritical POWER GENERATION TECHNOLOGY, INITIAL

- In 1957, the first USC units were put into commercial operation in UK and USA, the 375MW Drakelow C and the 125MW Philo (610/565/538C/31MPa) and in 1959 the famous Eddystone 1, which was designed for 650/565/565C/34.5MPa steam conditions but due to serious mechanical and metallurgical problems it was later down-rated to 605/565/565C/32.4MPa.

- **Most of the problems were due to the use of austenitic steels for thick section components operating at high temperatures.**

- **It is well known that austenitic steels have low thermal conductivity and high thermal expansion resulting in high thermal stresses and fatigue cracking.**

- **These problems and initial low availability of many SC power plants temporarily dampened utilities in building SC & USC power plants and consequently most utilities reverted back to power plants with sub-critical live steam conditions of about 550C/18MPa.**
ISSUES OF SUPERCRITICAL POWER GENERATION TECHNOLOGY, INITIAL

- After that, through more than 45 years of practices, fighting with protracted struggles, the technology has been unceasingly developed and gradually perfected.

- Operational experience worldwide has brought the evidence, that present availability of SC power plants is equal or even higher than those of comparable conventional (sub-critical) ones.
ISSUES OF SUPERCRITICAL POWER GENERATION TECHNOLOGY, INITIAL

- However, now SC units are more efficient and more flexible. Combination of SC design with OT boiler technology results in better operational dynamics.
- SC unit ramp rates are higher, namely 7 to 8%/min over a wide output range and in sliding pressure mode compared to about 3-5%/min for sub-critical drum units.
- With about 1’000 built units, the Benson Boiler is the most common implementation of the OT design. It can accept a wide range of fire systems, and can be built with essentially the same design for sub-critical and SC steam pressure.
- Comparing to sub-critical power plants, SC power plants can maintain higher efficiency at rather low load. On the other hand, conventional drum-type boilers have bigger material requirements because of the thick-wall drums, and also the water/steam inventory.
### Major Concerns with initial Super Critical Technology

<table>
<thead>
<tr>
<th>Issues experienced in older supercritical units</th>
<th>Causes</th>
<th>Countermeasures (As applied in new supercritical units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erosion of start-up valves</td>
<td>High differential pressure due to constant pressure operation and complicated start-up system</td>
<td>Sliding pressure operation, simplified start-up system, and low load recirculation system.</td>
</tr>
<tr>
<td>Long start-up times</td>
<td>Complicated start-up system and operation (ramping operation required, difficulty establishing metal matching condition, etc.)</td>
<td>Sliding pressure operation, simplified start-up system, and low load recirculation system.</td>
</tr>
<tr>
<td>Low ramp rates</td>
<td>Turbine thermal stresses caused temperature change in HP turbine during load changing (due to constant pressure operation)</td>
<td>Sliding pressure operation.</td>
</tr>
<tr>
<td>High minimum stable operating load</td>
<td>Bypass operation &amp; pressure ramp-up operation required</td>
<td>Application of low load recirculation system</td>
</tr>
</tbody>
</table>
## Major Concerns with initial Super Critical Technology

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<th>Issues experienced in older supercritical units</th>
<th>Causes</th>
<th>Countermeasures (As applied in new supercritical units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slagging</td>
<td>Undersized furnace and inadequate coverage by soot blower system</td>
<td>Design of adequate plane area heat release rate and furnace height, without division walls. Provision of adequate system of soot blowing devices and/or water blowers.</td>
</tr>
<tr>
<td>Circumferential cracking of water wall tubes</td>
<td>Metal temperature rise due to inner scale deposit and fireside wastage</td>
<td>Oxygenated water treatment (OWT). Protective surface in combustion zone of furnace for high sulfur coal, e.g. thermal spray or weld overlay.</td>
</tr>
<tr>
<td>Frequent acid cleaning Lower efficiency than expected</td>
<td>Inappropriate water chemistry High air leakage due to pressurized furnace. RH spray injection required due to complications of RH steam temperature control in the double reheat cycle configuration.</td>
<td>Application of OWT Tight seal construction. Single reheat system with high steam temperature and temperature control by parallel damper gas biasing.</td>
</tr>
<tr>
<td>Low availability</td>
<td>All the above</td>
<td>All the above</td>
</tr>
</tbody>
</table>
Major Concerns with initial Super Critical Technology – CONSTANT PRESSURE OPERATION

- Sliding pressure operation with a low-load recirculation system enables the Benson type boiler to start-up with similar operation characteristics and a start-up pressure profile as for an NC drum type boiler.

