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ANALYSIS OF SUPERCRITICAL BOILER

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ABSTRACT

Coal fired power generation is switching over to supercritical (SC) and ultra supercritical (USC) plants which operate with steam on higher temperature and above critical pressure to produce power output at higher thermal efficiency. Due to involvement of high heat resistant material, manufacturing cost of the components of supercritical plants are increases, but due to higher efficiency its operating cost is low as compare to subcritical plants. An analysis has been made in the study to explore the possibilities of operating power plants with steam at higher temperature and pressure. Due to high efficiency of this plant 15 % lower co2 emission is achieved by high steam parameters as compare to subcritical plants. Analysis shows that for different operating condition of boilers and turbine, if there is an increment in the load of boiler and drop in the load of turbine higher efficiency is obtained. There are two parameters boiler maximum continuous rating (BMCR) and turbine maximum continuous rating (TMCR) are varied by increasing the value of steam flow rate of super heaters and repeaters'. By increasing or decreasing these values we can find out which condition is best for power generation. A comparative study between subcritical and supercritical boilers and analyzing the performance of boilers, Factor affecting efficiency of boilers has carried out with identification and analysis for improved working of supercritical plants.

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1. INTRODUCTION

1 Supercritical Technology

The current thrust of thermal power development in the country is on supercritical units so as to improve the conversion efficiency and reduce carbon footprint. A number of power generation utilities are going for supercritical technology and a large number of supercritical units of 660/800 MW size are already under construction. Apart from BHEL and L&T, several other manufacturers are setting up facilities for manufacturing supercritical boilers and turbine generators in the country. Considering these developments, this document on "Standard technical features for BTG system of supercritical 660/800 MW thermal units" has been prepared with a view to evolve common understanding amongst utilities, manufacturers and consultants on design and sizing philosophy for supercritical units. The objective is to incorporate broad functional aspects deemed necessary for specifying major quality and performance parameters unambiguously; and at the same time provide flexibility to the manufacturers. Steam generator and auxiliaries, being the major focus area for supercritical units, have been dealt with in more detail. This document is not intended to be detailed specification for use as bid document. The generation efficiency of coal fired stations depends on the steam parameters adopted - higher the steam parameters, higher is the efficiency. It is with this objective that the steam parameters have been constantly raised from 60 kg/cm 2 for 50 MW units to 170 kg/cm2 for 500 MW units

supercritical technology implies use of steam pressure beyond the critical point of water/steam which is about 225 kg/cm2. Thus, supercritical units use higher steam parameters of over 240 kg/cm2 with various combinations of temperature and pressure.. Ultra supercritical parameters with pressure of 250-300 kg/cm2 and main steam reheat steam temperatures of 600/6100C are also being adopted. Research is underway to further increase the steam temperatures to 7000C.

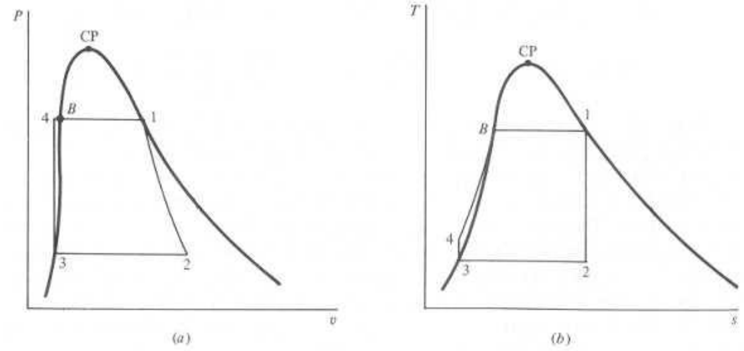
Whilst the earlier supercritical units installed in the country adopted steam parameters of 247 kg/cm2, 535/5650C, higher steam parameters of 247 kg/cm2, 565/5930C are being adopted for later units and have been adopted in this document. The Central Electricity Authority (Technical Standards for Construction of Electrical Plants and Electric Lines) Regulations, 2010, stipulate the maximum turbine cycle heat rate for supercritical units as 1850 kcal/kWh with turbine driven BFP and 1810 kcal/kWh with motor driven BFP and this would require adoption of minimum steam parameters of 247 kg/cm2, 565/ 5930C at turbine inlet. Efficiency improvement of about 2.38 % over the present 500 MW sub-critical units is expected with these minimum steam parameters. Parameters higher than above may also be adopted to achieve better heat rate/ efficiency as per standard practice of OEM. Supercritical technology being a recent introduction in the country, a brief introduction of this technology along with implications on design/construction has also been covered hereunder.

2. HISTORIC BACKGROUND

Supercritical technology was first developed in the U.S. in the 1950s. The early units however experienced problems related to reliability and operational flexibility. The technology was adopted in Japan in the 1960s, has been refined by members of the related industries and is now utilized for all new large capacity boilers. The continuing development of high strength pressure parts materials to be used for high temperature regions has enabled the technology to extend the steam temperatures to higher than 1100ºF (593ºC). Reflecting a strong desire of reduction in CO2 emission by achieving high efficiency, recently constructed large capacity boilers in Japan have employed this technology unexceptionally. The industries in most countries in Asia, Europe and Oceania have almost adopted the supercritical technology as a standard. This established technology can easily be applied to new U.S. coal-fired units with the same level of efficiency and reliability as those achieved in Japan. For the new 790MW net coal-fired unit under construction at the Council Bluffs Energy Centre Unit 4, the application of a reference plant such as the Hitachi-Naka unit, and appropriate furnace sizing and selection of advanced materials for the special properties of U.S. coals, shall ensure the same levels of high performance as the reference unit. Supercritical boiler technologies will contribute to provide not only stable and high quality electricity, but also a better solution for reducing CO2 emissions and reduce impact to the environment. In this paper, the advanced technology and reliability of the latest supercritical boilers will be described.

