Supercritical Technology in Indian Power Sector

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Abstract – Supercritical is a thermodynamic expression describing the state of a fluid above a certain pressure when there exists no clear distinction between the liquid and gaseous phases. The pressure at which such a transition to the supercritical state takes place is known as the critical pressure. For water this pressure is 22.064 Mpa. The corresponding saturation temperature is known as the critical temperature and for water it is 647.096 K. The term critical has been used for this thermodynamic state because it is a singularity in the fluid property states. Fluids below the supercritical pressure are termed as subcritical whereas those above the critical pressure are regarded as supercritical.

Several modern plants operate at peak pressures of more than 24 Mpa and hence function as supercritical power plants. Supercritical coal fired power plants with efficiencies of around 45% have much lower emissions than subcritical plants for a given power output. Today's state of the art in supercritical coal fired power plants permits efficiencies that exceed 45%, depending on cooling conditions. Options to increase efficiency above 50 % in ultra-supercritical power plants rely on elevated steam conditions as well as on improved process and component quality. Steam conditions up to 30 MPa/600°C/620°C are achieved using steels with 12 % chromium content. Pressures of up to 31.5 MPa/620°C/620°C have been proposed using Austenite, which is a proven, but expensive, material. Nickel-based alloys, e.g. Inconel, may permit 35 MPa/720°C/720°C, yielding efficiencies of nearly 50%.In order to improve coal-fired power plant efficiency leading to a proportional reduction in coal consumption and carbon dioxide emissions, it is widely accepted that the domestic power industry must move from sub critical to supercritical steam cycles. Medium to large capacity thermal power plants in India are now increasingly adopting the more efficient & bigger 660/800 MW supercritical units. Higher efficiency translates into reduced environmental impact. Less coal and water are used, smaller volumes of fly ash and scrubber waste is produced, and uncontrolled emissions of CO2 and mercury will be lowered.

KeyWords: Supercritical, Steam, Reheat, Indian Power Sector.

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1. INTRODUCTION

Many regions of the world are experiencing fast growing electricity demand. Permitted emissions from power plants have been reduced so as to meet air quality standards. Power plants are a source of CO_2, one of the greenhouse gasses that the Kyoto Protocol intends to limit. Electricity generated from coal currently accounts for about 40 % of worldwide generation & more than 60 % in India. Coal is an abundant fuel resource in many of the world's developing regions and the forecasts indicate that coal is likely to remain a dominant fuel for electricity generation in many countries for years to come[1][2].

It is against this backdrop that power plant suppliers have invested heavily in generation technologies that produce power more efficiently. Worldwide, more than 400 supercritical plants are in operation. Super Critical plants reduce CO_2 emissions and other pollutants significantly by using less fuel per unit of electricity generated[3].

2. SUPERCRITICAL TECHNOLOGY

While the definition of Supercritical conditions is straightforward, the meaning of USC is subject interpretation. Depending on upper limit of pressure and temperature parameters, supercritical cycles are generally categorized as supercritical (SC),Ultra-supercritical (USC) and advanced ultra-supercritical (advanced USC) as indicated below:

1. SC is a thermal cycle with main steam temperature of less than 600 °C operating at pressures between 221.18 and 275 bar.
2. USC is a thermal cycle with maximum steam temperature greater than 600 °C operating at pressures higher than 275 bar.
3. Advanced USC is a thermal cycle with steam temperature of 705 °C or greater.

3. EFFICIENCY IMPROVEMENT WITH SUPERCRITICAL TECHNOLOGY

Improvement in efficiency can be achieved by using supercritical steam conditions. The supercritical design not only improves efficiency by increasing the working fluid pressure but it allows superheating of the steam to higher temperatures which provides significant further efficiency improvement. For many years the most popular boiler design has been the sub critical drum boiler. This technology is low cost and well proven but does not have the potential for efficiency improvement inherent in supercritical cycles. Typical improvement in cycle efficiency with increase of steam temperature & pressure is shown below:

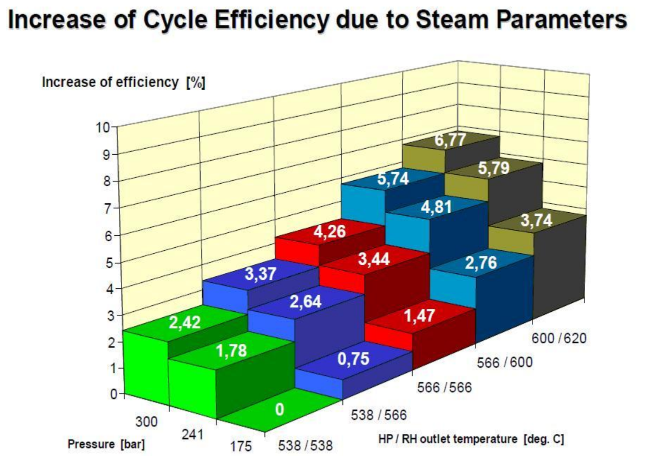

Fig.1. Increase of cycle efficiency due to steam parameters

The initial step in the development process is thermodynamic cycle optimization, followed by an effort to increase steam turbine overall efficiency by improving the efficiency of high pressure (HP) and intermediate pressure (IP) modules. Besides steam turbine technology dictating the selection of the temperatures and pressures, cycle optimization is sometimes governed by coal properties and the effect of aggressive/corrosive coals on the materials selected for the boiler tubes, headers, and other internal components. If the coal contains deleterious components, the thermal cycle optimization should focus on pressure increase rather than more-effective temperature increases. Equipment manufacturers also continue to aggressively pursue upgrading the low pressure (LP) turbine, which, in many cases, accounts for 40 percent of the power generated by the turbine. One of the development objectives is to increase the size of the last-stage blade (LSB), which could reduce the number of LP modules and boost the power output at lower condenser pressures [4].

4. ENVIRONMENTAL BENEFITS OF SUPERCRITICAL TECHNOLOGY

Current supercritical coal fired power plants have efficiencies above 42%. Higher efficiency leads to lower coal consumption and aux power reduction. It also leads to lower specific water consumption & small BOP system. One percent (1%) increase in efficiency leads to reduction of specific emissions such as CO2, NOx, SOx and particulates by two percent (2%).

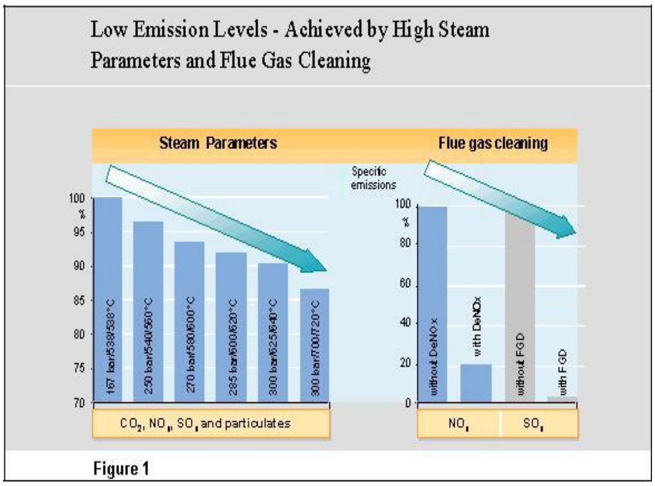

Fig.2 Emission Levels

5. ADVENT OF SUPERCRITICAL TECHNOLOGY IN INDIA

After Electricity Act 2003 come into effect, rapid buildup of generation capacity was stressed in India. To cater the rising demand of electricity, the power sector was opened up to private players. Maximum numbers of thermal units installed initially were with subcritical technology of 250/500 MW class. But for Ultra Mega Power Projects of 4000 MW & above capacity, the government made it compulsory to use supercritical steam parameters.

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6. STEAM PARAMETERS ADOPTED IN INDIA

The first generations of SC parameters used in India for 3x660MW Sipat are with lower steam temperature (MS - 537 °C with re-heater 565 °C). To take enhanced benefits of SC technology, CEA vide its regulation dated August 2010 has specified maximum permissible turbine heat rate for supercritical units as

1850 kcal/kwh (with TD BFPs) and 1810 kcal/kwh (with MD BFPs) with cooling water inlet temperature of 33 deg C and 0% cycle make-up.