- While the start-up valves in a constant pressure supercritical boiler have to resist a large pressure difference during the bypass operation, the start-up valves in a sliding pressure boiler are only used during the swelling period, which occurs immediately after boiler light-off.

- The differential pressure during such swelling is less than 100psi, and therefore the duty of the start-up valves is much less in a sliding pressure boiler than the constant pressure boiler.
## Major Concerns with initial Super Critical Technology

<table>
<thead>
<tr>
<th></th>
<th>NC Boiler</th>
<th>Typical Constant Pressure Operation Once Through Boiler</th>
<th>Benson Boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flow diagram</strong></td>
<td>![NC Boiler Diagram]</td>
<td>![Typical Constant Pressure Operation Once Through Boiler Diagram]</td>
<td>![Benson Boiler Diagram]</td>
</tr>
</tbody>
</table>
| **Start-up bypass system** | Not installed  
- Operation of drain valves is necessary to establish turbine start-up condition | Required for  
- Maintaining furnace minimum flow  
- Heat recovery to HP heater and deaerator through flash tank  
- Ramping (shift from recirculation mode to once through mode, temperature dip is inevitable)  
- Continuous recirculation mode operation is impossible | Installed for steam temp and press control (TB bypass)  
- Maintaining furnace minimum flow  
- Automatic smooth shift operation from recirculation mode to once through mode  
- Direct heat recovery to economizer inlet  
- Continuous recirculation operation is possible |
| **Low load recirculation system** | Not required | | Required  
- Maintaining furnace minimum flow  
- Automatic smooth shift operation from recirculation mode to once through mode  
- Direct heat recovery to economizer inlet  
- Continuous recirculation operation is possible |
| **Start-up pressure at furnace during cold start** | Atmosphere | Full pressure (3500psig) | Atmosphere |
The formation of steam oxide scale in stainless steel tubing is an important issue to be taken into account in the design for high steam temperatures.

The steam oxide scale formation rate increases with operating temperature, and as a result the potential for exfoliation of oxide scales can become very high.

As a countermeasure against the once extensive scaling problems, austenitic stainless steel tubes have been internally shot blasted as part of the manufacturing process since the early 1980s.

By appropriate internal shot blasting, the formation of steam oxide scale on the inside surface of shot-blasted tubes is negligible in the operating range of supercritical boilers. This technique can be applied for tubes for service well above 1100°F (593°C).
Major Concerns with initial Super Critical Technology - - STEAM OXIDATION
Major Concerns with initial Super Critical Technology - SULFIDATION

- Sulfidation is a process where hydrogen sulfide (H2S) created in the combustion process reacts with waterwall tubes and leads to severe wastage.

- The key parameters that determine the level of sulfidation are sulfur content in fuel, burner stoichiometry (the atmosphere around the burners), tube material compositions and metal temperature.

- Liquid phase corrosion

- Liquid phase corrosion of stainless steel tubes at high temperature zones is a phenomenon that depends on the sulfur dioxide content in the combustion gas, the tube metal temperature, and the material composition.
Major Concerns with initial Super Critical Technology - SULFIDATION

Corrosion loss (mg/cm²) vs. SO₂ content in fuel gas (%)

- Temperature: 1202°F
- Time: 20h
- Ash: 1.5M Na₂SO₄ - 1.5M K₂SO₄ - 1M Fe₂O₃

Materials:
- 18Cr, 9Ni, 3Cu, Cb, N (A213 UNS S30432)
- 20Cr, 25Ni, 1.5Mo
- 25Cr, 20Ni, Cb, V (A213 TP310 HCBN)
Major Concerns with initial Super Critical Technology - SLAGGING AND FOULING