3. BASIC WORKING PRINCIPLE

The Rankine cycle is the most common off all power generation cycles and is diagrammatically depicted via Figures 1 and 2. The Rankine cycle was devised to make use of the characteristics off water as the working fluid. The cycle begins in a boiler (State 4 in figure 1), where the water is heated until it reaches saturation in a constant-pressure process. Once saturation is reached,, further heat transfer takes place at a constant temperature,, until the working fluid reaches a quality off 100% ((State 1)). At this point,, the high-quality vapour is expanded isentropically through an axially bladed turbine stage to produce shaft work.. The steam then exits the turbine at State 2. The working fluid, at State 2, is at a low--pressure, butt has a fairly high quality, so it is rerouted through a condenser, where the steam is condensed into liquid ((State 3)). Finally, the cycle is completed via the return off the liquid to the boiler, which is normally accomplished by a mechanical pump. Figure 2 shows a schematic off a power plant under a Rankine cycle.



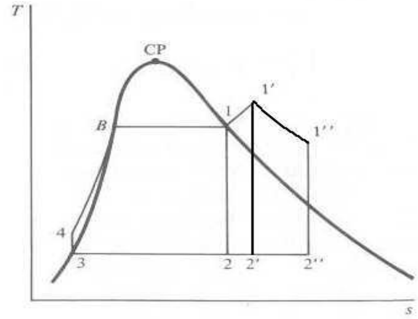


Figure 1.1:: Diagrams for a simple ideal Rankine cycle :: Figure 1.2: Real Rankine cycle
a) P -V diagram,, b) T -S diagram

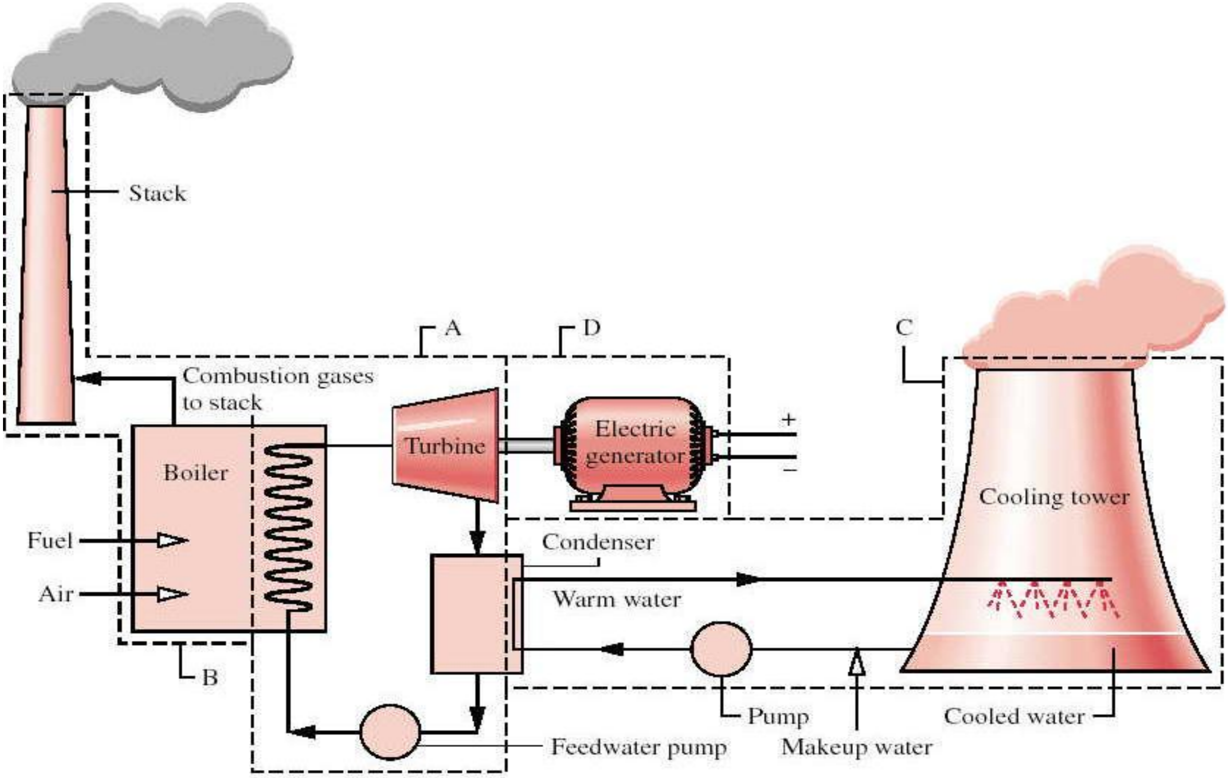


Figure 1.3 :: Schematic of a simple ideal Rankine cycle

4. SUB AND SUPER CRITICAL STEAM CYCLE

4.1 SUB CRITICAL BOILER

Water when heated at sub critical pressure(less than 22.1mpa) increase in temperature until it starts to boil. While the water is boiling it exists as two phases, liquid and gas that have different mass and densities, and remains at constant temperature known as saturation temperature for the given pressure. Once all of the liquid has boiled of to steam (evaporated) the temperature of the steam will continue to rose, at constant pressure, and is then referred to as super heated steam.

