Modern boiler design

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1. Abstract

Introducing modern boiler concepts in the design of thermal power stations is nowadays becoming mandatory, not only from an economic point of view of new investments, but also as a significant and pro-active step towards the reduction of greenhouse gases & dust emissions by the enhancement of efficiency.

The increase in the cycle efficiency in modern power station is mainly achieved by increasing the steam parameters. The technological steps in boiler design are therefore shifting steam from sub critical to super critical and ultra supercritical parameters.

In addition to elevated steam parameters, other measures such as double reheat design and increased boiler efficiency are the key factors to achieve the desired maximization in heat rates.

BWE has expertise in enhanced boiler efficiency and reduced emissions (CO2 and NOx) with special design features such as:

- Fuel flexibility
- Effective design for air pre-heater
- Full control of air-coal ratio for each burner
- T-firing system and reduction of air excess
- Optimized design for main steam piping to fit elevated design parameters
- Single flue gas train
- Compactness

This article elucidates BWE's experience in achieving the goal. The benefits of the tower type boiler in comparison with 2 pass type traditional boiler design have also been described and analyzed.

Flexibility in operation of modern power stations is achieved by the Benson technology with sliding pressure, a well proven, reliable and effective operational mode.

The material selection in a modern boiler, being one of the key aspects of supercritical and ultra supercritical design in the past, is showing good results in the long term.

The controlled safety valve concept has been analyzed in comparison with the spring load type.

BWE's experience with co-combustion of biomass in ultra supercritical boiler has been summarized.

Future steps in modern boiler design have been elucidated.

2. Introduction

The objective of this article is to describe the main features of modern utility boilers reflecting the state of the art clean coal technology adopted by BWE. This article is an update of the article issued in January 2010 for the conference in Delhi. The article has been updated with information about latest development and experience from design and operation of newly commissioned boilers. The article also highlights the overview of advantages and limitations of once through tower type boiler designs and much familiar normally operating two pass drum boilers with moderate steam parameters.

3. Tower type – two pass

Since the mid 19th century two pass boilers have been the preferred boiler design in Europe. During this period BWE has mainly supplied two pass boilers to the Danish utilities. The two pass boilers designed have been in the range from 80 MWe to 640 MWe. Since the oil crisis in the 1970´s, utility boilers have all been pulverized fuel (PF) fired based on imported coal typically bituminous coals from Poland.

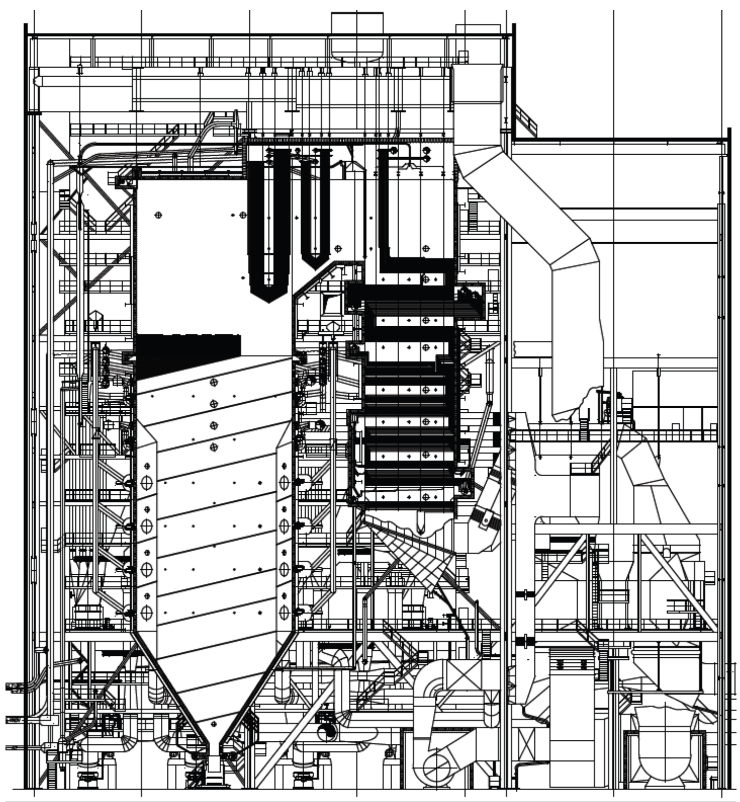

Figure 1: *Two pass boiler Fynsværket Unit 7 400 MW*

In the 1980´s the market required more flexible and effective boilers with high focus on boiler efficiency, load change rate and fuel flexibility. BWE decided to introduce the tower type design for utility boilers. In 1984 a 150 MW unit, front fired tower type boiler for Volkswagen in Germany and following this in 1988 a 400 MW unit tangential fired tower type boiler for Walsum Unit 9 also in Germany were supplied. Since then the main part of the 400 MW class boilers in Denmark have been of the tower type design supplied by BWE.