- Severe slagging and/or fouling troubles that had occurred in early installed coal fired utility boilers are one of the main reasons that led to their low availability.
- Some coals are classified as severe slagging fuels from their inherent properties.
- In addition to the degree of slagging, some coals are known to produce ash with specific characteristics, which is optically reflective and can significantly hinder the heat absorption.
- Therefore an adequate furnace plan area and height must be provided to minimize the slagging of furnace walls and platen superheater sections.
- For furnace cleaning, wall blowers will be provided in a suitable arrangement. In some cases as deemed necessary, high-pressure water-cleaning devices can be installed.
- As for fouling, the traverse pitches of the tubes were fixed based on the ash properties. An appropriate number and arrangement of steam soot blowers shall be provided for surface cleaning.
Major Concerns with initial Super Critical Technology - SLAGGING AND FOULING
PROBLEMS THAT HAVE NOTHING TO DO WITH SUPERCRITICAL TECHNOLOGY - SLAGGING AND FOULING
Major Concerns with initial Super Critical Technology - INNER SCALE DEPOSIT

- For the earlier supercritical boilers, the use of AVT water chemistry programs resulted in increased pressure drop through the furnace walls due to scaling,
- and hence the necessity for frequent acid cleaning or metal temperature rise.
- The use of OWT after initial start-up ensures the control of inner scaling of furnace wall tubes.
- There is no significant increase in pressure drop, and hence no requirement for future acid cleaning.
OXYGEN TREATMENT FOR SUPER CRITICAL POWER PLANTS

- Supercritical boilers do not have a steam drum. Therefore, extremely high levels of purity is required for feed water.
- Poor feed water can result into carry over of impurities which will result in turbine blade deposits.
- Oxygen Treatment improves the quality of water by reducing the flow assisted corrosion.
OXYGENATED TREATMENT

- Oxygen treatment minimizes flow assisted corrosion by the production of more stable iron oxide Hematite layers.
- Oxygen gas is dosed at deaerator and Condensate polishing unit outlet through gas cylinders in a controlled manner.
ADVANTAGES OF OXYGEN TREATMENT

- Virtually no iron transport
- Virtually no flow assisted corrosion
- Chemical cleaning—10 + Years (vs 2 years in AVT)
- Reduced Condensate Polisher regeneration
- Broad pH application range
Major Concerns with initial Super Critical Technology – INNER SCALE DEPOSIT

- Figure shows the pressure drop history of a coal-fired supercritical plant in Japan that changed the water chemistry from AVT to OWT in 1996. After 7 years operation since the change, there has been no significant increase in pressure drop.
- This plant has not required acid cleaning since the change, and no future cleaning is planned.
## Acid Cleaning Interval

<table>
<thead>
<tr>
<th>Boiler type</th>
<th>Sub-critical Drum</th>
<th>Super-critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water treatment</td>
<td>Phosphate</td>
<td>OWT</td>
</tr>
<tr>
<td>Chemical cleaning interval</td>
<td>4 years</td>
<td>No need or 20 years</td>
</tr>
<tr>
<td><strong>Annual cost impact of Chemical cleaning</strong></td>
<td>$125,000</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.04 mills/kWh</td>
<td></td>
</tr>
<tr>
<td>Plant outage</td>
<td>5 days</td>
<td>-</td>
</tr>
<tr>
<td>Chemical waste disposal</td>
<td>63 ton</td>
<td>-</td>
</tr>
</tbody>
</table>
**Comparisons of Operation Characteristics**

<table>
<thead>
<tr>
<th>Operation</th>
<th>NC Boiler Constant press</th>
<th>Benson Boiler Super-critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start-up time</td>
<td>easy</td>
<td>easy</td>
</tr>
<tr>
<td>Load ramp</td>
<td>base</td>
<td>faster</td>
</tr>
<tr>
<td>Load ramp range</td>
<td>1~2 %/min</td>
<td>3~5 %/min</td>
</tr>
<tr>
<td>Steam temp control range</td>
<td>MST 50~100%MCR</td>
<td>MST 35~100%MCR</td>
</tr>
<tr>
<td></td>
<td>RST 75~100%MCR</td>
<td>RST 50~100%MCR</td>
</tr>
<tr>
<td>Range of coal quality</td>
<td>base</td>
<td>wider (multi sources)</td>
</tr>
<tr>
<td>Stable min. Load (coal)</td>
<td>30 % MCR*</td>
<td>30 % MCR*</td>
</tr>
<tr>
<td>Load runback stability</td>
<td>unstable drum level</td>
<td>stable</td>
</tr>
<tr>
<td>High load efficiency</td>
<td>base</td>
<td>high</td>
</tr>
<tr>
<td>Part load efficiency</td>
<td>base</td>
<td>high</td>
</tr>
</tbody>
</table>
PROBLEMS THAT HAVE NOTHING TO DO WITH SUPERCRITICAL TECHNOLOGY

