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Increasing boiler super-criticality – end user's understanding of process and design issues crucial

Introduction

Supercritical technology which saw first installation about six decades ago is considered largely mature with over 1000 installations globally. However, large number of water wall tubing failures and consequent replacement of full water walls in recent European/Chinese ultra-supercritical builds is a reminder of the soft underbelly of the technology as it has already seen one reversal in the 1970s.

NTPC has been quite mindful of such issues since the 1980s and it gets reflected in NTPC's differentiated engineering treatment to the extent that the evaporator design experience for supply of supercritical boilers is considered for supplier's qualification. As Indian industry endeavours increasing supercriticality, the process/design as well as material selection elements of the overall boiler design continue to require the age old end user's focus.

The crux of technology for a supercritical boiler remains its thermo-hydraulic design of the evaporator and mechanical design of the water walls. However, the importance of integrated development of thermal/mechanical design of heat exchangers like economiser, superheater and reheater for achieving good operational response from the boiler is imperative and cannot be overstated. In Indian situation the importance gets amplified as Indian coals characterise uniquely in terms of their burning profile, high ash content of highly erosive ash etc. The requirements have become only more exacting as very low levels of NO_x through primary means are now being targeted.

The paper discusses some 20 key design elements of which the end customer must tie-up with the supplier while setting up new supercritical boilers. The discussion reflects NTPC's experience beginning from setting up its first once-through subcritical boiler at its Talcher-I unit leading to its first supercritical unit at Sipat and its recent ultra-supercritical units. The experience is as well being channelled to the development of advanced-USC boiler in the Indian AUSC programme for which NTPC is one of the consortium partner.

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Supercritical technology evolved to acquire a large global foot print.

With over 1000 units already operating globally, supercritical technology represents a fairly established technology. A large base of units with conventional parameters around 250 kgf/cm^2 540°C/540°C was established in the early decades. There has been explicable impetus to increase the steam parameters in the meanwhile. Many units with steam parameter over 600°C (popularly referred to as ultrasupercritical) have been established in the last two decades.

The recent focus on large coal units with USC parameters in many ways can be attributed to the clean coal focus in the light of the global climate action as also as a replacement to nuclear units in many countries. The approach has seen targeting of ever higher efficiencies by establishing power plant technology operating at 700+°C parameters. The programme was first initiated by European Union in late 1990s and was later followed by similar programmes in the USA, Japan, China and India.

Supercritical technology has had its share of setbacks and even one reversal

Supercritical units saw first installations in the 1950s in the USA. This was a major shift, after a series of developments in the boiler design that largely took place in the preceding 2 centuries. The key here was once-through nature of water-flow as against drum type conventional boilers.

With increasing steam parameters – around 180 kgf/cm^2 – it is no longer possible to separate steam and water, hence drum type boilers are not suitable for supercritical plants. The

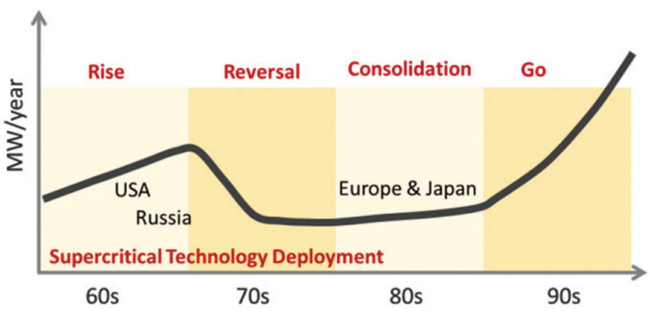

Fig.1: SC technology deployment cyle

boiler that emerges has once through circulation system (water to steam formation takes place in one go without any circulation in between).

It is interesting to note that the early supercritical units used steam pressure around 300 kgf/cm^2 and temperatures around 600ºC whereas the contemporary sub critical plants were typically only at about 80 kgf/cm^2-500°C/520°C. The pioneering spirit of the engineers is indeed notable who attempted quite a steep jump. As a result, the 1960s saw installation of series of large supercritical plants in the United States.

Of the nearly 11,000 MW in large units committed by U.S. utilities in 1962 and 1963, 70% were designed for supercritical steam pressure with either single or double reheat. The boilers used in these plants were universal pressure boilers (UP type boilers) wherein pressure of the evaporator is kept constant by placing a valve between the superheater and evaporator.

These boilers of 1960 vintage started to experience number of operational issues. These were metal fatigue and creep, and scale deposits from boiler walls induced greater corrosion and erosion damage in the boiler, turbine nozzles, and other parts of the plant. As a result, the availability of these plants dropped and they became costlier to operate. The root of many issues lay into use of austenitic steels which have a high coefficient of expansion – a simple fact which was insufficiently recognized at an stage which could be termed as pre-martensitic steels period.