Sub-critical boilers typically have a means of separating the two phases, liquid and steam, to allow the process to be continuous. The separated liquid is reticulated through the evaporating section of the boiler and steam passes through to the super heating section. This separation typically occurs in the boiler drum, a heavy thick wall steel pressure vessel with a series of cyclones and baffles to separate liquid from steam.

It is the mass of this boiler drum which limits the rate at which a sub-critical boiler can be brought on a line and how well it respond to load changes which result in fuel being consumed for no energy output compare with a more responsive boiler. To great a firing rate will result in damaging thermal stresses in the heavy boiler drum.

4.2 What Is a Supercritical Boiler?

A supercritical boiler burns pulverized coal and is a once-through boiler, meaning that it doesn’t require a drum to separate steam from water. Rather than boiling water to produce steam and then using that steam to turn a plant’s turbine, a supercritical boiler operates at such high pressure (3,208 psi/221.2 bar or above) that the fluid matrix in it ceases to be liquid or gas. Instead, it becomes what is known as a “supercritical fluid.”

This supercritical fluid turns the turbine that generates electricity. As it does so, it drops below the critical pressure point and becomes a mix of steam and water, passing into a condenser. In the process, less fuel is consumed than in a traditional drum boiler, making supercritical boilers more efficient than their subcritical counterparts.

When water is heated at constant pressure above the critical pressure its temperature is never constant and no distinction between gas and liquid can be made, the mass density of the two phases is the same. Property of the water in the super-critical boiler continuously change from liquid to gas, for example

- Temperature rises steadily
- Specific heat and rate of ruse changes considerably

Liquid in the super-critical boiler is assume to have change to steam after the critical temperature for the super-critical pressure, as the steam is heated further it continues to gain the temperature in a super heated state.

With the super critical boiler there is a no stage where the water exists as two phases and requires separation, so the boiler is constructed without a drum. Typically super-critical boiler are once through boilers where water pump in at pressure by the boiler feed pump passes progressively through the heating stages of the boiler and it is delivered to the turbine at final temp. with no circulation.

The actual location of the transition from liquid to steam in a once through super-critical boiler is free to move with differing condition. This means that for changing the boiler loads and pressures the process is able to optimize the amount of liquid and gas regions for efficient heat transfer keeping the high boiler efficiency over a wider range than sub-critical boiler with drum.

3. Evaporator design

Unlike at sub-critical pressures, there is no co-existence of the two phases, water and steam at supercritical pressures and there is no fixed transition point for phase change like the drum in sub-critical boiler acting as evaporation end point. Therefore the standard circulation system (natural/assisted), which relies on the density difference between steam and water and steam separation in drum is no longer suitable for supercritical units. Instead, supercritical units necessarily use a once-through type of boiler. These boilers also operate in subcritical recirculation mode, subcritical once- through mode and supercritical mode under different pressure regimes. Many types of supercritical once through boiler design exist. While some allow complete variable pressure operation, where the pressure across whole boiler is varied (reduced at low loads), others operate at fixed evaporator pressure and thus involve loss of energy for part load operation. Due to requirement of cyclic operation, variable pressure type evaporator system has been adopted in this document.

4. Water walls design

Supercritical units deploy spiral wall furnace using smooth tubes or vertical wall furnace with rifled tubes. Spiral wall furnace increases the mass flow per tube by reducing the number of tubes needed to envelop the furnace without increasing the spacing between the tubes. It also leads to uniform heat absorption in each tube rendering the spiral wall system less sensitive to changes in the heat absorption profile in the furnace. However, it involves a complex support structure and is relatively difficult to construct and maintain. Standard Technical Features of BTG System for Supercritical 660/800 MW Thermal Units .The vertical water wall design uses rifled tubing for improved cooling effect with uniform temperature across the walls and is also operating satisfactorily. Its advantage lies in ease of construction and maintenance. Keeping in view the fact that various manufacturers have standard water wall configurations which are proven, both the options viz. spiral and vertical tube designs have been included.

5. Boiler start up circulation systems

Supercritical boiler starts operating in the once through mode beyond a particular minimum load of say 30 to 40 %. Below this load, it operates in the circulation mode and needs a separator and circulation system for water steam separation; the separated water is circulated back to the boiler. Generally, two types of circulation systems are in use. In one of the systems, separated water from the separator is led to the desecrator/ condenser and is circulated to the feed water system through boiler feed pump. This system is simple and relatively inexpensive but involves loss of heat from boiler during cold start-up. In other system a circulation pump is provided to circulate the water from separator directly to the economizer. This prevents heat loss from boiler during cold start- up but adds to cost. Both systems have also been provided in some of the supercritical units to improve reliability. Other proven standard systems for boiler start-up drain circulation system are also acceptable. An alternate drain connection to main condenser has also been envisaged to enable start up of steam generator even when the Start up drain recirculation pump is not in service and for initial flushing of boiler to achieve water/ steam quality.

6. HP turbine extraction

In the sub-critical units up to 500 MW, the highest pressure extraction in the regenerative feed heating cycle is from the HP Turbine exhaust. This conventional design with highest feed water extraction from CRH line is able to achieve a final feed water temperature of about 2550C. Designs with extraction from HP turbine are available leading to increased final feed water temperature of about 2900C or higher. The higher feed water temperature due to HP extraction leads to a marginally better turbine cycle heat rate. It also involves additional heaters. Keeping in view the advantages of higher efficiency, design with HP turbine extraction has been adopted.

