International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 06 | June 2018 www.irjet.net p-ISSN: 2395-0072

CASE STUDY OF SUPERCRITICAL BOILER TECHNOLOGY

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Abstract - *The case study is on supercritical boiler technology which includes the basic origin of supercritical technology and the differences between sub critical and supercritical technology. It focuses on the technological improvements over the sub critical systems to achieve the supercritical parameters for improved efficiency. Constructional aspects of supercritical boilers, material selection, and difference in feed water treatment systems of supercritical boilers from sub critical one are included. Typical schemes of supercritical boilers have been incorporated, it also covers various operational practices including cold light-up, loading up to rated parameters and planned shutdown. Important aspects of erection, commissioning and maintenance activities are also incorporated in this report.*

***Key Words*: Supercritical boiler, Sub critical, Efficiency, Feed Water Treatment, Constructional material, operational practices etc.**

1. INTRODUCTION

When temperature and pressure of live steam are increased beyond the critical point of water, the properties of steam will change dramatically. The critical point of water is at 374 °C and 221.2 bars, it is defined to be the point where gaseous component cannot be liquefied by increasing the pressure applied to it. Beyond this critical point water does not experience a phase change to vapor, but it becomes a supercritical fluid. Supercritical fluid is not a gas or liquid. It is best described to be 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). It has similar solvent power as liquid, but its transport properties are similar to gases.

1 BASIC RANKINE CYCLE:

The Rankine cycle is the very a basic vapor power cycle which is adopted in all the thermal power plants. It is a four step process which involves the heating of the working fluid to its saturation temperature and vaporizing it isothermally, expanding the vapor on a turbine (work cycle), condensing the steam isothermally to the liquid phase and pumping it back to the boiler.

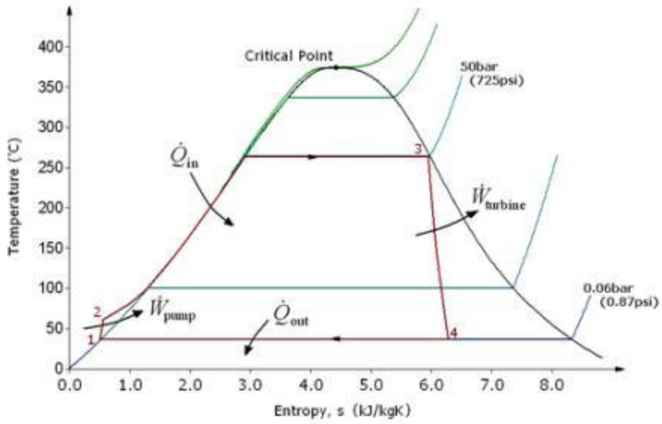

Fig1.1. Basic Rankine cycle (with various pressures)

The T-S diagram for a supercritical cycle can be seen in Figure 1.2. With the use of reheat and regeneration techniques, point 3 in Figure 1.2, which corresponds to the T-S vapor state of the coolant after it has expanded through a turbine, can be pushed to the right such that the coolant remains in the gas phase. This simplifies the system by eliminating the need for steam separators, dryers, and turbines specially designed for low quality steam.

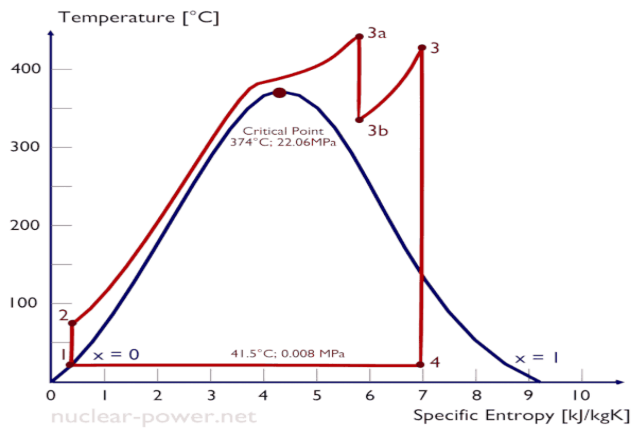

Fig. 1.2 Re heat Supercritical Rankine cycle

1.1 Factors Increasing the Rankine Efficiency

- Lowering the condenser pressure
- Superheating the steam to high temperature
- Increasing the boiler pressure

2. CHALLENGES OF SUPERCRITICAL TECHNOLOGY

- Water chemistry is more stringent in super critical once through boiler.
- Metallurgical Challenges
- More complex in erection due to spiral water wall.
- More feed pump power is required due to more friction losses in spiral water wall.
- Maintenance of tube leakage is difficult due to complex design of water wall.
- Ash sticking tendency is more in spiral water wall in comparison of vertical wall.