The inability at that time to improve the metallurgy of boilers and turbines led the utility industry to retreat from supercritical units to the more reliable subcritical units. By the early 1980s, however, supercritical boiler technology was essentially abandoned in the U.S., with subsequent new plants reverting to less efficient subcritical units. [1]

The supercritical technology development arena then shifted to Europe (particularly in Germany) followed by Japan. The Europeans (Benson/Sulzer designs) initially tried designs similar to UP types but soon adopted the design having spiral wound water walls. Around the same time Russians (Taganrog and Podolsk works) independently developed their design somewhat similar to the American concept. The Japanese (Mitsubishi, IHI, Hitachi) initially developed on designs borrowed from the Americans then switched to the European concept. They eventually focused on developing their own design with vertical rifled tubing (by MHI) with an eye of large rating units. The 1990s can be termed as the decade of full return of supercritical technology.

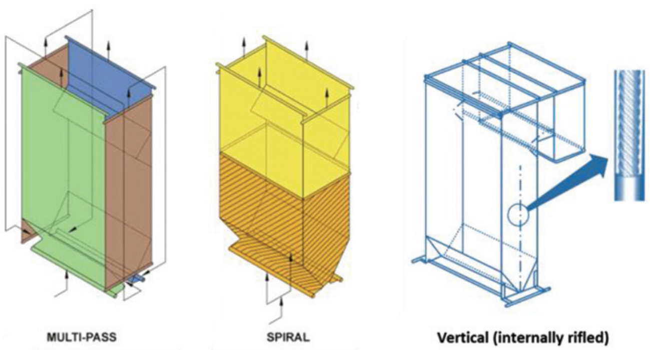

Fig.2: Three concepts evolved in the industry- vertical smooth tubing, spiral smooth tubing and vertical rifled tubing

The natural progression to ultra-supercritical in the decade of 2000s however soon became stony. The USC (600ºC) units planned in Europe again witnessed serious setback. This time around the water walls have been at the eye of the storm. Several welding failures were observed while commissioning of power plants being commissioned in Europe (primarily Germany as also Netherlands, Czech Republic etc.). The first such plant was Steag owned Kraftwerk Walsum in Germany. The commissioning was started in 2010 while actual commercial operation could start only in 2013 as complete water wall had to be replaced.

The problem arose due to use on T24 steels in water walls. These steel were originally developed form embrane water walls. Accordingly, no preheating and post weld heat treatment (PWHT) was supposed to be required by the material. However analysis for weld failures indicated, that the damage mechanism is characterized hydrogen induced stress corrosion cracking (SCC) caused by combined influence of tensile stress and a corrosive environment. Hence it becomes necessary to relieve stress through PWHT, among other interventions.

Solutions adopted by various utilities include optimized chemical cleaning, modified start-up procedure, replacement of full T24 sections of the wall by panels made of another proven DIN steel (corresponding to T12); modifying the flow scheme of the boiler such that the upper walls are arranged as superheater and not as evaporator heating surface; Heat treatment at 450°C to 520°C of the complete boiler with external burners [2].

Age old end user s checks are essential when increasing supercriticality

The setbacks to supercritical technology are a reminder to the involved design complexities of a coal fired boiler which normally go to the background as equipment start operating on routine basis. However, the importance of certain basic checks by the end user as in defining the operational ambit and checking the suitability of offered designs remains as important as ever. Such checks especially become important when design/material changes are made or the equipment needs to operate in new operating environment.

NTPC has been quite mindful of the technology design and process issues while inducting its own supercritical fleet. Talcher-I became the first once-through boiler installed by NTPC. It became the harbinger for understanding the nuanced reality of such designs. As a result holistic technology induction studies were in fact initiated in the 1997 when NTPC started looking seriously at the option. These studies which included technology scan, dialogue with almost all OEMs globally, visits to supercritical plants in Japan/Europe/USA for 1st hand operational feedback, international expert inputs etc. One key differentiator is visible in the evaporator design being selected as a focus for supplier qualification during boiler procurement.

NTPC has been spearheading supercritical technology induction in power plants as a part of its clean coal focus aimed at higher unit efficiencies. Presently the company has 10 supercritical operating units with combined installed capacity of 6880 MW. Further 27 units with 19800 MW capacity are under different stages of construction.

The focus has only been reinforced during with the engineering experience gained from dealing with all the major supercritical boiler OEMs. NTPC is perhaps in a unique position where-in it has engineered boilers from all the major boiler OEMs. The experience is as well being channelled to the development of advanced-USC boiler in the Indian AUSC programme for which NTPC is one of the consortium partner.

Such experience in respect of boiler design/engineering represents a continuum, however, it can also be seen as discreet issues. These flags can be gainfully utilized by end customer's as leads in tying up with the boiler supplier. In any case these leads cannot be used on 1:1 basis and would require examining of the design proposal and operating scenario at hand.