Wall corrosion due to inappropriate Primary NOx-Measures
Comparison of energy availability of sub and supercritical units
OPERATING SCHEME AND DEFINITION OF AVAILABILITY

energy availability = normal energy - unavailable energy

energy utilization = energy generated - nominal energy

time availability = reference period - unavailable time
AVAILABILITY, EFFICIENCY AND ECONOMY OF SUPERCritical UNITS FOR LOW GRADE COAL?

Coal washing instead of:

- Transportation of ash over thousands of km
- Design of a supercritical unit for high ash content
- Additional CAPEX
- Additional OPEX
- Lower availability
- Large area for ash dump
- And as a result higher land consumption
INFLUENCE OF ASH AND WATER CONTENT ON COSTS OF A HARD COAL FIRED POWER PLANT (EXAMPLE)
Typically coal washing is more economic than transportation and combustion of low grade coals.
Key Statements

⇒ High efficient use of coal for power generation asks for supercritical technology
⇒ The major difference is between natural circulation and once through and not between sub- und supercritical design
⇒ Proper design of the boiler especially the evaporator is needed
⇒ Combined water treatment and careful material selection is recommended
⇒ A lot of causes for unavailability in coal fired power stations have nothing to do with supercritical technology, availability of sub- and supercritical pp is the same
⇒ Coal washing is more economic than transportation and combustion of low grade coals
⇒ Flexible operation also of supercritical units is a special challenge of the future
# Issues & Challenges of SC Tech in India

## Financial / Business Barriers & Approaches

### Imported Coal

<table>
<thead>
<tr>
<th>No.</th>
<th>Barriers</th>
<th>Approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>1)</td>
<td>High capital cost (while decreasing fuel cost by increasing thermal efficiency)</td>
<td>Low interest loan / Government support (Tax incentive, CDM, Viability Gap Fund etc)</td>
</tr>
<tr>
<td>2)</td>
<td>Payment security (Off taker default risk i.e. by cheap electricity tariff)</td>
<td>(The situation is getting better than before. But we still need to study more.)</td>
</tr>
<tr>
<td>3)</td>
<td>Merchant power business</td>
<td>(Power trading market is getting sufficiently developed. But we still need to study more.)</td>
</tr>
</tbody>
</table>
ISSUES & CHALLENGES OF SC TECH IN INDIA

The technical barriers to use Indian domestic coal

**Domestic Coal**

<table>
<thead>
<tr>
<th>No.</th>
<th>Barriers</th>
<th>Approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>4)</td>
<td>High ash content / Variability in quality of India domestic coal</td>
<td>Appropriate boiler design and periodical inspection / maintenance are required.</td>
</tr>
<tr>
<td></td>
<td>(Low availability / Increased maintenance cost by ash erosion)</td>
<td>Step by step approach for joint efforts by utilities &amp; manufactures is important.</td>
</tr>
</tbody>
</table>
FLEXIBLE OPERATION FOR MULTIPLE COAL TYPE FIRING

- The combustion of different types of coals with varying combustion properties leads to different heat absorption profiles in the furnace, and hence different fluid conditions through the boiler.
- This creates a challenge in designing the steam temperature control system when multiple types of coals must be considered.
- The differences in steam profiles for the firing of coals with different combustibility properties are shown in Figure.
FLEXIBLE OPERATION FOR MULTIPLE COAL TYPE FIRING
ISSUES & CHALLENGES OF SC TECH ADOPTION IN INDIA

- Skilled manpower
- Operational Issues
- Sustenance of performance
- Reference data
- Consolidation of experience
- Safety & Environment Issues