The tower type design has number of advantages such as the reduced foot print, reduced weight of boiler pressure part, easy installation of selective catalyst reactor (SCR), fully drainable pressure part, no extraction of fly ash and uniform flue gas temperature profile. The advantages are described more in detail below.

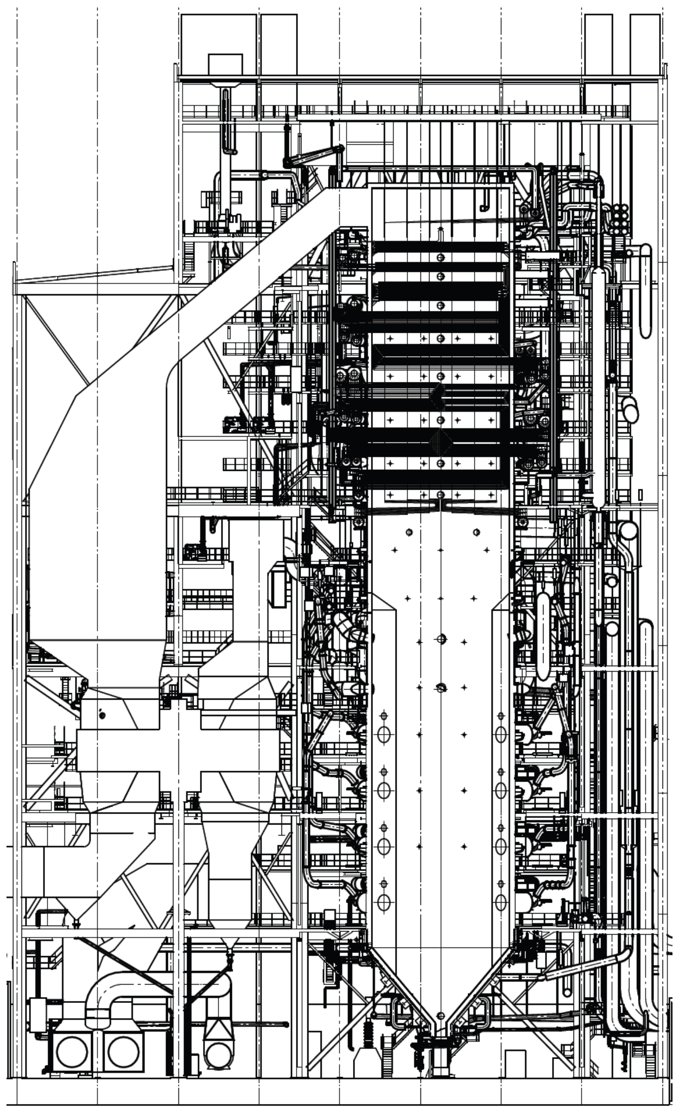

Figure 2: *Tower type boiler Nordjyllandsværket 415MW USC*

The foot print of the tower type boiler will be smaller than the one of the two pass boiler. The tower type design enables a very compact design of the boiler, SCR and APH (air pre heater).

The reduced foot print subsequently leads to a reduced boiler steel structure even through the total height is increased.

Since the heating surfaces of a tower type boiler are affected by a flue gas flow perpendicular to the banks, the heating surface will be fully effective as opposed to the two pass boiler where the heat absorption efficiency of the hanging super heaters is reduced. Subsequently the weight of the pressure part for a tower type boiler will be reduced compared to a two pass boiler.

The arrangement of boiler and APH makes it natural and easy to install an SCR. Ammonia injection will be installed just after the boiler outlet. The flue gas duct with possible installation of static mixer ensures that there will be a uniform distribution at the SCR reactor inlet.