Flags which need to be tied-up with the supercritical boiler supplier's

The following represents key elements of supercritical boiler design which end customer must consider while setting up new supercritical boilers. Most of the points need to be segmented w.r.t. level of detail of ensuing actions. These will get divided for tie-up with the supplier as part of tender specifications or as part of pre-award design tie-ups (points specific to OEM design) or at the detail engineering stage. The issues covered here pertain only to the main boiler and do not cover the auxiliaries as these do not directly get impacted by the supercriticality. The 20 odd points enumerated hereunder when appropriately detailed out will develop into a full engineering programme for the boiler but shall be justified many times over in terms of their value to operational response and operating reliability of the supplied boiler:

Restrict evaporator degree of superheat to about 15°C

The degree of superheat (i.e. the temperature above the saturation temperature) at the outlet of evaporator should be limited to about 15°C at the lowest once though load. The degree of super heat at minimum circulation flow is an essential check point as higher degree of superheat results increase in tube-tube temperature differentials at the end of the evaporator (end of spiral and end of vertical tubing). Such differentials when they go beyond 50°C is a matter of concern. Attempt is made at design stage to minimise such temperature differential which requires deeper understanding of the evaporator design elements.

The complete water walls of supercritical units in India supplied by various OEMs have been designed as evaporators barring the MHPS supplied boilers in which the complete furnace containment (1st pass) and the convective section containment (2nd pass) are designed as evaporators.

With increasing super criticality there is an increase in high pressure circuit super heating and reduction in heat input fraction of evaporation. Since furnace containment is determined by fuel properties, higher steam parameters (essentially pressure here) inevitably result in higher degree of superheat at evaporator exit. One of the solutions adopted for USC boilers in European boiler OEM's is configuring part of the water wall (till intermediate header where spiral tubing ends) as evaporator while the rest acts as a super heater. The intermediate header therefore becomes the off- take point for steam. This requires four number of additional headers at the water walls. This practice has been in vogue for lignite fired SC/USC boilers as these have a very large furnace containment and hence heat capture.

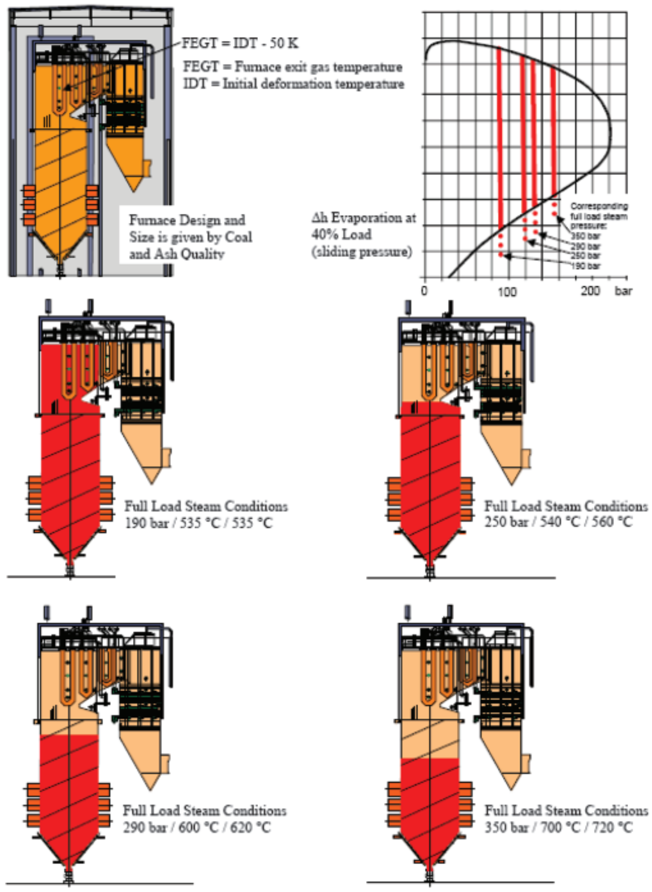

Fig.3: Increasing steam conditions leads to different evaporator design [2]

Water wall tubing thickness should be focused if higher than 6.3 mm

While reviewing the water wall design waterwall tubing thickenss must be a key check. Traditional German practice has been to limit the water wall tube thickness to 6.3 mm as stipulated in the Section 12 of TRD 301 for its once through boilers. All the water wall performance protocols were designed taking this into consideration. With increase in boiler steam parameters the water wall design temperatures also increases. Choosing a higher wall thickness for these is not considered as a good design solution as the baseline thickness value has matured for tube-fin system over long period of time. For the USC fleet, in absence of superior material options, the European OEMs settled for 7.1mm. The same was carried out with changes to the cooling mass-flux which is integrated to the tube thickness. Crossing such proven tube thickness threshold need to be carried out with utmost caution. The OEM need to be asked to provide detail calculation for tube metal temperatures over different operating loads along-with justification for such selection.

Water wall material should not require PWHT

In a modern boiler, the membrane water walls together with buckstays form a monolith design. These are also heavily loaded with self-weight, burners, wind-box/duct, wall blowers, ash in furnace hopper etc. Such a 2-diemnsional system tends to accumulate stresses when it is locally heated due to distortion/warping which is quite indeterminate due to nature/complexity of load distribution. As a result it has been a practice in the boiler industry to select water-wall materials that do not require post weld heat treatment (PWHT).

