Understanding of OHDR and its repercussions on over all operation of super critical power plant

Rahul Pachouri
M.Tech.Student (Thermal System & Design) SRCEM,MORENA (M.P) India

Devendra Dandotiya
Assistant Professor, Deptt.of M.E. SRCEM,MORENA (M.P.) India

Surendra Kumar Agrawal
Assistant Professor, Deptt.of M.E. SRCEM,MORENA (M.P.) India

Abstract-The efficiency of coal-fired power generation is primarily dependent on when the steam generated from the boiler and the combustion of coal is at a more elevated temperature and pressure. However, the strength of the boiler decreases when used at high temperatures and pressure for long periods of time. In an effort to solve this problem, Hitachi has reviewed the design by focusing on strength and heat transmission, and developed high-strength steel. Hitachi has also established ultra-supercritical pressure power generation technology, which is able to withstand high temperatures in the (600 degrees) class and high pressure (25MPa, about 250 times greater than atmospheric pressure). This approach is resulting in the reduction of CO2 emissions by 7% in ultra-supercritical pressure power generation, compared with current sub-critical pressure power generation. The super critical thermal power plants are coming in India with size 660MW and above. The boiler plays a key role in availability of power plant, and at the same time is a key factor for optimum power generation. There are few different parameters in super critical boiler than conventional sub critical boiler operation. One among such parameters is OHDR i.e. Over Heat Degree of Super Heat in the evaporator. The OHDR is measured, monitored and controlled to maintain steady state or rated load conditions of boiler. The degree of super heat monitored is calculated as it is the difference between the temperature of evaporation of steam in evaporator zone and the pseudo critical temperature of water at any particular pressure. The OHDR gives the stability to super critical boiler in terms of water, coal and air at any operating condition. The water to coal ratio of boiler is maintained at OHDR 25°C at arch inlet manifold.

Key words: - Super-critical, OHDR, Pseudocritical, Critical point, Sub-critical.

I. INTRODUCTION

The Thermal efficiency improvement in cost-effective way has been an important technological endeavor for over 250 years. The Newcomen steam engine appeared in 1750 and attained 0.5% efficiency [1]. James Watt patented improvements in 1769 and achieved 2.7% efficiency by 1775, launching the Industrial Revolution. Watt limited operating pressure to about 0.034 MPa. Richard Trevithick is credited with engine improvements that permitted increasing steam pressure to 1 MPa, to achieve 17% thermal efficiency by 1834. American Electric Power's (AEP) Philo Plant Unit 6 steam generator was the first commercial supercritical unit in service early in 1957 (Figure 1). Philo 6, a double reheat design, delivered 120 MW, operating at 85 kg/s, 31 MPa, 621C/565C/538C (675,000 lb/h, 4500 psi, 1150 F/1050 F/1000 F) and was supplied by The Babcock & Wilcox Company (B&W). In 1959, Philadelphia Electric Company's Eddystone steam generator, a dual reheat design supplied by Combustion Engineering, Inc., initially delivered 325 MW at 252 kg/s, 34.5 MPa, 649C/565C/565C (2,000,000 lb/h, 5000 psi, 1200F/1050F/1050F) and later operated at 32.4 MPa, 610C/554C/554C (4700 psi, 1130F/1030F/1030F) [2]. Once-through supercritical plants became valued to the U.S. market again in about 2000 and most new larger electric utility coal-fired plants have been supercritical with variable pressure operating mode. Two Babcock & Wilcox Power Generation Group, Inc. (B&W PGG) design efforts have been underway in this period. In one effort, the DOE and OCDO are sponsoring a materials development program by a consortium of boiler vendors that are seeking qualification of ASME Code Section I alloys suitable for 760C (1400F) turbine throttle steam temperatures [3, 4].

II. DESCRIPTION

Research programs in word for Boiler Materials for supercritical Coal Power Plants have set a goal to improve thermal efficiency and reduce carbon dioxide emission through application of materials with higher temperature capability up to 760C (1400F) [4]

The supercritical boiler operated in once through cycle of operation where in all the water fed to boiler gets converted in to steam instantaneously. The conversion takes place in evaporator zone of the boiler. The Rankine cycle followed by once through boiler is different than the sub critical one. In subcritical boiler operation the water passes through sensible heat, latent heat and super heat while in super critical boiler it passes through only sensible heat and super heat. The water saturation line and dry steam line at different pressure and temperature points is shown below in figure 1.
As the result of a B&W PGG economic study applying B&W PGG/Air Liquide (AL) technology and starting with references [5, 6], the relative efficiency and levelized cost of electricity for A-USC with oxy-combustion CCS are shown to be lower in comparison to other technologies
In super critical boiler the water undergoes heating at pressure above the critical pressure and therefore requires zero latent heat for evaporation. As the super critical boiler operates above critical point pressure and temperature which affects the boiler metallurgy, the operator needs to be cautious while operating the plant.