3. FEED WATER CHEMISTRY

Water Chemistry is very important, as it determines the life of boilers, deposits, heat transfer efficiency, tube failures and requirement of chemical cleaning of boiler. Improper boiler water quality can even lead to huge deposition in turbine blades. The purpose of boiler water chemistry may be summarized as follows:

1) Avoid Corrosion
2) Avoid Scaling
3) Avoid Fouling (substances excluding scale)
4) Avoid Priming (carryover of water droplet)
5) Avoid Foaming
6) Efficient Heat Transfer
7) Minimum Boiler Tube Leakages
8) Steam Purity

3.1 Water Quality in Supercritical Boilers

The water quality is very important for high pressure steam generators. For supercritical boilers its importance is much more due to following reasons:

a) No boiler blow down or solid treatment which is used for maintaining boiler and steam purity.
b) Drum boilers water walls have generally wet surface, here both dry and wet walls exists resulting in high salt concentration.
c) No physical separation of impurities, it deposits in super heaters, re-heaters and turbine blades. Results in increased pressure drop, reduce efficiency and heat transfer. Demands chemical cleaning.

3.2 Boiler Water Treatment:

Boiler water treatments are mainly of three types, solid treatment and all volatile treatment and Oxygenated treatment. The treatment methods are as follows:

- All Volatile Treatment (Oxidizing, Reducing)
- Phosphate Treatment (Na: PO_4 > 2.8 and allow upto1 ppm of free NaOH, here Phosphate Concentration is 3-10 ppm)
- Equilibrium Phosphate Treat same as PT with lower Phosphate concentration
- Congruent Phosphate Treat (Na: PO_4 <2 .6)
- Oxygenated Treatment

Sr. No	Parameters	Sub critical	Supercritical
1.	Type of water wall treatment	HP or LP dosing or All volatile treatment (Hydrazine - Ammonia)	No HP dosing Combined water treatment
2.	Silica	<20ppb in feed water and steam <25 ppb in boiler drum	Standard value <15 ppb in cycle Expected value < 10 ppb in cycle
3.	PH	9.0-9.5 for feed, steam and condensate 9.0-10 for boiler drum	9.0-9.6 for AVT (All volatile treatment) 8.0-9.0 for CWT (combined Water Treatment)
4.	Dissolved Oxygen	< 7 ppb for feed	< 7 ppb for feed in case of AVT 30-70 ppb for feed in case of CWT
5.	Cation conductivity (H+)	<0.20 µS/cm in the feed & steam cycle	Standard value <0.15 µS /cm in the cycle Expected value- <0.10 µS /cm in the cycle
6.	CPU	CPU is optional	CPU is essential for 100% flow.
7.	Silica and TDS control	By maintaining feed water quality and By operating CBD	Blow down possible till separators are functioning (up to 30% load)

Table 1.1 Feed water comparisons between subcritical and supercritical.

4. METALLURGICAL ASPECTS

Supercritical boilers have different operational characteristics because of the higher steam temperatures and require more stringent material characteristics than subcritical boilers. The four key components are high -pressure steam, piping and headers, super-heater tubing and water wall tubing. The materials used should be sustainable to the very high pressure being developed and should not get Oxidized due to the very high temperature. Different high temperature materials are being used like 9 to 12% ferrite steels T91/P91, T92/P92, T112/P122 steel, Advanced Austenitic alloys TP347, HFG, Super 304, Nickel and chrome nickel super alloys like Inconel 740.

Heat surface	Tube material	Header material
Economizer	SA-210 C	SA-106 C
Furnace Walls	SA-213 T12	SA-106 C
Super heater	SA-213 T12	SA-335 P12
Re-heater	SA-213 T23 SA-213 TP 304H SA-213 TP347HFG	SA-335 P91 SA-335 P911
Steam Piping		SA 335 P91

Table 2 Materials for different boiler parts

5. DESIGN CONSIDERATION

Among the heat-absorbing surfaces, the furnace walls are exposed to the highest heat flux. This is because of the intense radiant heat from the fireball. Currently, two design variants are used for once-through units: **the spiral furnace tube arrangement and the vertical tube arrangement**. Design choice is governed by furnace size and customer preference – both variants have advantages, depending on project drivers.

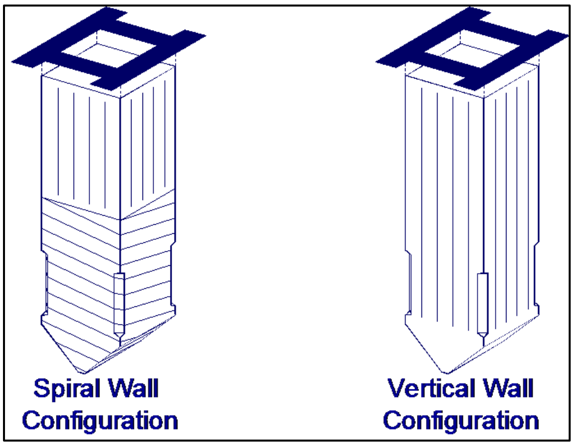

Fig. 3 Spiral and Vertical Furnace Water wall

5.1 Spiral tubes

Benefits from averaging of lateral heat absorption variation (each tube forms a part of each furnace wall). It have Simplified inlet header arrangement. It also doses the use of smooth bore tubing throughout entire furnace wall system. There are no individual tube orifices. Main advantage of these tubes is that it can be used in boilers of any capacity. And most importantly the tubes pass through all the furnace walls more uniform heat absorption.