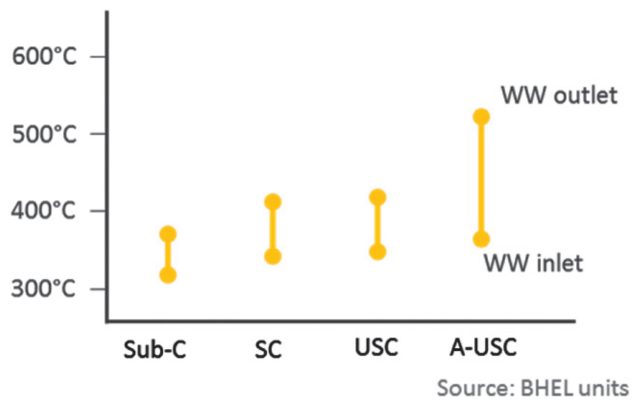

Fig.4: Water wall fluid temperatures for boilers with different operating parameters

The requirement was never an issue with sub-critical boilers as metal temperatures are in sub 400ºC range allowing carbon steels (SA210 gr. C typically is used) to be used for tube-fin system. For once-through boilers, the temperatures were higher due to boiling crises around the dry-out point, low alloy steel sufficed for subcritical boilers. For supercritical boilers (water wall outlet temperature about 420°C) higher grades like T11, T12 worked well for many decades. As USC boilers were planned in Europe, T24 was developed (also T23 which is considered an improvement) with expectation of higher creep strength without any need for PWHT. This to improve water wall temperature limits by 50 to 70°C. The same was accordingly applied to the European USC fleet. The realization that T24/T23 do require PWHT has put these units and further USC programme onto a stony road.

The water wall material availability is today identified worldwide as a major challenge in the development of USC/AUSC technology. Many of the European boilers have replaced water walls by their proven DIN materials corresponding to T12/T22. The change however had to be done by tuning boiler performance. In China replacement material is of indigenous origin. Paralely, many OEM's have started looking for innovative PWHT methods which could be applied to water walls in-situ with minimal residual stresses.

The recent experience need to be taken in perspective to avoid knee-jerk reactions. While material selection for water walls need to look for options which do not require PWHT, options for limited area of panels could be attempted in consultation with the supplier. Additional warrantees and an observation plan for initial years could be tied up. Segmented water walls having two or more materials is another option. Methods to reduce furnace temperatures and water wall

Table 1: Available materials for waterwalls [2]

	100 MPa (1) creep rupture Strength at [ºC]	Δt_{TRD} [K]	Max. fluid temperature [ºC]	Approved by
T12 (13Cr.Mo44)	515	50	465	ASME/DIN
T22 (10 Cr.Mo9-10)	520	50	470	ASME/DIN
T24 (7Cr.MoVTiB1010)	575	50	525*	DIN
T23 (HCM2S)	580	50	530*	ASME
T91(2)	590	50	540**	ASME/DIN

1) Standard value for streem pressure at turbine inlet of about 250 bar

2) Post-weld heat treatment necessary

* For T23/T24 limited to 500ºC because of steamside corrosion

** For T91 limited to 530ºC because of steamside corrosion tubing temperatures need to be considered. The latter is an important step. Accurate tube metal temperature calculation is a must to do away with unnecessary margins. The requirement however do not apply to free panels (like for a super-heater).

Cyclic loading and start-up capability need to be clearly defined and its impact on design features checked

Increasing supercriticality translates into increase in pressure parts thicknesses. The higher pressures and fluid temperatures call for increased thicknesses as material options are generally limited and designer tend to restrict themselves to familiar material grades (also a desirable factor w.r.t. OEM's sourcing/manufacturing arrangements). For the higher supercritical and ultra-supercritical steam parameters the thicknesses of headers/tubing generally require attention w.r.t. creep-fatigue life. The issue is linked to thicknesses as well as zones of stress concentration. For achieving sound operational reliability it is important to focus on the aspect in terms of defining the operating life, expected start-stops, load cycling and load ramp rates. Preferably, calculations need to be sought from the supplier which are generally based on standards like TRD (Technical Rules for Boilers as developed in Germany).

NTPC has been specifying number of start-ups as well as ramp rates to improve the responsiveness of the units to grid requirements. The plant is required to be designed for cyclic/ two shift operation and should be able to sustain about 4000 hot starts (start after 8 hours of unit shutdown), 1000 warm starts (start after 36 hours of unit shutdown) and 150 cold starts(start after 72 hours of unit shutdown).

Ramp rates are generally governed by thick components (to avoid thermal fatigue). Super critical boilers have inherent advantage over the sub-critical as the thickest components in sub-critical units the boiler drum is replaced with multiple separators having lower thickness. Also sub-critical units (drum type) have fixed line of evaporation which create distortions in heat pickup impacting the SH/RH tube metal temperatures/spray levels. There are other requirements as in bigger size vents/drains due to rapid start-up and ramping requirements as unit takes part in grid load cycling.

Cyclic loading capability has been accorded increased focus during engineering in view of the increased renewal influx into the grid. The boiler suppliers are asked to perform the start-up and cyclic loading calculations (as per EN code 12952) to demonstrate the compliance of the offered boiler design w.r.t the specification. As a general principle the reducing the thickness of the components as well as adopting manufacturing practices like full penetration welds for pressure parts improve the behaviour of components due to cyclic thermal stresses.