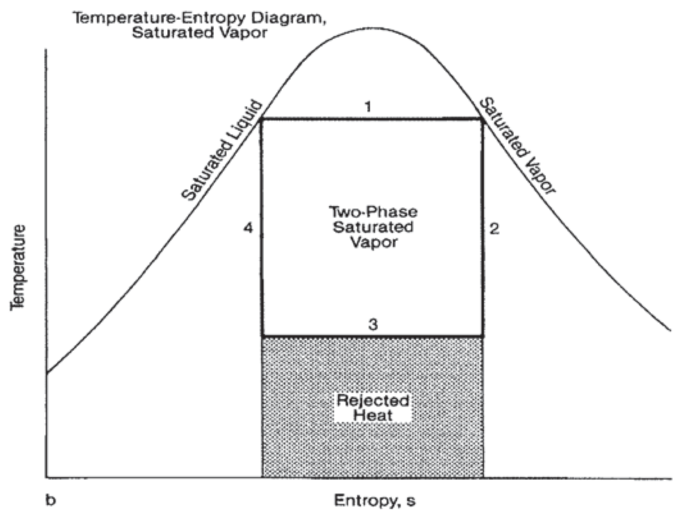


Fig. 1: Temperature entropy diagram of water

There are many important parameters of boiler which need continuous monitoring. Some of the important parameters are given below [7,8]

(i) Over heating i.e. degree of super heat in evaporator.
(ii) Water-coal ratio.
(iii) Total feed water flow.
(iv) Temperature and pressure in main steam and reheat steam.
(v) Total load in MW.
(vi) Limits of operation for above all

One of the important parameter in above list is Over Heat Degree (OHDR) of Superheat in evaporator zone of boiler. The degree of super heat in super critical boiler is necessary to maintain the stability of steady state operation of boiler. It also gives the operator the balancing of water and coal in the boiler which otherwise is necessary to maintain. The manufacturer's specification of super critical boiler defines the water to coal ratio as 7:1. The stable water coal ratio at rated conditions gives stability of the Over Heat Degree (OHDR) of Steam in the evaporator zone of the boiler [9].

The OHDR is the difference between the pseudo critical temperature and the actual temperature at which water is getting evaporated at any particular pressure above critical point.

In 660MW super critical boiler at rated load, pressure is 25MPa and the evaporation temperature is maintained 410°C at Arch Inlet Manifold in evaporator. The pseudo critical temperature is 385°C as given in the graph below. The 25°C is the difference between pseudo critical temperature at 25MPa and Ach Inlet manifold temperature which has to be maintained by the operator for safe operation of once through boiler. As per boiler manufacturer for stable operation, the OHDR need to be maintained around 25°C when boiler is working in once through mode [10]