7. Boiler feed pump configuration

A number of configurations viz. 2x50% TDBFP+2x30% MDBFP, 2x50% TDBFP+1x50% MDBFP, 2x50% TDBFP+1x30% MDBFP, 3x50% MDBFP is in use for boiler feed pumps in large size units. The normal practice being followed in the country for 500 MW units is to provide 2x50 % turbine driven Boiler feed pumps (TD-BFP) and 1x50 % motor driven BFP (MD-BFP). The above configuration has the advantage for having same pump for both TDBFP and MD-BFP leading to interchangeability of spares etc. and better Standard Technical Features of BTG System for Supercritical 660/800 MW Thermal Units inventory management. For large size supercritical units also, the same configuration i.e. 2x50 % TD-BFP and 1x50 % MD-BFP has been adopted. Alternate provision of 3x50% MDBFPs has also been suggested. However, this shall be resulting in increased auxiliary power consumption and reduced net unit output.

8. Design pressure of HP heaters and feed water piping

In case of sub-critical units, feed regulating station is generally located at downstream of HP heaters, and HP heaters and feed water piping from BFP discharge to boiler inlet are normally designed for the shut off head condition of BFPs. However, in case of supercritical units, such a design criteria may lead to extremely high design pressure rating for HP heaters and lead to extremely high thicknesses for pipes and heater tube sheet etc. Thus, in supercritical units, feed regulating station is located at upstream of HP heaters and no isolation valve is provided at economiser inlet. The feed water piping and HP heaters are designed as per design pressure of the boiler with provision of pressure relief valves across

HP heaters or media operated three way valves are provided at inlet/ outlet of HP heater(s) so as to prevent BFP shut off pressure from being communicated to downstream piping system and HP heaters.

9. Water chemistry

Unlike the sub-critical units that offer flexibility for water chemistry correction in the boiler (drum), the supercritical units require necessary quality correction of condensate to ensure final steam quality. High chemical concentration in the boiler water and feed water cause furnace tube deposition and allow solids carryover into the superheated and turbine. Further, dissolved oxygen attacks steel and rate of attack increases sharply with rise in temperature. Accordingly, water chemistry of boiler feed water is maintained using combined water treatment (oxygen dosing and ammonia dosing in condensate and feed water system). Oxygenated treatment (OT) using high purity DM water minimizes corrosion and flow accelerated corrosion (FAC) in the feed water train. Provision for dosing of ammonia and hydrazine (all volatile treatment) is also made during start up and chemical excursions. Further, the units are also provided with 100 % condensate polishing units to achieve requisite condensate quality to the regenerative feed heating systems.