Water wall mechanical design should be checked at buckstay support points

In a vertical water wall boilers the self-weight of the membrane walls and bottom ash load, which is applied axially, is carried by the vertical tubes before transferring the load to boiler structure at the top. The load due to flue gas pressure (explosion or implosion) is taken up by the buck stays. The inclined tube arrangement as in a once-through boiler however cannot take the vertical self-loads. This leads to excessive stresses at the tube-fin weld joints. For the spiral wall a system of vertical straps is therefore used – which are welded to the spiral wall. The water wall spiral cage load gets transferred to the upper cage (which has vertical tubing arrangement). These straps are connected to the spiral membrane on the fins through brackets (on multiple point for each support). These support points become points of very concentrated loads.

The temperature differentials between the wall tubes and straps during start-up and shut downs cause secondary stresses due to restrained thermal expansion. This impacts the start-up times particularly the cold start-up times. However thus far this is not the governing factor (or has been contained by means of proper support designs) in the present current supercritical units. As we increase the supercriticality, high steam parameters will increase the tube material weight as a result of the higher wall tube thickness. The water wall design therefore need to consider these secondary stresses in addition to the internal pressure.

Ash loading for furnace hopper should be defined owing to limitations of a spiral wall

The spiral arrangement limits the ash load carrying limitation. As the vertical load increases the thickness of the plates (and welds) which attach the spiral cage to vertical cage increases. This limits the cyclic loading response to limit the stresses on these zones during start-up and load change. For Indian situation this becomes more important as the furnace hoppers need to be designed for certain amount of ash loads a value which could easily cross 1000 tonnes, traditionally opted by many lignite fired boilers.

In line with the limitation water wall mechanical design which considers ash load equivalent to bottom hopper fully

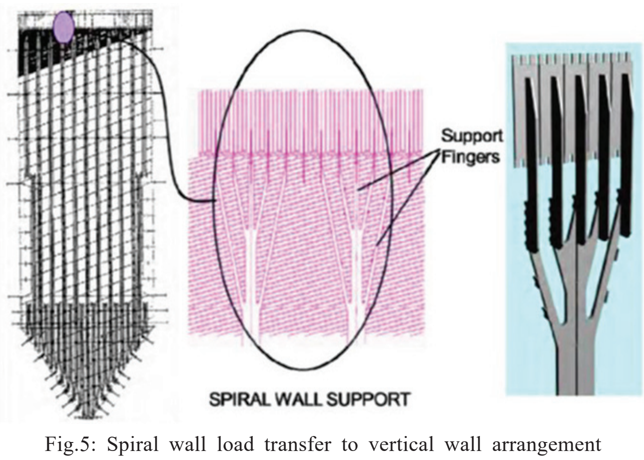

Fig.5: Spiral wall load transfer to vertical wall arrangement

filled for sub-critical units only considers half of this load for supercritical units in NTPC. As a compensatory step load cells are installed in the furnace roof enclosure to give indication of ash build up in the furnace bottom hopper. NTPC experience with various OEMs have indicated the requirement to explain the requirement as the OEMs are accustomed to design with far lower ash loads-like 500 MT ash load for coal fired boilers and 1000 MT for lignite fired boiler whereas for 660 MW Indian furnace it would be about 1800 MT (50% full of ash in terms of volume).

This is a design/cost intensive area and unless properly specified, clarified and tied-up with the supplier is likely to be missed out or avoided in the form of operational guidelines (which are difficult to adhere during clinkering)

Evaporator Stability Analysis (static and dynamic) should be carried out

Stability analysis is an important tool to assess the thermo-circulation characteristics of the evaporator for each of its circulation circuit. Stability of an evaporator is seen as static stability and dynamic stability. Concept of evaporator stability is linked to uneven heating of different circuits and difference in pressure drops (due to different lengths as they envelope openings for burners, wall blowers etc.). Under certain operating conditions there could be flow fluctuations and even reversals. This phenomenon is evaluated under dynamic stability. Also the flow conditions lead to tube-tube temperature differentials which are important from membrane reliability standpoint. This is evaluated as part of static stability.

Static stability is of particular interest to coal fired boilers. Static stability is used to establish the impact of change in heat flux and mass flow on the pressure drop. One of the outputs of the static stability calculations of particular interest for the end user is the calculation distribution of tube outlet temperatures at spiral evaporator outlet. In the pressure design of the spiral evaporator openings for burners, over fire air, manholes and others lead to different tube lengths and a different number of bends in the tubes. Thus the pressure drop of every tube is different which leads to different mass flows and therefore to different enthalpies and temperatures at the outlet. Additionally the heating is not equal for every tube. The investigated tube-tube temperature difference should remain within about 40°C while temperature of candidate tubes remains within about 50°C (preferably within 30°C) of the average of tubes outlet temperatures.

The practice of performing stability varies with the various OEMs. Some perform it for all the steam generators while some carry out only when a major changes are envisaged in the boiler. Owing to unique fuel characteristics which are typical of the Indian coals NTPC has been asking the boiler suppliers to perform stability analysis. The requirement is also warranted as some of the data inputs required for stability analysis is still not available for Indian boilers.