5.2 Vertical Tubes

It has simpler wind box openings, simpler furnace water wall support system and easier to identify and repair tubes leaks. These tubes also help in elimination of intermediate furnace wall transition header. It is also less costly to lower water wall system pressure drop thereby reducing required feed pump power. The tubes are self-supporting hence transition headers at spiral/vertical interface are avoided. The bottom ash hopper tubing geometry is simplified in this arrangement. Lastly Corners are easier to form which reduced complexity of system and as the pressure drop is less auxiliary power consumption is less.

5.3 Rifled Tubes:

For sliding pressure operation, boiler maintaining uniform fluid condition at low load / low pressure operation becomes critical to reduce the potential of tube damage caused by high metal temperature; spiral configuration with rifled construction is used.

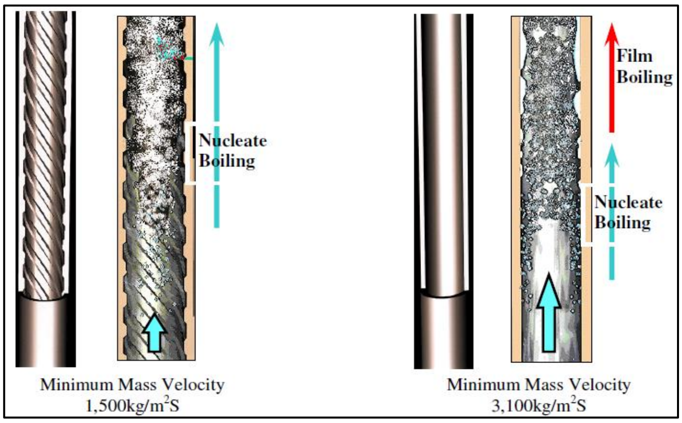

Fig. Rifled Tubes and Normal Tubes

6. Operation of Supercritical Boilers

Supercritical boiler starts operating in the once through mode beyond a particular minimum load of say; the separated water is circulated back to the boiler. Before fuel can be fired in a once-through boiler, a minimum fluid mass flow rate must be established within the evaporator tubes that form the furnace enclosure to protect the tubes from overheating .Around 30 to 40 % is taken below this load, it operates in the circulation mode and needs a separator and circulation system for water steam separation. Separated water is drained to a water collecting vessel from which the water is pumped back to the economizer. To ensure that sub-cooled water enters the pump, a small amount of cold feed water is piped to the pump inlet line.

7. Maintenance

Most boilers are subject to jurisdictional regulations that require annual or biannual shutdown for inspection. Arrange for complete water and fireside cleaning when these inspections are conducted. More frequent inspections may be required by operating conditions or the boiler manufacturer. See the National Board Inspection Code for more information. Monitor all repair activities to ensure proper hot work procedures are employed and that proper safety precautions are taken.
For effective maintenance planning 3 aspects should be considered

- Past performance data
- Effective use of maintenance personnel
- Spare parts or store management

Generally maintenance is sub divided into 3 types

- Predictive (Routine)
- Preventive (Stand by auxiliaries)
- Annual overhaul

8. Advantages of Supercritical over subcritical

- **Efficiency: -** The main advantage and the reason for a higher pressure operation is the increase in the thermodynamic efficiency of the Rankine cycle.
- Operational Flexibility:-Most of the Supercritical units use the once through technology. This is ideal for sliding pressure operation which has much more flexibility in load changes and controlling the power grid.
- Water chemistry:-In supercritical units the water entering the boiler has to be of extremely high levels of purity. Supercritical boilers do not have a steam drum that separates the steam and the water.
- **Materials:-**Supercritical power plants use special high grade materials for the boiler tubes. The turbine blades are also of improved design and materials.
- **Heat transfer Area:-**Higher steam temperatures in supercritical units results in a lesser differential temperature for heat transfer.

9. CONCLUSION

Supercritical boiler is probably the best and clean technology for the upcoming project in India due to the higher plant efficiency & less environment pollution which reduces the amount of coal used per MWh. Higher plant efficiency can be achieved due to the higher pressure, temperature at turbine inlet and the advance combustion technology. In order to achieve the targets set out for the XI and XII plans, large capacity addition is only possible with the setting up of supercritical units of more than 660MW. With the growing environmental concerns on emissions, there is an urgent requirement to use the most advanced technology currently available in the world.

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ACKNOWLEDGEMENT

We would like to express our gratitude towards our parents & members of (N.P.T.I. Nagpur) for their kind co-operation and encouragement which help us in completion of this Case study.

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