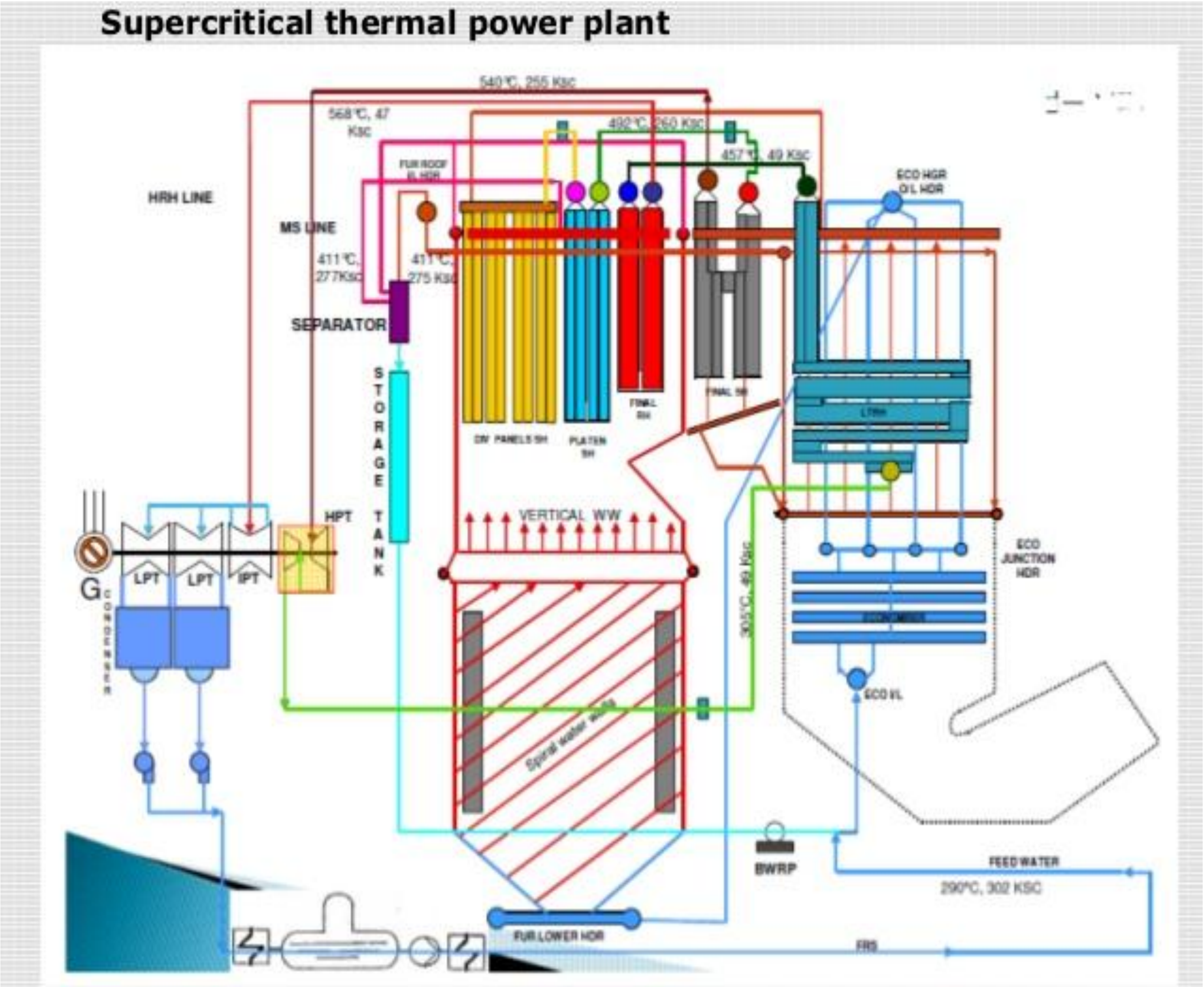
10. ID fan selection

Normal practice in the country has been to provide radial type Induced Draught (ID) fans for upto 500 MW unit size as radial fans are considered more reliable especially under conditions of high dust loadings (and consequent high wear of fan). However, radial fans of high capacity (for 660/800 MW unit size) may not be available and hence axial type variable pitch ID fans have been adopted. These are more efficient and lead to considerable power savings. Also with considerable improvements in ESP performance, problems of fan wear etc. are not expected to be significant. Standard Technical Features of BTG System for Supercritical 660/800 MW Thermal Units

11. Materials

High steam pressure and temperature parameters adopted in supercritical boilers require use of improved materials to withstand the severe operating conditions. Gas side corrosion & erosion and steam side scaling and exfoliation are some of the major issues in material selection for coal-fired boilers. Higher temperature leads to creep, high temperature oxidation and accelerated attack of materials due to the presence of aggressive corrosive species, such as sulphur and chlorine, in the coal. Ferrite, austenitic, or nickel-based alloy with mechanical strength at high temperatures are used in supercritical boilers. Materials being used are T11, T12, T22, T23, T/P91, T/P92, TP-304H, TP-347H and super-304H or equivalent. The relative use of these materials for various surfaces depends on the steam parameters adopted and also on design philosophy of the manufacturer. The high temperature superheater sections normally require advanced materials; however use of advanced materials in other sections can provide design flexibility (e.g., thinner piping/headers for cycling service), though they may not be essential in those areas. Thus sufficient flexibility has been provided for choice of materials for various equipments/ sections and piping to enable design freedom to the manufacturers.

Materials of Construction Modern boilers consist of steel tubes of various dimensions, shape and thickness. The material used is of great importance as it has to withstand high temperatures and pressures. Low-carbon steel is used in most water-tube boilers operating between 270°C and 400°C. Medium-carbon steel, with 0.35% maximum of carbon, permits higher stresses than low-carbon steel at temperature upto 500°C For superheater tubes; alloy steels are required as they have to resist temperatures above 500°C. These may contain chromium, chromium-molybdenum and chromium-nickel. They may be of ferric structure or, for the highest temperature, at which modern boilers operate, of an austenitic structure. Steamless tubes or electric-resistance welded tubes are used in water-tube boilers. Electric-resistance welded tubes are becoming increasingly popular for most applications, except for high pressures where wall thickness makes the use of steamless tubes more practical.



12. Latest experience in supercritical boiler

12.1. Outline of Hitachi-Naka No.1

The Hitachi-Naka Thermal Power Plant Unit 1 (1,000MW), which commenced commercial operation from December 2003, is the latest supercritical unit to be placed in operation in Japan. The plant is located in Ibaraki prefecture in Japan, approximately 60 miles from Tokyo city. The engineering and construction of the boiler, turbine and generator (BTG) Power Island was managed by Hitachi Ltd. The supercritical sliding-pressure Benson boiler was engineered and manufactured by Babcock-Hitachi K.K. (BHK), a subsidiary company of Hitachi Ltd group. At the plant rated load, the boiler can supply the turbine generator with 6,327,000 lb/h of steam at supercritical steam conditions. The main stream parameters at the turbine inlet are 3,550 psig and 1,112ºF, and the reheat steam temperature is 1,112 ºF. The plant was designed for load cycling operation, to follow the changing load demands throughout the operation day. As Japan does not have its own coal resources, coal-fired plants in Japan have to use imported coals. Therefore, utility companies must be flexible to purchase coal from a wide range of different sources from different countries, depending on the, market price levels. The Hitachi-Naka boiler was designed to be able to burn a wide variety of imported coals, including those from Australia, Indonesia, China, U.S.A. and Canada.