All heating surfaces are arranged horizontally resulting in a fully drainable pressure part. Especially during start up, condensate can be drained out, pipe lines heated up and the steam temperature increased faster. For short overhauls dry preservation can easily be used. Steam side oxidation and increased formation of magnetite (Fe_3O_4) layers inside super heater tubes is critical in USC boilers. The risk of blocking the super heaters by exfoliated magnetite is considerably reduced in tower type boilers with horizontally arranged super heaters.

With the arrangement of the flue gas path from the boiler and downwards through the SCR and APH, there is no need for additional or intermediate extraction of fly ash as needed for the two pass boiler design where the flue gas is changing from downward to upward flow below the ECO. When the flue gas is leaving the APH, it proceeds in horizontal direction. The hoppers in the flue gas duct below the APH can be designed only to collect water from washing of the APH and not for extraction of fly ash. In this way all the fly ash will end up in the filter.

The tower type design especially in combination with T-firing results in a very uniform flue gas profile entering the first super heater. Temperature peaks in the flue gas profile is avoided resulting in less temperature imbalances in the super heaters. This is very important for materials operated at their limit in the creep range.

The advantages of the two pass boiler are the lower total height of the boiler and the easy erection of the boiler top including headers, heating surfaces and boiler ceiling. However the design of the boiler top of a two pass boiler is quite complicated. The boiler ceiling of the tower type is un-cooled. The boiler suspension is very simple and does not require any penthouse. In the light of a better performance in the total life time of more than 35 years some extra months for construction of the tower type boiler should be accepted.

The two pass boiler has some design limitations which are difficult to avoid. Temperature difference between first pass and vestibule / second pass membrane wall will often lead to crack after some years of operation. The tower type boiler has a very simple design of membrane walls and a smooth increase in temperature. An additional problem in the two pass boiler is when the flue gas is leaving the first pass and enters into the second pass, the particles of the flue gas will be concentrated close to the rear wall of the second pass and result in erosion of the super heater banks. Especially for high ash coal this will be a challenge and normally call for erosion shields.

The two pass boiler has some geometrical limitation which makes it difficult to optimize the boiler pressure part design. The pitch of the first hanging super heater banks SH-1 needs to have a mutual distance (400-800mm) to avoid blocking of slag. On the tower type boiler the first super heater banks SH-1which are typically arranged just above the final reheater can be designed with smaller pitch (100-200mm). The number of parallel tubes can be higher and subsequently the pressure loss will be smaller.

Tower type	**Two pass**
Uniform flue gas profile and reduced temperature peak in pressure part	Uneven flue gas flow profile and high ash concentration on second pass rear wall
Excellent RH temperature characteristic	Cold built in conditions for final RH
Effective heating surfaces, no ineffective (dead) areas	Partly in-effective heating surfaces
Reduced foot print, increased height	Reduced height, enlarged footprint
Low pressure loss due to high number of parallel tubes in super heater banks	Higher pressure loss due to limitation in heating surface design
Easy installation of SCR	Difficult installation of SCR and increased duct work
Smooth membrane wall temperature increase	Thermo stress and cracks in membrane wall between first pass and vestibule / second pass
No extraction of fly ash	Extraction of fly ash below ECO
Fully drainable super heaters, fast start up.	Risk of blocking the hanging super heaters by exfoliated magnetite.
Simple boiler suspension, penthouse not required	Complicated boiler suspension

Figure 3: *Comparison table tower type versus two pass boilers*

4. Ultra Super Critical (USC)

The USC boiler operates at high efficiency resulting in lower fuel consumption for electricity generation. The combustion in the USC boilers will therefore lead to a reduced CO2 emission compared with other type of boilers.

BWE has designed a number of 400 MW USC boilers which have been in operation since 1998. The data from actual operation shows a very high plant efficiency and high availability. The boilers are operated with steam parameters of 290-305 bar and 580 – 600 °C. New USC boilers (Porto Tolle 3 x 660MWe) are being designed using steam temperatures of 600 – 610 °C.