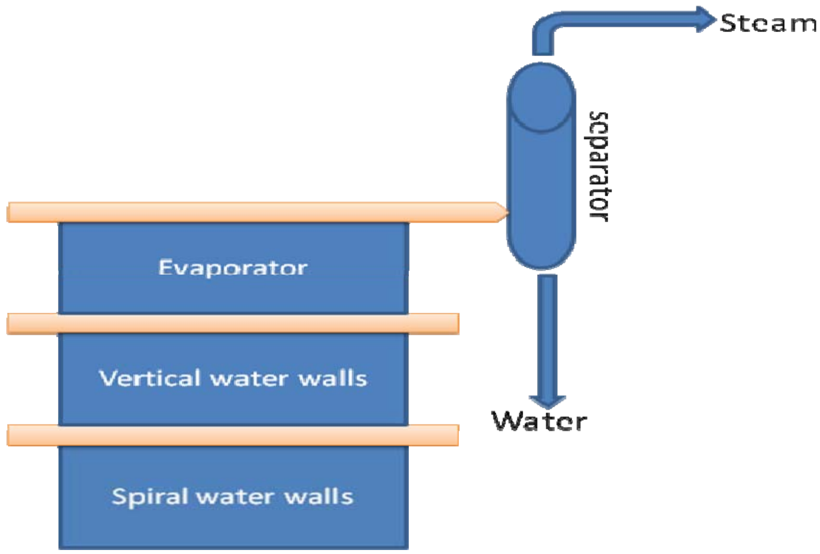


Fig. 2: Super critical boiler

Initially when boiler is in wet state or subcritical mode of operation, the evaporator is in saturation phase where in the steam water separation takes place by density difference as well as through cyclonic motion of mixture inside the Separator. The degree of super heat in evaporator matters only when the boiler is in once through mode. During boiler operation in once through mode if the OHDR is less, the water quantity is likely to be more than coal proportion. This will lead saturated steam to go to super heaters, due to lesser heat transfer. If the OHDR is more, the coal flow to boiler is likely to be more with respect to water flow which can cause higher temperature of superheated steam [11]. The advantage of superheated steam is the absence of residual moisture in the steam pipes. The thermal conductivity of super heated steam i.e. its ability to deliver heat to surrounding bodies is much lower than that of saturated steam. Hence, it will not transmit heat as rapidly to the walls of pipes compared to when it is flowing in saturation phase. In short, it is important that super heated steam delivers heat to the prime movers and not the pipes in which it is carried[13,14].

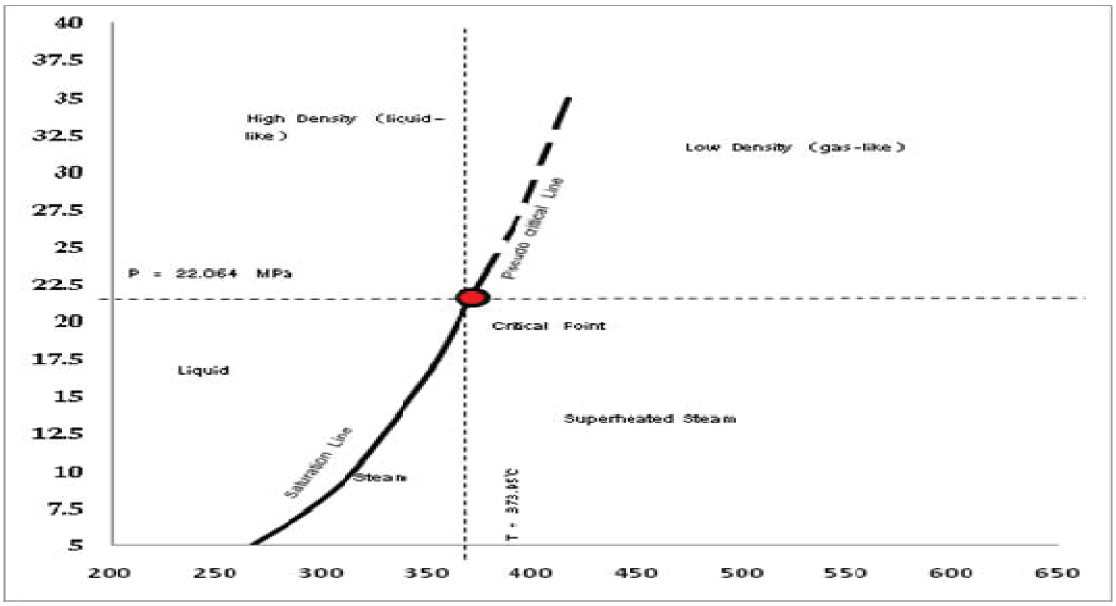
As mentioned in the graph below, the pressure and temperature relation of water and steam is given by the saturation line up to critical point at which the pressure is 22.06 MPa and temperature is 373.99 °C. Above this, water doesn't absorb latent heat and it directly evaporates with certain degree of super heat. The temperature of saturation can be calculated by characteristic curve like in the graph given below which is pseudo critical line of water. The evaporation temperature is measured in evaporator zone at Arch Inlet Manifold and the difference between evaporator temperature and characteristic critical temperature is calculated by software at any instant which is referred as OHDR.
Above critical pressure i.e. 22.064MPa the pseudo relationship between pressure and temperature is given in the table below;

Pressure, MPa	Pseudo critical pressure, °C	Peak value of specific heat, kJ/Kg
23	377.5	284.3
24	381.2	121.9
25	384.9	76.4
26	388.5	55.7
27	392.0	43.9
28	395.4	36.3
29	398.7	30.9

30	401.9	27.0
31	405.0	24.1
32	408.1	21.7
33	411.0	19.9
34	413.9	18.4
35	416.7	17.2