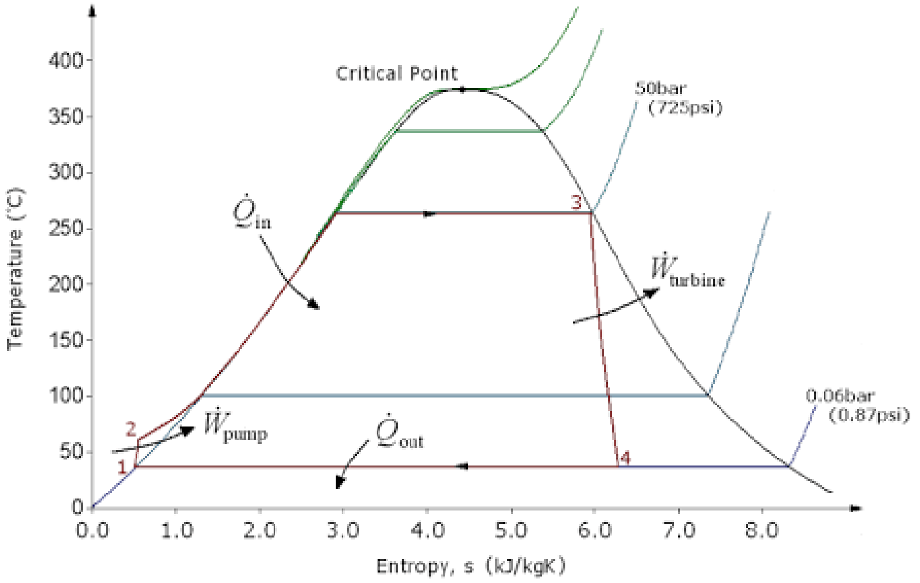
The main specification of the boiler is summarized in Table 1, and a cross-sectional side view of the boiler is shown in Figure 1. During the engineering process, various design features were incorporated based on past operating experience to ensure improvement in operability, maintainability and reliability together with plant performance development. These efforts were made in parallel with an activity to standardize the Benson boiler design and arrangement. As many types of coals are imported from overseas, the standardized boiler can be easily applied to meet the specific requirements for each user worldwide.

12.2 Operating experience

Since the start-up period, the Hitachi-Naka boiler has been operating with stable and reliable performance parameters for both steady load and dynamic load operation modes. The main features of the boiler performance are summarized as follows.

12.3 Boiler performance

The main steam and reheat steam temperatures have reliably achieved 1112 deg. F. The boiler efficiency was confirmed to be higher than the anticipated values at each tested load.



12.4 Combustion performance

The Hitachi-Naka No.1 boiler is the first unit equipped with the newly developed Hitachi NR-3 burner. The NR-3 burner is the latest design in the NR series of rapid ignition low-NOx pulverized coal burners for large-scale commercial plants. The results of combustion testing are summarized in Figure below. Two types of coals, type. A coal from Indonesia and type B from Australia, were tested during the commissioning phase. For both the coals, combustion tests were made with varying combustion settings and adjustments including air flow ratios. As shown in Figure 3, a reduction in outlet NOx emission led to less complete combustion of the fuel, resulting in a higher unburned carbon (UBC) level in the fly ash. As type B coal has a high fuel ratio (i. e. ratio of fixed carbon to volatile matter, 2.0) and high nitrogen content, it is normally difficult to achieve low levels of both NOx and UBC in the fly ash simultaneously. However, when burning type B coal, the observed NOx emission and UBC were much lower than the design point In the case of type A coal, which has lower fuel ratio and nitrogen content, significantly lower NOx and UBC emissions levels were measured.

13. ANALYSIS

After a thorough parametric study and analysis of steam power plants based on SCRC without RH/SCRC with SRH/ and SCRC with DRH, conclusions have been drawn and presented below parameter wise.

1) Turbine inlet temperature

The following conclusions have been drawn from SCRC cycle without reheat, with single reheat, with double reheat on variation of turbine inlet temperature. ¬

- The energy efficiency of the mentioned supercritical cycles increases with an increase of steam turbine inlet temperature at a given pressure. ¬
- Maximum energy efficiency occurred at a turbine inlet temperature of 8000C and at a turbine inlet pressure of 425 bar for all the cycles and at a condenser pressure of 0.05 bar. The maximum energy efficiency obtained for SCRC with double reheat was 51.52%, SCRC with single reheat was 50.06%, and SCRC without reheat was 45.66%.
- The energy efficiency of the mentioned supercritical cycles increases with an increase of steam turbine inlet temperature from 5000C to 8000C at a given pressure.
- Maximum energy efficiency occurred at higher turbine inlet temperature of 8000C and at higher turbine inlet pressure of 425 bar for all three supercritical cycles. The maximum energy efficiency obtained for a SCRC with DRH was 70.14%, SCRC with SRH was 68.70%, and SCRC without RH was 65.95%.
- Total energy loss of all the above supercritical cycles decreases with increase of turbine inlet temperature at a given turbine inlet pressure.
- Minimum total energy loss is occurred at a temperature of 8000C and a at a turbine inlet pressure of 425 bar. Minimum total energy loss of SCRC with DRH was 307.6276 MW and SCRC with SRH was 314.2263 MW and SCRC without RH was 341.8306 MW for the given 1000MW capacity.
- Fractional energy loss of boiler was found to be 59.28% in SCRC with DRH and FEL of the turbine was found to be 29.57% in SCRC with DRH. FEL of the condenser was 6% and FEL of the pump is less 1% in SCRC with DRH. FEL of the exhaust was 4.36% in SCRC with DRH.

2) Turbine inlet pressure

The following conclusions have been drawn from supercritical /ultra supercritical/advanced ultra supercritical cycles without reheat, with single reheat and with double reheat on variation of turbine inlet pressure for the given 1000 MW capacity.