Utilities need to develop strategies to address the various concern areas and build on each others’ experience.
ISSUES & CHALLENGES

Availability of skilled manpower

- Need for trained professionals (Erection, Operation & Maintenance)
- Need for specialised trainings (Metallurgy, Chemistry and O&M of Supercritical units)
- Development of local skilled manpower for contractors (Hand holding of craftman institutes)
- Trainings through Simulators
- Exposure to O&M practices of similar units in EU/USA (Workshops, Seminars, Sharing of best practices, Association during overhauls of Supercriticals)

A WELL MANAGED STRONG TECHNICAL WORKFORCE PROVIDES THE COMPETITIVE EDGE
SIMULATOR TRAINING

- Advanced Hands on training tool
  - Unit Start up, shut downs
  - Routine operations
  - Infrequent procedures
  - Emergency Handling
- Must for Operator confidence
- Verification of Operating procedures
- Fine tuning of Control Loops
- Safe, Efficient & Economic Trainings
OPERATIONAL ISSUES

- Strict compliance to Commissioning Procedures (chemical cleanings, commissioning of control loops etc.)
- Precise & Concise Operating Procedures
  - Start ups and shutdowns
  - Hot restarts
  - Expected alarm response
  - Known Emergencies
- Water chemistry requirements (Stringent operating limits, Oxygenated chemical treatment)
- Coal quality variations & coal mixing / blending
- Dos & Don’ts

THERE IS A NEED TO DEVELOP OGNs – OPERATION GUIDE NOTES FOR SUPERCRITICAL UNITS
REFERENCE OPERATION & PERFORMANCE DATA

- Benchmarking indices for disparate designs
- Operating parameters (*Baseline under defined conditions for monitoring & analysis*)
- Validation of Measurements (*Sensor calibrations, process simulation and reconciliation*)
- Performance indices of equipment & systems (*HP/IP Cylinders, condenser, FW heaters, air heaters, furnace, fans*)
- Thermal Cycle Modelling
- O&M practices (*vis-à-vis other utilities*)

There’s a need to develop documents on ‘Best O&M Practices’ similar to the ones for sub critical units.
SUSTENANCE OF PERFORMANCE – O&M STRATEGY

- Operation by Qualified and Trained personnel
- Systems for tracking performance deviations
- Parametric Optimisation
- Monitoring & analysis support
- Maintenance Systems & Strategies for 2 year overhaul cycle
- Maintenance procedures & related facilitation
- Availability of spares (*dependence on OEM*)
- Availability of experienced contractors for quality maintenance
- Welding of special materials (*skilled welders / procedures*)
- Expert technical support & Specialized Repair Services
  - Advanced tools & overhaul services
  - Test instruments, Simulation & CFD modeling software
  - Performance optimization after major repair work
Consolidation of experiences

- Major Concern Areas
  - Boiler tube leaks
  - Circumferential cracking
  - Corrosion/erosion issues
- Experiences at Once through boilers
- Experiences of Foreign utilities
  - Weld overlays / laser claddings
  - Scale detection in SH/RH tube bends
  - Water Chemistry

There’s a need to share, learn and build on each other’s experiences to improve the learning curve.
Weld Overlay

- Inconel 622
- Automatic & Semi Automatic GMAW
- High Heat Input – High stresses & Distortion
- 3 mm minimum wall requirement
- Failures have occurred in field weld overlays
- Shop (new panels) or field (existing)
- 360° spiral overlays
BOILER REPAIR PRACTICES - US EXPERIENCE

Laser Clad Water wall Panels

- Powdered alloy (Inconel) 622 applied to boiler tube panels
- Laser cladding process
  - Lower heat input versus GMAW – Less distortions
  - Smoot, flat, ripple free finish
- Zero failures in laser cladding (>3 years)
- Shop only application

IN-SITU Erosion Resistant Coating of Boiler Tubes in erosion prone areas near burners and wall soot blowers can help to increase overhaul intervals.
Water wall Bypass

