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Advantages of Ultra Super Critical Technology in Power Generation

by

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Introduction

In recent years the Clean Coal Technology has been a must in power generation based on steam power cycles. Coal will still in the global perspective be the most important energy resource in power generation for many years. The increasing demand of harmful emissions from power stations has required the ongoing development of the Clean Coal Technology.

The very best Clean Coal Technology must be based on high efficiency plants where the coal consumption per KWh of electricity will be the lowest, and as a natural consequence bring the very best reduction of emissions.

It is well known that the efficiency of the water/steam cycle used in conventional power plants can be optimized by

- increasing live steam parameters (temperature and pressure)
- reducing the condenser pressure by means of a cold and effective cooling media preferably sea water
- using reheat and maybe double reheat
- optimising the feed water temperature
- selecting the single train mono component solution for the air/flue gas path

Further the total heat input to the cycle can be reduced by focusing on an increase of the boiler efficiency by

- a reduced flue gas exit temperature by means of an effective air preheater
- reduced Unburned Carbon (UBC) in the fly ash by effective and improved combustion
- a reduced air excess and thereby a reduced flue gas loss
- reduced leakage in the air prehaeter
- reduced pressure loss of the water/steam cycle
- selecting the single train mono component solution for the air/flue gas path

Some of these measures have been taken into account developing the high efficient Ultra Super Critical Power Plants in both Europe and Japan achieving plant efficiencies of nearly 48%.

Recently a number of new candidate materials for the last super heater tube bundles as well as steam lines have been introduced to the market making live steam temperatures of 620˚C possible.

Double reheat seems to add an extra 1.5% point to the cycle efficiency of the single reheat water/steam cycle. However, the latter has more or less become the standard water/steam cycle for the coal fired units of today. Demands for ever higher cycle efficiencies might though give the double reheat cycle the advantage over time.

Even though the increase of live steam pressure results in a higher cycle efficiency attempts to go much beyond the standard of 255 barg set by the Americans back in the 1960's have been few. A reason for this might be that whenever the live steam pressure is increased the temperature of the water/steam in the boiler furnace walls increases accordingly. The lack of weldable and reliable materials for these high temperature membrane walls has for years now blocked for a further increase of the live steam pressure. Presently both a Japanese and a European candidate seems to fill this hole, therefore live steam pressures well above 300 barg might be the near future.

Combining these new possibilities it can be possible to reach the 50% cycle efficiency in the near future (2010-12).

BWE Boiler Design

In Denmark the water/steam cycle has been developed step by step over the years. Until 1975 all units were of the sub-critical design. Hereafter the super critical design was introduced and further developed into the Ultra Super Critical (USC) design after 1990. This development has resulted in an ever increasing cycle efficiency illustrated on Figure 1.

It can be seen that the efficiency from the sub-critical units built in the beginning of the 1970's has increased from 38% to 48% for the last USC unit commissioned in 2001.

The development of BWE's boiler technology very much reflects this development. BWE started developing their once through boiler technology back in the 1950's when acquiring a license for the Benson technology from SIEMENS. BWE supplied the first Benson boiler in 1959 and has been an essential participant in the development of this technology. The biggest unit so far supplied was the sub-critical 600MWe unit 5 for the Energi E2's Asnæs Power Station commissioned in 1980.

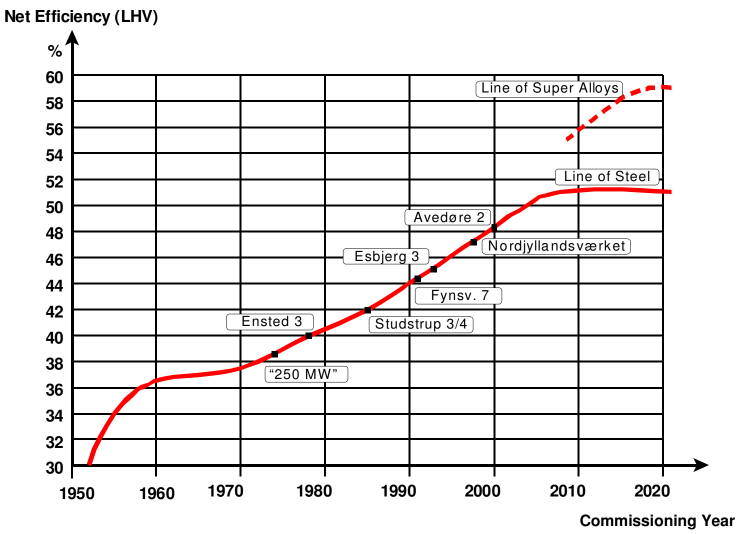

Figure 1*: Development of the steam power cycle in Denmark.*

The first many units were designed as 2 pass boilers. In 1987 BWE supplied their first once through boiler of the tower type. This was the 400MWe unit 9 for the STEAG's Power Plant Walsum. The tower boiler was found to solve a number of problems related to the 2-pass boiler design. Among these can be mentioned

- The flue gas changes direction through the convection zone of the boiler resulting in an uneven flow distribution and thereby a reduced efficiency of the heating surfaces.
- The media temperature in the membrane walls of the first and the second pass are not identical causing problems with temperature jumps where the membrane wall sections meet.
- Uneven load distribution on the top frame.
- The complicated penthouse is necessary.
- Complicated erection.