- The energy efficiency of the mentioned supercritical cycles increases with an increase of steam turbine inlet pressure in the range of 170 to 425 bar at a given turbine inlet temperature.
- Maximum energy efficiency was obtained at higher turbine inlet pressure, 425 bar which requires from 43.50% to 51.52% for a range of 5000C to 8000C of turbine inlet temperature of SCRC with DRH.

- The rate of increase in the energy efficiency with turbine inlet pressure was found to be less than the rate of increase in the energy efficiency with turbine inlet temperature.
- The energy efficiency of the supercritical cycles increases with an increase of steam turbine inlet pressure from 170bar to 425bar at a given pressure.
- Total energy loss of all the above supercritical cycles decreases with increase of turbine inlet pressure at a given turbine inlet temperature.

3) Reheat pressure ratio

The performance of SCRC with SRH and SCRC with DRH was found to vary with reheat pressure ratio. In view of this the present investigation carried out thermodynamic analysis of this cycles in order to find the optimum value of reheat pressure ratio for (i) SCRC with single RH and (ii) SCRC with second reheat.

- Optimum value of reheat pressure ratio for SCRC with SRH was found to be 0.25.
- Optimum value of second reheat pressure ratio for SCRC with DRH was found to be 0.25.
- The energy efficiency of SCRC with SRH at optimum value of reheat pressure ratio was found to be 50.06% at maximum turbine inlet temperature of 8000C and maximum turbine inlet pressure of 425 bar. Further, the maximum variation in the energy efficiency 185 with reheat pressure ratio was found to be 2.54% at maximum turbine inlet temperature of 8000C and maximum turbine inlet pressure of 425 bar. ¬
- The energy efficiency of SCRC with DRH at optimum value of reheat pressure ratio was found to be 51.22% at maximum turbine inlet temperature of 8000C and maximum turbine inlet pressure of 425 bar. Further, the maximum variation in the energy efficiency with reheat pressure ratio was found to be 2.82% at maximum turbine inlet temperature of 8000C and maximum turbine inlet pressure of 425bar. ¬
- The energy efficiency of SCRC with SRH at optimum value of reheat pressure ratio was found to be 68.7% at maximum turbine inlet temperature of 8000C and maximum turbine inlet pressure of 425bar. Further, the maximum variation in the energy efficiency with reheat pressure ratio was found to be 2.31% at maximum turbine inlet temperature of 8000C and maximum turbine inlet pressure of 425 bar. ¬
- The energy efficiency of SCRC with DRH at optimum value of reheat pressure ratio was found to be 70.14% at maximum turbine inlet temperature of 8000C and maximum turbine inlet pressure of 425bar. Further, the maximum variation in the energy efficiency with reheat pressure ratio was found to be 2.89% at maximum turbine inlet temperature of 8000C and maximum turbine inlet pressure of 425bar. ¬
- FEL of components of the cycle is not a strong function of reheat pressure ratio. ¬
- FEL of the SCRC with SRH of boiler, turbine, condenser, pump and exhaust are at a reheat pressure ratio of 0.25 are 61.19%, 28.31%, 6.1% ,0.68% and 3.72% respectively.

- FEL of the SCRC with DRH of boiler, turbine, condenser, pump and exhaust are at a reheat pressure ratio of 0.25 are 63.03%, 26.89%, 5.6%, 0.59% and 3.89% respectively at maximum turbine inlet temperature of 8000C and maximum turbine inlet pressure of 425bar..

4) Condenser pressure

The following conclusions have been drawn from supercritical/ultra supercritical/advanced ultra supercritical cycle without reheat, with single reheat, with double reheat on the performance of the cycles with variation of condenser pressure between 0.03bar to 0.1bar. ¬

- Energy efficiency decreases with an increase of condenser pressure for all the cycles. ¬
- The energy efficiency of SCRC with DRH was found to be high compared to other cycles at all the values of condenser pressure. Further, the maximum energy efficiency was obtained at a condenser pressure of 0.03bar for all the cycles. 187 ¬
- The energy efficiency of SCRC with DRH was found to give maximum efficiency at a turbine inlet temperature of 8000C and a turbine inlet pressure of 425bar at all values of condenser pressure. ¬
- It is further inferred that the maximum energy efficiency of the cycle was found to be 52.64% for a turbine inlet temperature of 8000C and a turbine inlet pressure of 425bar at a condenser pressure of 0.03bar for SCRC with DRH. ¬
- Energy efficiency decreases with an increase of condenser pressure for all the cycles. ¬
- The energy efficiency of SCRC with DRH was found to be high compared to other cycles at all the values of condenser pressure. Further, the maximum energy efficiency was obtained at a condenser pressure of 0.03bar for all the cycles. ¬
- The energy efficiency of SCRC with DRH was found to give maximum efficiency at a turbine inlet temperature of 8000C and a turbine inlet pressure of 425bar at all values of condenser pressure. ¬
- It is further inferred that the maximum energy efficiency of the cycle was found to be 70.94% for a turbine inlet temperature of 8000C and a turbine inlet pressure of 425bar at a condenser pressure of 0.03bar for SCRC with DRH. ¬
- Total energy loss increases with increase of condenser pressure for all the cycles.

5) Flue gas temperature at boiler entry

The following conclusions have been drawn from supercritical cycle without reheat, with single reheat and with double reheat by varying the boiler flue gas inlet temperature from 9000C to 14000C and by keeping boiler flue gas outlet temperature as 1000C.

- Energy efficiency of all the cycles was found to be independent of boiler flue gas inlet temperatures.
- Energy efficiency increases with an increase of boiler flue gas inlet temperature of all three mentioned supercritical cycles.
- The maximum energy efficiency of all supercritical cycles occurred at a boiler flue gas inlet temperature of 14000C.