Table 1: Pseudo critical pressure and temperature values

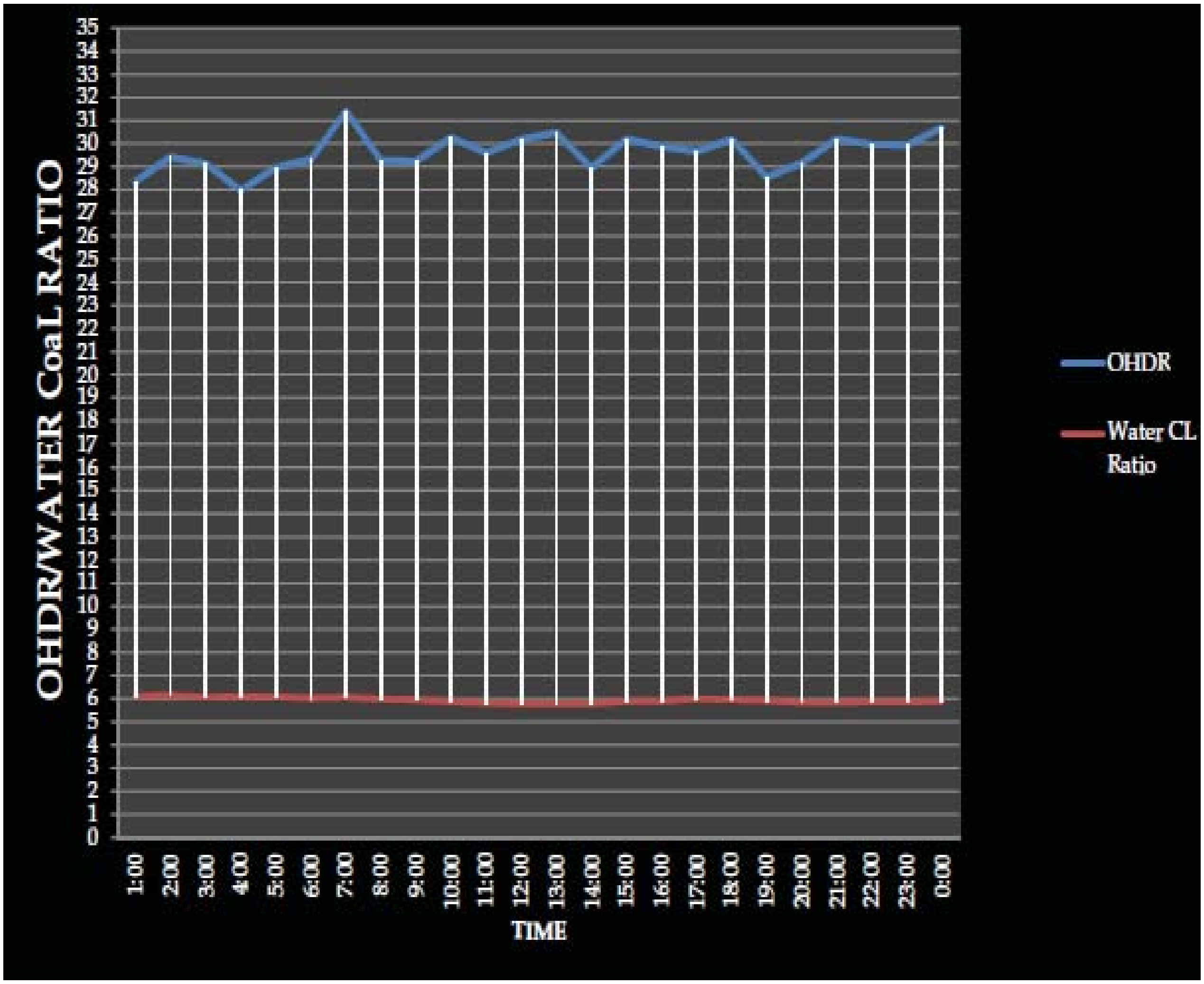
The pseudo saturation temperature of water at various pressures above critical point pressure is given in graph.1;



Graph 1: Pseudo critical pressure Vs temperature relationship

Practical view point:

In 660MW super critical thermal unit, the steady state performance of the unit with respect to OHDR and water-coal ratio is shown in the graph 2. The parameters above indicate the operating condition at 500MW load condition when the water coal ratio is 5.82 and OHDR is 30°C. The data collected is for 24 hours.



Graph 2: Relationship between OHDR, water- coal ratio and load for 660MW Super critical power plant.