Stability analysis is an specialized area even for the boiler OEMs. The protocols and data development was carried out in Europe largely by Sulzer and Siemens. Many of the developments were in response to issues observed in early once-through units. The know-how travelled with collaborations first to the USA and then to Japan. The way it evolved today the industry to industry is broadly divided into Sulzer design (Alstom/GE, BHEL etc. being licensees or adoptees) and Siemens (most of the OEMs are collaborators e.g. Foster Wheeler, HPE/MHPS, Doosan etc.).

Large number of thermos-couples should be provided to measure evaporator outlet temperature

The outlet temperature of the evaporator tubes is an element of central importance in the design of water walls of once-through steam generators as it is directly linked with the operating reliability of the water walls. This gains further importance as furnaces are relatively larger resulting in higher evaporator exit superheat. NTPC as a part of its technical specification require boiler supplier to provide 100 numbers of thermocouples for continuous monitoring of water wall tube metal temperatures. These are considered sufficient for operating the units. However, any generating company with fleet ambitions on USC AUSC units, it can be useful if the wall temperature lessons are fed back to the next unit design/ engineering. This requires much higher numbers of thermos-couples to generate data good enough for design purposes.

Interaction with various OEMs indicate varied practice however there is a consensus that any new design should be verified by field testing of water wall tube temperature measurements for all the tubes atleast during unit commissioning. With this understanding, mapping of the complete water wall temperatures at one of the supercritical units is being considered as a part of the AUSC technology development project. Similar requirement put in the specification for newer fuels shall definitely be beneficial to the user.

Furnace containment size should be limited to the minimum requirement determined by type of coal

The furnace cross section is decided based on the fuel slagging characteristics while the height of the furnace is defined provided for sufficient absorption of energy so that the flue gas exiting the furnace does not cause slagging in the convective section. While adherence to minimum furnace size requirement arising out of coal characteristic is essential, oversized furnaces should be avoided for supercritical boilers. The large furnaces result in higher evaporator exit super-heat which creates thermal issues as well as material requirements and also adversely impacts the heat recovery in the convective section.

NTPC presently limits the furnace exit flue gas temperature (FEGT) at 60°C lower than the Initial deformation temperature (IDT) of the ash for the specified coal. The FEGT limit can be increased with improvement of end user confidence in the slagging character of the fuel intended to be fired. Longer term linkage could be helpful especially if feedback from earlier units on similar coals (wherein controlled measurements have been made) on their slagging propensity would be of help. This would result in a reduction in the water wall steam exit temperature due to improved evaporator stability.

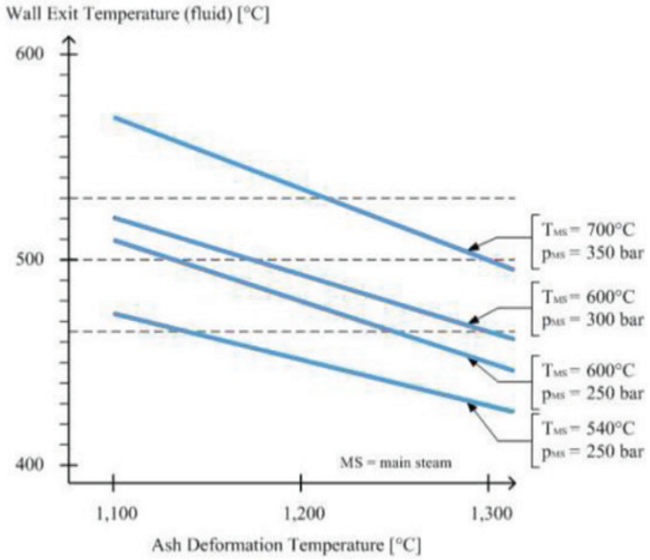

Fig.6: Impact of ash deformation temperature on water wall exit temperature. Figure is adapted from [2]

Furnace heat flux measurements need to be carried out to furnish coal specific values to the OEM

The furnace heat flux values form an essential input for the evaporator design. Heat flux distribution depends on a number of variables burner arrangement, fuel characteristics and firing rate, furnace size, etc. wherein burning profile of coal remains the most important. So far no measurement has been made on Indian boilers to measure the heat flux accordingly OEM's use values which have been obtained from units abroad. NTPC specified heat loading values are used to tune the numbers.

These values are generally integrated into the proprietary thermo-circulation calculations based on earlier measurements and experiences. The general practice with the OEMs is to map the flux distribution whenever a major change is being envisaged in the boiler design to validate the predicted values. A competitive era and also short timelines restrict any effort by the OEM to measure these values afresh for new fuels. Hence this must be essentially carried out as a pre-competitive work. Such measurements done by inserting metal thermocouples (similar to the ones used for smart soot blowing) can be useful while establishing boiler with a new fuel like lignite or shifting to higher parameters. Such measures are also being proposed as a part of the Indian AUSC programme.