- The maximum energy efficiency of supercritical cycle without reheat was found to be 71.93%, for supercritical cycle with single reheat was 77.67%, and that of supercritical cycle with double reheat was 79.61%.
- Total energy loss increases with an increase of boiler flue gas inlet temperature from 9000C to 14000C of all the mentioned supercritical cycles for the given capacity.
- Minimum total energy loss is occurred in SCRC with DRH at a boiler flue gas inlet temperature of 14000C over all cycles. Minimum total energy loss of supercritical cycle with DRH is 300.4138 MW, SCRC with SRH is 313.7313MW and SCRC without RH is 380.0716 MW for the given capacity.

6) Flue gas temperature at boiler exit temperature

The following conclusions have been drawn from supercritical cycle without reheat, supercritical cycle with single reheat, supercritical cycle with double reheat on their performance by varying the boiler flue gas outlet temperature from 800C to 3000C and by keeping boiler flue gas inlet temperature is 10000C.

- Boiler flue gas outlet temperature does not affect the energy efficiency of any cycle considered.
- Energy efficiency decreases with an increase of boiler flue gas outlet temperature for all the cycles considered.
- The maximum energy efficiency of all supercritical cycles occurred at a boiler flue gas outlet temperature of 800C.
- The maximum energy efficiency of SCRC without DRH was found to be 71.32%, for SCRC without SRH was 70.44%, and that of SCRC without RH was 64.76% at a boiler flue gas outlet temperature of 800C.
- Total energy loss increases with an increase of boiler flue gas outlet temperature of supercritical cycles.

14. Advantages/Reasons to Go Supercritical

Supercritical boilers offer benefits in the three interrelated areas that mean the most to plant owners and operators today: efficiency, emissions, and cost. While supercritical boilers cost more than comparably sized subcritical boilers, the larger initial capital investment can be offset by the lifecycle savings yielded by the technology's improved efficiency, reduced emissions, and lower operating costs —all due to its higher steam temperature and pressure parameters.

1. Improved Efficiency

Supercritical and ultra-supercritical boilers' ability to operate at much higher pressures and temperatures than subcritical boilers translates into noticeably better efficiency ratings.

Subcritical boilers typically run at 2400 psi/1000°F. By way of contrast, modern supercritical units can go as high as 3900 psi/1100°F. The even more advance ultra-supercritical units reach pressures and temperatures as high as 4600 psi/1120°F. Current research goals are set as high as 5300 psi/1300°F and seem to be on the horizon.

So how does all of this play out in terms of efficiency ratings? Well, the reports vary when it comes to the exact percentages, but here is a chart that summarizes the ranges that are usually cited. As a benchmark, the rating given by the 2007 MIT "The Future of Coal" study is also included.

Boiler Type	Efficiency	MIT Efficiency

	Rating Spread	**Rating**
Subcritical	32–38%	34.3%
Supercritical	37–42%	38.5%
Ultra-supercritical	42–45%	43.3%

2. Reduced Emissions

Improved plant efficiency also translates into reduced emissions, particularly of CO_2 and mercury, which are difficult to manage otherwise. The general rule of thumb is that each percentage point of efficiency improvement yields 2–3% less CO_2.

3. Lower Operating Costs

For all fossil fuel–fired plants, fuel represents the largest operating cost. By reducing the amount of fuel needed to yield the requisite energy, supercritical plants make a noticeable dent in bottom lines when compared to subcritical plants.

15. DISADVANTAGES

1. The only disadvantage of this boiler is tightness of high pressure gas passage is essential

16. SCOPE OF THE FUTURE WORK

- Earlier researchers have established that regeneration of steam in between expansion of the steam in turbine enhances the performance of cycle with the use of steam in the subcritical conditions. Similar studies are required to be carried out for the steam in supercritical condition.
- Thermodynamic analysis and optimization of Supercritical Rankine cycle with feed water heaters in supercritical conditions to be carried out.
- Research work on development of new material, nickel based alloys which can sustain supercritical conditions. Hence, there is huge scope for the research in the newer advanced materials.
- Emission analysis of flue gas for coal based thermal power plant may be carried out.
- Analysis of multi stage steam turbine can be done for various supercritical/ultra supercritical cycles.
- Economic analysis of supercritical power plants can be carried out to reduce the unit cost of electric power.
- Advanced coal combustion technologies could be used in Supercritical and ultra supercritical power plants.
- Analysis of once through boiler technology CFB (Circulating Fluidized Bed) boilers can be done for the higher efficiency of supercritical technology.
- Analysis of Once through HRSG (Heat Recovery Steam Generator) with supercritical and ultra supercritical parameters could be done.
- Effect of different fossil fuels can be used for the supercritical cycles.

17. CONCLUSION

Analysis shows that higher output can be obtained with high temperature steam at supercritical pressure comparing with the output of subcritical units operating with same steam flow rates. Thermal efficiency of supercritical plant is high as well as emission is also reduced due to higher efficiency. Performance of supercritical boiler is calculated by different graphical representation and it is compared to subcritical boilers curves. The increased pressure also increases cycle efficiency and, although this effect is a second-order effect compared with the effect of temperature, it can still make an important contribution to increasing overall plant efficiency. However Supercritical boilers operate in a higher pressure and temperature zone as compared to subcritical boilers leading to increased thermal efficiencies.

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