At steady state, the water coal ratio appears to be quite normal while the OHDR is changing from 28°C up to 30°C depending on local operating conditions. The lesser ratio of water to coal is because of low calorific value of coal. Hence, though the coal water ratio is specified by the boiler manufacturer, it depends upon calorific value of coal. In short we need to refer the OHDR which is the ultimate indication of balance of water and coal in the boiler at any operating condition.

The OHDR gives the overall stability to once through super critical boiler. For better clarity let's understand two different cases below;

Case#1: At 660MW, 25MPa pressure if the OHDR is 40°C

The pseudo critical temperature at 25MPa is 385°C.
The evaporator temperature at Arch Inlet Manifold- 385°C+40°C=425°C.
The evaporator temperature is higher than the design value 25°C.
The water is getting evaporated before it is reaching to evaporator zone.
The heat absorption by water is more than desired.
The coal proportion in boiler is more than required or water may be less.
This can over heat water walls, steam tubes as well as flue gas zone of the boiler which can cause water or steam tube failures.

The resultant temperature of main steam and reheat steam will also increase.

Case#2: At 660MW, 25MPa pressure if the OHDR is 10°C

The pseudo critical temperature at 25MPa is same i.e. 385°C.
The evaporator temperature at Arch Inlet Manifold- 385°C+10°C=395°C.
Evaporator temperature is lesser than design value i.e. 25°C.
The water is getting evaporated after evaporation zone i.e. near 'Separator'
The heat absorption by water walls in the boiler is less than desired.
The coal proportion is either less or water is more than required value.
This will lead to less main steam temperature.
Eventually, Load will start reducing.

III. CONCLUSION

Keeping above two conditions in view, we need to maintain the OHDR value at 25°C as far as possible with water coal ratio defined as per specifications which will lead to stable operating conditions of super critical boiler.

At once through operating conditions, the operator need to monitor OHDR regularly and take corrective measures to keep water to coal proportion in order to operate boiler as per specific load conditions.

In emergency, the OHDR value becomes more critical. In such cases the boiler operator needs to prepare action plan to have minimum possible deviations in OHDR value.

REFERENCES

[1] Burstall, A.F., "A History of Mechanical Engineering,"MIT Press, The Massachusetts Institute of Technology, Cambridge, MA, 1965.
[2] Silvestri, G.J., et.al., "Optimization of Advanced Steam Condition Power Plants," Diaz-Tous, I.A., (ed.), Steam Turbines in Power Generation – PWR-Vol. 3, Book No. H00442, ASME, 1992
[3] Bennett, A.J., Weitzel P.S., Boiler Materials for Ultrasupercritical Coal Power Plants – Task 1B, Conceptual Design, Babcock & Wilcox Approach, USC T-3, Topical Report, DOE DE-FG26-01NT41175 & OCDO D-0020, February 2003
[4] Viswanathan, R., Shingledecker, J., Phillips, J., In Pursuit of Efficiency in Coal Power Plants, (ed. Sakrestad, BA) 35th International Technical Conference on Clean Coal and Fuel Systems 2010, Clearwater, FL, June 2010.
[5] DOE/NETL 2007 - 1281 "Cost and Baseline for Fossil Energy Plants," Rev. 1.
[6] DOE/NETL 2007 – 1291 "Pulverized coal Oxycombustion Power Plants," Rev. 2.
[7] Silvestri, G.J., "Eddystone Station, 325 MW Generating Unit 1-A Brief History," ASME, March 2003.
[8] Viswanathan, R., "U.S. Program on Materials Technology for Ultrasupercritical Coal Power Plants," Electric Power Research Institute, Palo Alto, CA, March 2006.
[9] Viswanathan, R., et.al., "U.S. Program on Materials Technology for Ultra supercritical Coal-Fired Boilers," in Proceedings of the 5th International Conference on Advances in Materials Technology for Fossil Power Plants, ASM International, 2008.
[10] Sarver, J.M., Tanzosh, J.M., "Characterization of Steam-Formed Oxides on Candidate Materials for USC Boilers," Sixth International Conference on Advanced Materials for Power Plants, Sante Fe, NM, September 2010.
[11] Thermophysical properties at critical and super critical conditions by Igor Piro and Sarah Mokry Super critical technology, NTPC
[12] Wheeldon, J., Engineering and Economic Evaluation of 1300°F Series Ultra-Supercritical Pulverized Coal Powe Plants: Phase 1. EPRI, Palo Alto, CA: 2008. 1015699