Water wall design temperature should be adequately address the differential between the fluid and mid wall tube temperature

Various OEMs through their design protocols consider certain temperature margins in water wall design to account for the differential between the fluid temperature and the mid wall metal temperature of the tube. Calculation in certain cases by some OEMs have shown that this temperature differential can be as high as 90°C for some of the firing conditions at the high heat flux burner zone. The design temperature for tubes is considered based on such first principle calculations by OEMs. It can be observed that safety codes do not adequately cover these temperature differentials. The design margin of 50°C specified in the European code. As a basic design requirement NTPC specifies an additional 40°C temperature margin over and above margin specified by IBR for design of water walls. End user must check the adequacy of design margins considered for the water wall temperature with specific focus on the high heat flux zone in the burner areas.

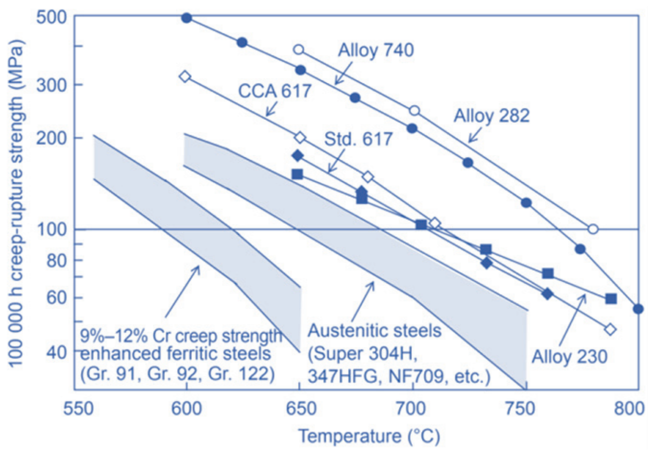

Fig.7: 100,000h creep-rupture strength of some Ni-base superalloys, together with 9%–12% Cr creep strength enhanced ferritic steels and austenitic steels, as a function of temperature. [3]

SH/RH tubing material may need to consider higher Chromium austenitic steel or Inconel for 600°C boilers considering fuel characteristics

For design metal temperatures up to 600°C martensitic steels have been applied in supercritical boilers however for tubes designed at higher temperatures austenitic steels are required. In addition to the creep strength requirement other critical properties determining the material selection for these sections is the resistance to corrosion as wells as steam side oxidation. Thus far austenitic steels like TP 347H (FG) and Super 304H (FG) have been used in the high temperature section of SH/RH for Indian boilers. However fuel characteristics considerations particularly chlorine content may require usage of higher chromium austenitic stainless steels or even Inconel tubing in the final sections of the SH-RH tubing. Final sections of SH and RH in Neurath USC lignite fired boilers are made of HR3C (25% chromium steel)[4]. Last portion of the final section of RH section at Walsum USC boiler is made up with Inconel tubes.

Water quality control is necessary to avoid SCC in austenitic steels

Austenitic steels are employed in high temperature section of superheater and reheater sections. These steels are prone to chloride stress corrosion cracking (CLSCC). Hence water quality control becomes essential to avoid tube weld failures. The feed-water quality is normally monitored and controlled as per standard norms during normal unit operation. Additionally the DM water should be used for along with monitoring for Chlorine should be used for hydro-testing at shop as well as site. These should be tied up with the supplier as a part of the quality protocol.

With increased supercriticality the organics present in the raw source water also need to become a focus. The organics on pyrolysis at high temperatures result into certainorganic acids, hydrogen, carbon-di-oxide etc. which could increase SCC occurrences. Controlling and monitoring of TOC (total organic content) in hence becomes essential. The committee of the Indian AUSC consortium evaluating the water chemistry requirements for the AUSC plant is evaluating possible design options to cater to such organic presence.

Size of the economizer need to be optimized to minimum

Economizers in boiler help to increase the efficiency as it captures some of the flue gas heat after it has passed super heater and reheater tube bundles. The sizing of the economizer is determined by the heat duty ambit defined by final feed water (FFW) temperature and approach temperature. FFW is defined by the overall cycle considerations. With rise of turbine cycle efficiency there is a general rise of this temperature. Some USC units have used unto 340°C. A FFW temperature of around 250°C would be found on subcritical units while for supercritical units 300ºC is more common. Approach temperature is defined as the difference between temperature at economizer exit and saturation temperature at that pressure. The temperature difference is comfort against economizer steaming which is something normally avoided. The size of the economizer therefore generally gets restricted between these two limits. Within these limits also it is always better to evaluate the maximum size w.r.t. its impact of evaporator exit temperature. The steam temperature at evaporator exit may impact the boiler furnace roof temperature so much so that the selection of material gets impacted.

NTPC specifies 17°C as approach temperature at economizer outlet within the control range. This must however also be checked at minimum once through load.

A mechanical filter upstream the CPU reduces CRUD and improves OT response

Due to once through nature (no blow down – as there is no dirty water accumulation due to absence of circulation) superior feed water quality is needed.