Table.1 Main steam and reheat steam temperatures adopted by various utilities in India

Sl. No	Name of Plant	Main steam temp.	Re-heat steam temp.
1	Sipat – NTPC (660 MW)	537 °C	565°C
2	Sasan Ultra Mega – Reliance(660 MW)	566 °C	566°C
3.	Mundra – TATA (660 MW)	565 °C	593°C
4.	AdaniTiroda (660 MW)	566 °C	566°C
5.	NTPC Barh-2 (660 MW)	565 °C	593°C
6	NTPC – Gadarwara (800	593 °C	593°C
7	RPCL – Yeramarus (800 MW)	565 °C	593 °C

Further, CEA in their Standard Technical Features of BTG System for Supercritical 660/800 MW Thermal Units published in July 2013 have also recommended (not mandatory) to use minimum reheat steam temperature as 593 deg C.

As per present trend in India and in keeping with the recommendations of CEA, main steam and re-heat temperature are preferred as 566 °C and 593 °C respectively. The metallurgy for this temperature range is techno commercially proven all over the globe and there are many thermal power plants presently under satisfactory operation.

Main steam and reheat steam temperatures adopted by various utilities in India are tabulated above.

7. CHALLENGES/ISSUES WITH SC TECHNOLOGY IN INDIA

As detailed above supercritical technology in proved itself most economical w.r.t operating cost &environment considerations & widely used in Europe, USA & China for low ash, high GCV coal, however SC boiler performance with high ash Indian coal yet to be established. Limited availability of skilled manpower for Construction, operation & maintenance for large capacity supercritical unit is also other major issue of concern in India. Welding of spiral panels, high temperature alloy steel (P91, 92) is new for Indian erection agencies.

Welding of spiral panels, high temperature alloy steel (P91, 92) is new for Indian erection agencies. Weld joints in these areas with proper heat treatment is necessary trouble free operation of the units.

Presently in India very few SC units are under operation with high ash domestic coal. Following are the problems associated with firing Indian coal:

- Low volatile matter in Indian coal leads to high-unburnt carbon loses.
- Low boiler efficiency due to low CV and high ash content in Indian coals
- High ash and coal handling costs and milling power lead to high auxiliary power consumption
- High ash and high silica in the coal leads to higher erosion. Though lower flue gas velocities and provision of shielding plates can reduce erosion, it leads to higher capital costs for the boiler.

8. ALLOY STEELS FOR SUPERCRITICAL TECHNOLOGY

The high thermal efficiency of the SC and USC steam power plants cannot be achieved without the use of new alloys with higher creep strength and improved oxidation resistance. Operation above 537□C was possible due to the continuous development effort to improve the 9–12 percent ferritic steels (T91/P91, T92/P92, T112/P122 ref fig. above), as well as some advanced austenitic alloys (TP347, TP347HFG, Super 304). While the most severe requirements to withstand SC and USC operating conditions apply to boilers, significant constraints are also relevant to steam turbines and interconnecting hardware such as main steam pipes, valves, and so on. A major problem associated with the use of P91/P92 materials is the need for quality control at the manufacturing facilities. In project execution, the quality of the welding and post-welding treatments, particularly in the field, continues to be a concern, requiring that the treatments be monitored closely.

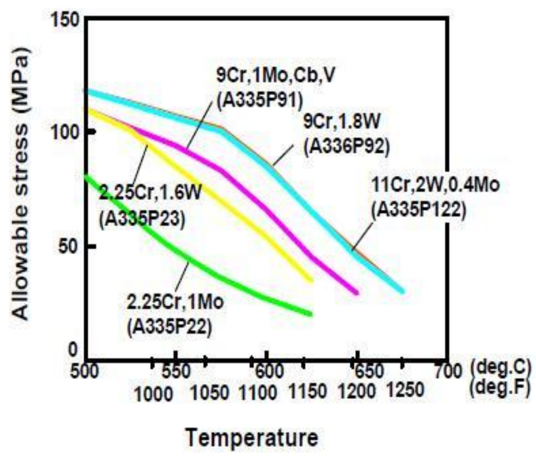

Fig.3 Allowable stress v/s Temperature

9. CONCLUSION

The population of Supercritical units in operation compared to 250/500 MW sub critical units is less in India. Although supercritical technology is mature & widely used in Europe, America, Japan & China with high GCV coal but their performance yet to be established with respect to lower GCV high ash Indian coal. The performances of few units which are operating with domestic coal are presently under observation. Learning form the problem/issues faced during operation & maintenance these units will lay foundation and decide future of SC technology in Supercritical Technology in Indian Power Sector.

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