- Used for Forced outages in External boiler walls
- Allows repair without entry into the unit
  - Avoids total cool down of the unit, de-slagging, scaffolding / pick installation etc.
- Quick Repairs
- Requires Custom Socket welded couplings
DETECTION OF EXFOLIATED SCALES – JAPANESE EXPERIENCE

**Inspection of SUS scales**

- Oxide scale of austenitic steel tubes of SH & RH exfoliates during long term operation and chokes the inside of tubes at bends.
- SUS method uses magnetic probes & detects magnetic scales inside the nonmagnetic boiler tubes on the principle of induction.
- Measurements in Platen SH / RH coil bends were demonstrated at Singrauli & Unchahar during a study with Japanese Study Team.
- Distinct advantage - Safe & Speedy detection.
IN CONCLUSION

- New technologies, although established worldwide, need to be proven for Indian environment.

- Focus on skill development of O&M personnel including simulators training and specialised trainings on welding, water chemistry etc.

- Concerns related to use of advanced alloy materials, welding techniques, equipment reliability, new controls etc. need to be addressed by all utilities proactively.

- The experiences by utilities can be shared to build on each others’ learning and improve the learning curve.
CONCLUSION & CONSTRAINTS

- Currently, USC power plants with steam conditions up to 30MPa, 600°C / 620°C have been matured and become high efficiency commercialized technology.

- This is indicating that SC & USC coal fired power plants will have broad prospects of development in this century, and in conjunction with conventional desulphurization and denitrification further perfected, will still combine to give high efficiency and clean coal firing power generation technology.

- Outlook for coal based SC & USC power plant technology is very positive and its further growth lies ahead. Intensity of this growth will depend on the following major factors:
CONCLUSION & CONSTRAINTS

- On a worldwide basis, the prospect for SC & USC technology is extremely good, esp. in rapidly developing markets like Asia.

- Several Asian countries using coal for base load power generation (e.g. Japan, China, India, and South Korea) have already large manufacturing capacity in the components common to conventional and SC units and are now intensifying the existing or building up new capacity in those components that are specific to supercritical technology.

- SC power plants have attained similar or even higher availability factor as conventional power plants.

- It is generally considered that SC power plants will have about 2-3% and USC about 3-6% higher efficiency than conv. power pl.

- If conventional 5GW power generation capacity is replaced by SC or USC technology, between 1 and 2 Mio tons of coal can be saved ever year (approximately 30-60Mio USD/Year).
CONCLUSION & CONSTRAINTS

- Even if construction of an USC power plant costs around 10% to 15% more than a comparable-scale conventional power plant design, the additional expense is more than offset by fuel savings.

- Evaluations have concluded that the capital cost of the boiler and ST in an USC power plant can be up to 50% higher than conventional components, and the USC power plant will still be cost-competitive, this means that the Life Cycle Costs of SC & USC power plants are lower than those of conventional plants.

- SC & USC power plants can maintain relatively high efficiency at rather low load.

- There are no operational limitations due to SC & USC once-through boilers compared to conventional drum type boilers. SC & USC power plants have better operational dynamics. i.e. their ramp rates are higher, namely 7-8%/min compared to about 3-5%/min for conventional units at higher loads.

- Once-through boilers do not have a boiler blow-down. This has a positive effect on the water balance of the power plant with less condensate needing to be fed into the water steam cycle and less waste water to be disposed of.
CONCLUSION & CONSTRAINTS

- If SC & USC power generation technology is to become one of the preferred choice in new power plant construction, it has to become economic against the alternative technologies such as subcritical coal-fired conventional power plants and NG-fired CCGT power plants.

- Advanced austenitic stainless steels for use as superheater and reheater tubing are available for service temperatures up to 650°C and possibly 700°C. Ni base superalloys would be needed for higher temperatures.

- Ferritic materials will be replaced by nickel-based superalloys for USC applications as steam conditions are increased. This changeover point is an issue still to be resolved.