Plant	**Year**	**Size MWe**	**Type**	**Country**	**RH Cycle**	**FW temp.**	**HP pres.**	**HP/RH temp.**	**Plant Efficiency**
Asnæsværket Unit 5	1981	640	Two pass	Denmark	Single	263 °C	190 bar	540/540	40%

Walsum Unit 9	1987	410	Tower	Germany	Single	253 °C	200 bar	535/532	39%
Fynsværket Unit 7	1991	400	Two pass	Denmark	Single	280 °C	250 bar	540/540	44%
Staudinger **	1992	550	Tower type	Germany	Single	275 °C	262 bar	545/562	43%
Skærbækværket Unit 3	1997	415	Tower	Denmark	Double	298 °C	290 bar	582/580/580	49%*
Nordjyllandsværket Unit 3	1998	415	Tower	Denmark	Double	298 °C	290 bar	582/580/580	47%
Avedøreværket Unit 2	2001	415	Tower	Denmark	Single	320 °C	305 bar	582/600	49%*
Porto Tolle Unit 2,3 and 4	design	3x660	Tower	Italy	Single	315 °C	252 bar	604/612	45%

* Avedøreværket Unit 2 and Skærbækværket Unit 3are designed for coal but operating on NG / HFO. The calculated efficiency for Avedøreværket on coal is 48%.** Scope partly by BWE and partly by Deutche Babcock

Figure 4: *Comparison table Sub critical, SC and USC plants*

Pressure part material selection

The elevated steam parameters require higher grade pressure part materials. Final HP superheater banks and final RH banks are made in austenitic steel. In order to reduce steam side oxidation, fine grain austenitic materials are selected. Relevant materials are TP347HFG (ASME Code case 2159) and TP304CuCbN (ASME code case 2328) 310N/HR3C and Sanicro25. The two latter with 25% Cr and subsequently high raw material cost. TP304CuCbN calls for inner shot peening in order to obtain sufficient fine grain structure.

For main steam and hot reheat lines at 600 – 610 °C, the traditional material P91 is no longer sufficient. On the 400 MW USC boiler Avedøreværket Unit 2 (AVV-2) the outlet headers and the steam lines are made fully in P92. The P92 material is a 9% Cr martensitic steel like P91 however with improved creep range data due to W alloy.