Feed water chemistry regime used in NTPC super critical units is combined water treatment (CWT) i.e. oxygenated treatment (OT) in combination with ammonia to maintain alkalinity for normal operation while all volatile treatment (AVT) is used for start-ups. This is in line with the global practice. Oxygenated treatment (OT), is based on the theory that slightly soluble oxides adhered to the surface of steel can prevent steel corrosion and elute corrosion products into water [5].

OT approach is now fairly standard practice for once-through boilers globally. However, the excess CRUD levels have been reported during start-ups and during commissioning/re-commissioning of the units. While there are alternatives suggested like amine approach which brings out a completely different protective layer but such alternatives are yet to see any significant commercial application. Engineering solutions like improved materials in the condensate/feed circuit, filter have being utilized though.

A mechanical filter was specified in the North Karanpura USC units upstream of the CPU as it was felt that since the unit had air cooled condenser, the level of crud generated shall be higher and shall impact the performance of CPU. Based on performance feedback of OT from international units, the same is now been specified as a standard requirement for all the subsequent units.

Water wall tubing ID roughness need to be minimized

The mass flow in the water wall tubes is sensitive to pressure drop in the tube circuits in addition to the tube length and number of bends, the roughness of the inner surface of water wall tubes also a key contributing factor. The low roughness values leads to a lower frictional loss. In this regard cold drawn tubes are lower roughness as compared to the hot finished tubes.

Coal burner size need to be restricted to proven size only to avoid heat concentration

Heat flux distribution varies in a furnace with high values in the burner zone. In a once through boiler the uniform heat pick is essential to avoid higher levels of temperature differences among the tubes. A spread out heat input is beneficial for this. Hence coal burner size as well as its spread becomes important. In this regard NTPC limits heat input per burner to 750×10^5 kCal/hras well as the burner zone heat release rate to 1.9×10^6 kCal/hr/m^2 for consideration during furnace containment sizing. These values are based on its experiences in boiler performance while firing Indian coals.

Furnace hopper opening elevation needs to consider maintenance access

Indian coals are characterized with high ash content. Hence the bottom ash content is quite high. Further underground bottom ash handling system if found to have difficulty in its MRO activities. The furnace hopper opening elevation therefore should consider adequate space for over ground bottom ash handling system.

In the present Indian supercritical units bottom ash hopper requirement determines the furnace hopper opening elevation. A higher steam temperature for the AUSC boilers however reduces the temperature differential between the flue gas and steam. Hence heat transfer would require relatively larger superheater and reheater heating surface areas. Accommodating these in the convective pass (2nd pass) becomes determinant in fixing the furnace hopper elevation. This will require optimization of space between banks and also the tube bank depth.

Water wall thickness margins for corrosion with low NO_x burners should be taken with care

In an endeavour to limit the NO_x emissions from the boiler, air staging (i.e. creating a reducing environment around the burners zone by decreasing the combustion air through the burner and channeling the extra air through over fire air nozzles at an elevation above the burners. This while decreases the NO_x emissions however increases the corrosion in water walls. While providing for erosion allowance for water wall consideration for this increase corrosion should be given due consideration.

Boiler tail end heat be better utilized by placing additional heat exchanger

The endeavours towards increasing the steam parameters are aimed at improved efficiencies. These need to be complemented with efforts towards utilizing boiler waste heat for improving unit heat rate. In NTPC early boilers were designed for flue gas temperature of 140°C and above which were then reduced to 140°C and subsequently to 130°C in early 1990s. Simahadri onwards 125°C was specified which continues since. It is understood that reduction below 120°C using air heaters lead to problems associated with dew point of sulphuric acid. Any further cooling requires installation of flue gas cooler. The absorbed boiler waste heat is generally fed to the turbine cycle to improve its efficiency. Also it reduces the evaporative water consumption in the FGD scrubbers. Power plants in Denmark, Germany and Japan came up with fairly involved schemes. China is also lately employing the heat exchangers in their plants.

Installation of a low pressure economizer to reduce flue gas temperature in NTPC Ramagundam Stage-I units is presently being considered.

Table 2: Boiler APH exit temperatures have successively decreased over the years

Boiler Generation	NTPC plants	Boiler tail end temperature (°C)
1G	Singrauli-1, Korba-1, Ramagundam-1, Badarpur-2	145 plus
2G	Singrauli-2, Korba-2, Rihand-1, Vindhyachal-1 Dadri-1	140
3G	Unchahar-2, Vindhyachal-2	130
4G	Simhadri-1, Talcher-2, Vindhyachal-3, Mouda-1, Bulk-660, Bulk-800	125

Nomenclature

APH	Air preheater
AUSC	Advanced Ultrasupercritical
AVT	All volatilized treatment
CPU	Condensate polishing unit
CWT	Combined water treatment
FEGT	Furnace exit gas temperature flue gas desulphurization
IDT	Initial deformation temperature
IHI	Ishikawajima-Harima Heavy Industries Co., Ltd.
MW	Megawatt
NO_x	Oxides of nitrogen
OEM	Original equipment manufacturer
OT	Oxygenated treatment
RH	Reheater
SC	Supercritical
SH	Superheater
USC	Ultrasupercritical

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