The tower boiler has a simpler structural design and is from a process point of view more efficient. Thereby the material consumption is reduced and the erection period is shorter. Main obstacles for the tower boiler design is:

- Increased height of boiler of app. 15-20%.
- The economizer being the final heating surface must be arranged in the less efficient parallel flow.

All together the tower boiler design was found to be economical and technical feasible and the design has been improved over the years.

Firing System

Back in the 1960's BWE started developing the circular burner. This product has been developed over the years until today's low NOx burner having 3 air ways (Figure 2) where the swirl is controlled by the use of axial turbulators.

1. Primary air, transporting the coal dust
2. Secondary air, for stabilising the ignition
3. Tertiary air, the main part of the combustion air in a stage combustion burner

The three air ways represent an in-flame air staging.
Properly adjustment of each burner creates an attached and slim flame witch provides the best circumstances for a low NOx formation in a tangential firing system.

The principle of air staging is further extended by in-furnace air staging by the use of Over Burner Air (OBA) and Over Fire Air (OFA). The direction of the OBA nozzles is angled somewhat towards the membrane walls. Hereby the oxygen content near the membrane walls is maintained at a level where reductive corrosion, often reported to occur in the oxygen poor zones of low NOx combustion, is avoided.

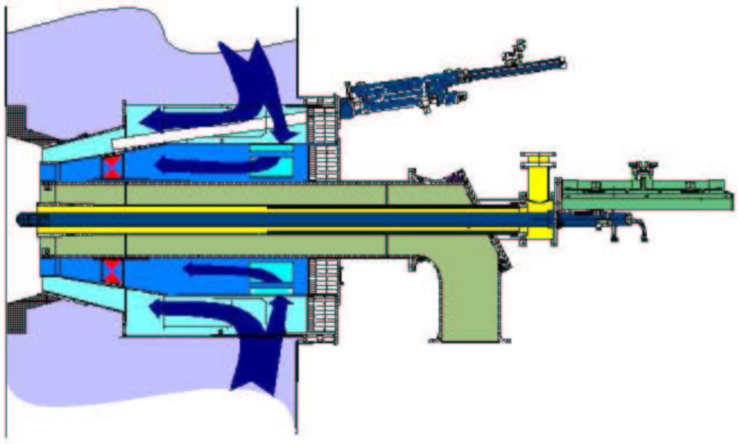

Figure 2*: BWE Low NOx burner*

BWE introduced the tangential firing concept for the Walsum unit 9 and have used this on all major boiler ever since. The results obtained have been convincing. The vortex created by the direction of the burners (Figure 3) results in an evenly distributed flue gas temperature field. In order to realize a homogenous flue gas distribution the OFA nozzles can be oriented counter wise the vortex of the burners.

Furnace Design

For obvious reasons the tangential firing concept works best in a quadratic furnace. In order to position the burners correctly the 4 corners are cut off forming an octagonal geometry (Figure 3). The long slim flames from the low NOx burners have optimal conditions used in tangential firing. As the flames wind upwards they do not create local hotspots but smoothens out the heat flux.

Since the problem with the flame length has diminished the cross section of the furnace is more or less determined by the vertical flue gas velocity entering the convection pass. The height of the furnace is adjusted to meet the required furnace gas exit temperature and ensuring that the residence time for complete combustion will be sufficient.

A general problem for the once through boiler is to ensure an effective cooling of the membrane walls in the burner zone where the radiation level is high. Several solutions for this have been seen over time. BWE's traditional solution has been the spiraled membrane wall designed to provide satisfactory cooling by means of water/steam velocity and an evenly distributed heat flux.

From an engineering point of view this design is a complication compared to solutions with vertical tubes. However, the experience is that the spiraled membrane wall contributes to form a uniform steam exit temperature profile of the membrane wall tubes.

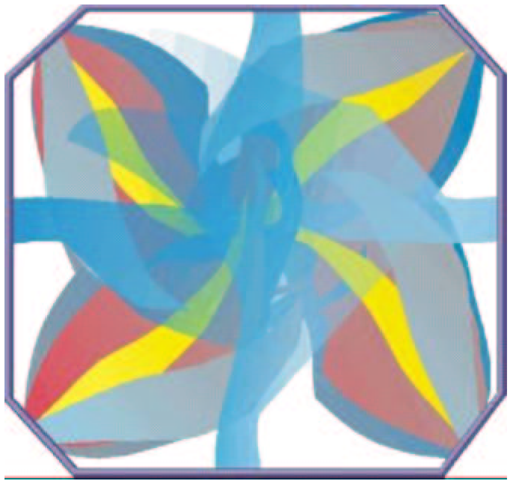

Figure 3*: Furnace cross section for tangential firing. Primary air (yellow), secondary air (red), tertiary air (blue), Over Burner Air (light blue) and Over Fire Air(clear blue)*

USC Boiler Design

The Coal fired USC boiler technology from BWE was developed as Clean Coal Technology in the beginning of the 1990's when Elsam ordered 2 x 415MWe units. These units, to be considered state of the art for that time, were characterized not only by their high live steam and reheat steam parameters (see Table 1) but also by reintroducing the double reheat water/steam cycle. Further as a consequence of the elevated steam parameters the feed water temperature was as high as 290˚C.