- Better understanding of maintenance needs of the USC boiler & ST and related auxiliary systems is essential for long-term, reliable operation.
THANK YOU

FOR YOUR ATTENTION

ASHOK SARKAR
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<table>
<thead>
<tr>
<th></th>
<th>once through</th>
<th>natural circulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>pressure</td>
<td>not limited</td>
<td>&lt;190 bar</td>
</tr>
<tr>
<td>supercritical design possible</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Life steam temperature (LST)</td>
<td>not load dependent, depends only on ratio feedwater / firing rate</td>
<td>with lower loads ratio of evaporated steam to superheated steam increases</td>
</tr>
<tr>
<td>over load</td>
<td>spray attemperator over load constant</td>
<td>high need of spray attemperators, special heat exchangers or flue gas recirculation to adjust LST over load</td>
</tr>
<tr>
<td>Reheater temperature</td>
<td>decreases with lower loads</td>
<td>decreases heavily with lower loads</td>
</tr>
<tr>
<td>Maximum capacity</td>
<td>no limits like drum size</td>
<td>limited by drum size</td>
</tr>
<tr>
<td></td>
<td>once through</td>
<td>natural circulation</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>---------------------------------------------------</td>
<td>---------------------------------------------------</td>
</tr>
<tr>
<td>Variation of calorific value of fuel</td>
<td>could be influenced by adjustment of ratio fedwater / firing rate</td>
<td>higher cv leads to lower LST due to higher heat consumption in furnace</td>
</tr>
<tr>
<td>Higher furnace outlet temperature due to fouling, fuel variation or too high air ratio</td>
<td>higher reheater spray</td>
<td>higher superheater and re heater spray and higher material temperatures of high pressure part</td>
</tr>
<tr>
<td>time for start up</td>
<td>shorter governed by thich walled components</td>
<td>longer governed by drum and natural circulation super heater and re heater temperature decrease with lower load</td>
</tr>
<tr>
<td>Temperature behavior</td>
<td>decreasing re heater temperature with lower load</td>
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COLD START UP OF ONCE THROUGH & NATURAL CIRCULATION BOILER
### ONCE THROUGH & NATURAL CIRCULATION CONTROL BEHAVIOUR

<table>
<thead>
<tr>
<th></th>
<th>Once Through</th>
<th>Natural Circulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sliding Pressure Operation</td>
<td>Possible</td>
<td>Not Possible</td>
</tr>
<tr>
<td>Allowed Pressure Drop</td>
<td>Higher (20-30bar)</td>
<td>Lower (5-10bar)</td>
</tr>
<tr>
<td>Storage Volume</td>
<td>Smaller</td>
<td>Larger</td>
</tr>
<tr>
<td>Feed Water Necessities</td>
<td>Full desilinated water, condensate treatment recommended</td>
<td>Above 120 bar same purity as for once through boiler</td>
</tr>
</tbody>
</table>
AVERAGE STORAGE CAPACITY OF ONCE THROUGH & NATURAL CIRCULATION BOILERS
SWOT Analysis of Supercritical & Ultra-Supercritical Power Plants

Strengths:
- High Thermal Efficiency
- Environment Friendly
- Significant breakthroughs in R&D
- Lower fuel cost per unit of power
- Run-of-Mine Coal can be directly used
**Weaknesses:**

- Materials Limitation
- High levels of corrosion
- Increased supervision and maintenance costs
- Limited scope for retrofitting opportunities
OPPORTUNITIES:

- Vast Scope for Power Plant capacities based on Supercritical Technologies
- Ever increasing demand for power
- Optimum use and higher dependence on domestic sources of energy
THREATS:

- R&D setbacks will restrict the growth
- Fossil Fuels are likely to be exhausted in not too distant a future
- More stringent environmental regulations
- Development of cheaper and more efficient sources of energy
Magnetite layers are generated in evaporator tubes by alkaline water treatment. Magnetite forms rippled covering layers.

In the water phase of a boiler the upper coarse crystalline magnetite layer is forming above a certain velocity: the so called ripple surface roughness which causes an increased pressure loss. Preconditions are pH-values of ~ 9 and a water temperature of app. 300°C.

At the metallic surface 2 reactions can be observed:

a) Crystallites of the steel are transformed topotactical to $\text{Fe}_3\text{O}_4$:

$$ 3 \text{Fe} + 4 \text{H}_2\text{O} \Rightarrow \text{Fe}_3\text{O}_4 + 8 \text{H}^+ + 8 \text{e}^- $$

b) Bivalent iron ions are dissolved:

$$ \text{Fe}_{\text{met}} \Rightarrow \text{Fe}^{++} + 2\text{e}^- $$

Formation of the magnetite layer
“Ripple surface roughness” - Influence of Water Treatment on Boiler Pressure Loss (100% Load 400 MW)

By changing from alkaline to combined water treatment the ripples can be smoothened in 1 to 2 years.