Table 1*: Main data for Danish USC boilers built by BWE.*

Plant	Year	Capacity	Steam data			FW
		MWe	t/h	barg	˚C	˚C
Skærbækværket Unit 3	1997	415	972	290	580/580/580	290
Nordjyllandsværket Unit 3	1998	415	972	290	580/580/580	290
Avedøreværket Unit 2	2001	415	1067	305	580/600	310

BWE's USC technology was further developed designing Energi E2's 415MWe USC unit 2 for the Avedøre Power Station. In this case the single reheat water/steam cycle was preferred. An overall plant efficiency of 48% was achieved by increasing live steam pressure to 305barg and the reheat steam parameters were increased to 600˚C and 70barg.

Experiences for NVV-3

The only coal fired USC boiler in Europe is Elsams 415MWe NVV-3 illustrated on Figure 4. Main data for the plant appear from Table 2.

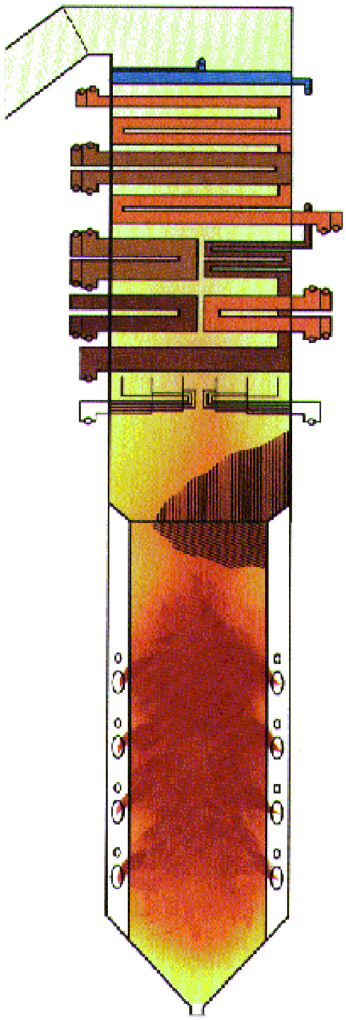

Figure 4*: NVV-3 Boiler elevation. Horisontal section 12.25x12.25m, Boiler house roof level 85m*

This unit was put in commercial operation in 1998 and has until now (2005) recorded 50000 hours. During almost all these hours the boiler has been running on coal.

During the commissioning of the boiler some minor problems were identified and adjustments were executed in the summer of 1999. Since then the operational record is more than convincing. The availability is more than 98%. The plant efficiency has been measured to > 47%. The emissions are within the required. The high steam characteristics have not caused any special problems and the double reheat system is easy to handle in daily operation.

Table 2 is recorded results from daily operations. It should be observed that the plant is a Combined Heat and Power plant (CHP). Column 1 states the results from power production only while column 2 reflects simultaneous generation of heat and power. In the power production mode the thermal efficiency achieved is 47.2% while the CHP mode realizes 90%,

Table 2 *Operational data from Nordjyllandsværket Unit 3. Column 1: Power production only100% load, condensing mode, 10 ˚C cooling water. Column 2: Combined Heat and Power production 100% load, back pressure mode, 4 ˚C cooling water*

Generator output	MW	411	339,5
Aux Power cons incl. DeNOx- and DeSOx plant	MW	26	26,5
Aux Power cons excl. DeNOx- and DeSOx plant	MW	23	23,5
400 kV to grid, incl. DeNOx- and DeSOx	MW	385	313
400 kV to grid, excl. DeNOx- and DeSOx	MW	388	316
District heating output	Mj/s	-	422
Turbo generator, heat rate, based on gen. output	kJ/kWh	6.736,6	8150,3
Boiler efficiency	%	94,2	94,2
Power plant, heat rate, based on gen. output	kJ/kWh	7.151,4	8652,1
Gross calorific value of coal	MJ/kg	26	26
Specific coal consumption, based on gen. output	g/kWh	275	148
Specific coal consumption (400 kV output to grid)	g/kwh	293	154
Thermal efficiency (400 kV output to grid)	%	47,20	90

Conclusion

USC is probably the best clean coal technology because it reduces the amount of coal used pr MWh due to the higher efficiency. The further development of this technology is ensured due to the continued development of new high temperature resistant materials as required by the joint European project AD700 heading for live steam temperatures of 700 ˚C. For this development the tower boiler seems to bee the preferred candidate.

The tangential firing system having circular burners has over the years proved to be very efficient in the tower boilers and will therefore be an important part of the Clean Coal Technology.