Microcrystalline hematite is covering the coarse crystalline magnetite structure.

A faster decrease of the pressure drop could be achieved by pickling (acid cleaning).

Continuation of the alkaline water treatment results in formation of new ripples shortly.

K4 to K6 No. of boiler
AF AWT (alkaline water treatment)
KF CWT (combined water treatment)
During the steam production in the drum(s) the ammonia-content of the drum water decreases as well as the pH-value.

To reach a sufficient pH-value to protect the material against corrosion, a solid alkalizing agent like sodium hydroxide or sodium phosphate has to be added.

The different conditioning treatments are possible as described for once through boilers.

The control technique for a sufficient dosing is possible by pH-measurement and phosphate-analyses.
WATER TREATMENT NEUTRAL CONDITIONING
(WITH OXIDIZING AGENTS)

<table>
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<th>pH-range 7-8</th>
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</thead>
<tbody>
<tr>
<td>NH₃-amount average 0.01 mg/l</td>
</tr>
<tr>
<td>O₂-content &gt; 0.05 mg/l</td>
</tr>
</tbody>
</table>

Advantages of the combined conditioning

By the oxygen dosed there is a neutral operating characteristic and therefore there is no ammonia corrosion on brass pipes.

High service life of the condensate polishing plant, because of the absence of ammonia on the cation exchange resin.

Simple control technique for the dosing of oxygen (normally no dosing and control of ammonia necessary).

Disadvantages of the combined conditioning

There is a risk that the unbuffered feed water or condensate input of carbon dioxide of cooling water leads to a reduction of the pH-value. This results in an erratic increase of the corrosion velocity.

Another disadvantage is the 10 times higher corrosion of copper based alloys.
WATER TREATMENT - ALL VOLATILE TREATMENT (WITH ALKALIZING AGENTS)

Advantages of the all volatile treatment

Reduction of the corrosion rate at metallic material by increased pH-value of the condensate up to 9.4. Formation of a magnetite protection layer at the inner side of the tubes and reduction of the corrosion rates.

Simple control technique for the dosing of ammonia (volume-dosing dependent on the water-/steam flow rate and controlled by conductivity).

First dosing point after condensate polishing plant, corrected by a second dosing before feed water-pumps.

Disadvantages of the all volatile treatment

With changing temperature the grade of dissociation of ammonia solutions decreases according to $\text{NH}_3 + \text{H}_2\text{O} \rightleftharpoons \text{NH}_4 + \text{OH}$ and also the pH-value decreases.

The service life of the condensate polishing plant is low because of the dosing of 0,7 mg/l condensate. This results also in higher costs for treatments of this effluent.

The optimum protection of the preheater with ferritic steel piping is reached only at high ammonia concentrations ($\text{pH} > 9,4$). Because of the high ammonia concentration in the steam brass condenser pipes are affected in the area of air exhaustion.

Risk of ripple roughness.
Advantages of the combined conditioning

Formation of a hematite protective layer on the magnetite. Therefore a reduced increase of pressure losses in the evaporator because of smoothing the ripple roughness with hematite.

The condensate polishing plant has an 3 - 5 times higher service life. The costs of chemicals for regeneration are reduced to 1/3 - 1/5.

Lower Costs for treatment of regeneration - effluents.

Disadvantages of the combined conditioning

The stability of wear-resistant alloy of the stellite type decreases after dosing of oxidizing agents (e.g. at the minimum-flow control valve of the feed water pumps and the corresponding spool valves).

An increased control technique is necessary for the combined dosing of oxygen an ammonia.

\[
\begin{align*}
\text{pH-range} & \quad 8-9 \\
\text{NH}_3\text{-amount average} & \quad 0,2 \text{ mg/l} \\
\text{O}_2\text{-content} & \quad 0,03 - 0,150 \text{ mg/l}
\end{align*}
\]