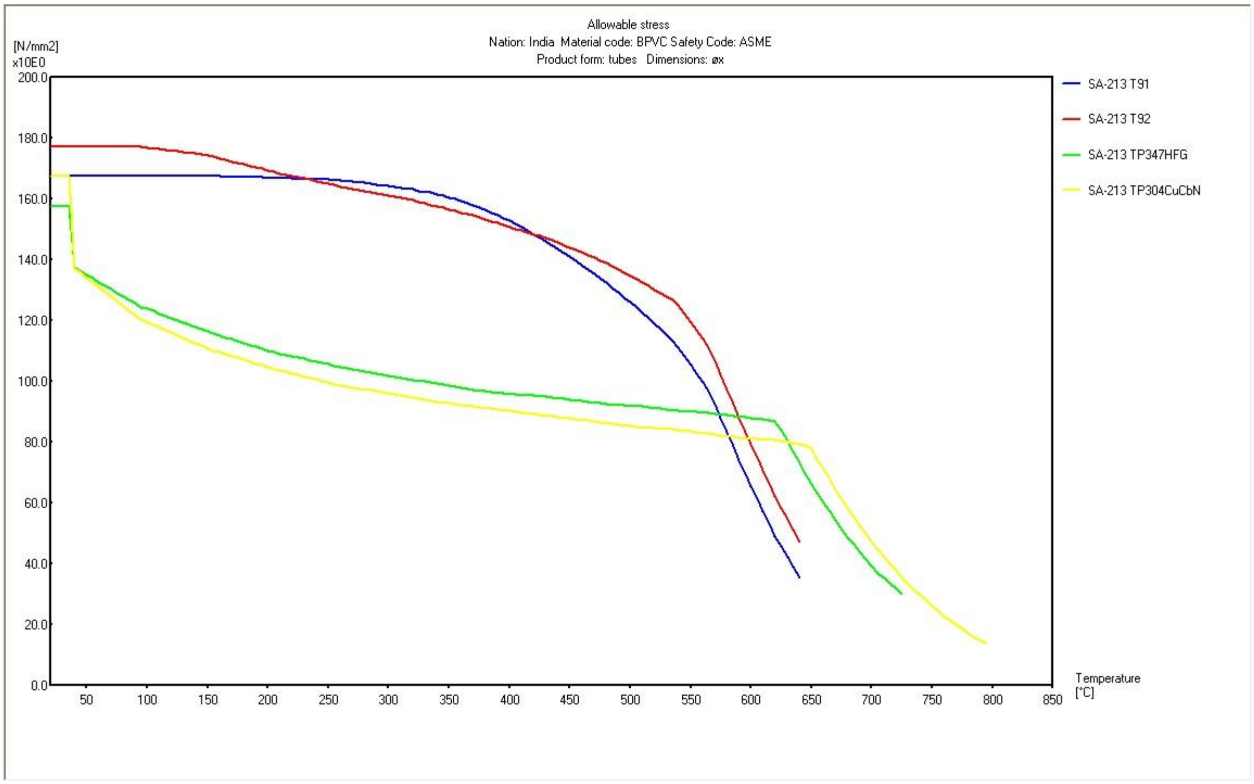

Figure 5: *Allowable stress T91, T92, TP347HFG and TP304CuCbN*

When ultra super critical boilers operate, the materials after the evaporator are mostly in the creep range. Due to the elevated steam temperature, the materials operate in the creep range on the edge of what is possible. A small increase in temperature will result in a tremendous reduction of allowable stress. It is therefore essential to reduce the temperature imbalances in the boiler by correct boiler design. This is possible by a number of well proven measures as uniform flue gas profile (as result of T-firing), intermediate outlet headers, cross over of steam from left to right boiler side and extraction of main steam via four outlet headers (instead of usual only two).

The furnace membrane walls are usually designed in T12 (13CrMo4-5) material for boilers up to 290 bar. Also the upper pass with vertical membrane wall is made in T12 material with design temperature up to 500 °C. Such a membrane wall design using fully T12 is only possible through a detailed and careful design with focus on reduction of temperature imbalances and stress concentrations. Actual operation has shown that chemical cleaning of the evaporator after 70-90.000 hours is needed.

An important precondition for a proper evaporator design is a combustion system resulting in well distributed heat absorption. On the tangential fired boilers the spiral helical rotation is opposite to the combustion vortex resulting minimum temperature imbalances at spiral transition outlet.

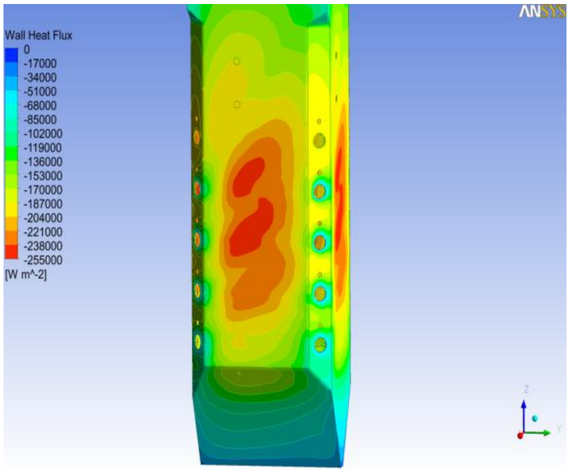

Figure 6: *heat flux distribution resulting from tangential firing*

It is possible to increase the steam parameters even further by using T23 material (ASME Code case 2199). The T23 material has good creep behavior up to 550 °C and does not require PWHT on smaller dimensions. T23 is developed based on T22 modified by adding mainly tungsten (W) and reducing Mo and C content. In 2009 BWE has commissioned a small Benson boiler (350 MJ/s heat input) using T23 for membrane walls. However T23 is very sensitive to deviation in welding parameters. Care must be taken in order to avoid too high hardness and low ductility in the welds and HAZ. PWHT is needed for larger dimensions.

Using elevated steam parameters also requires a turbine that fits in. Adequate turbine materials and design are also important issues however not described in this article.

Feed Water system

Studies of the cycle calculations including the number of preheaters have indicated that there is a optimum plant efficiency using FW temperatures at approximately 320 °C.

Using the traditional material SA-106 Gr. C for the FW system and inter connecting piping down to the evaporator inlet results in high wall thicknesses. When USC technology with design pressure above 250 bar is introduced, it should be considered to use alternative materials. In Europe it has been a common practice for more than 20 years to use the material 15NiCuMoNb5-6-4 (also known under the trade name Wb36) (ASME Code case 2353). Wb36 is a copper-nickel-molybdenum alloyed weldable high temperature steel used up to 371 °C (450 °C acc. EN code). Even valve manufacturers have included the material in their standard program. Using Wb36 the wall thickness can be reduced by 25% resulting in cost savings on material, welding, induction bending, hangers, support structures and resulting in a more flexible pipe system.

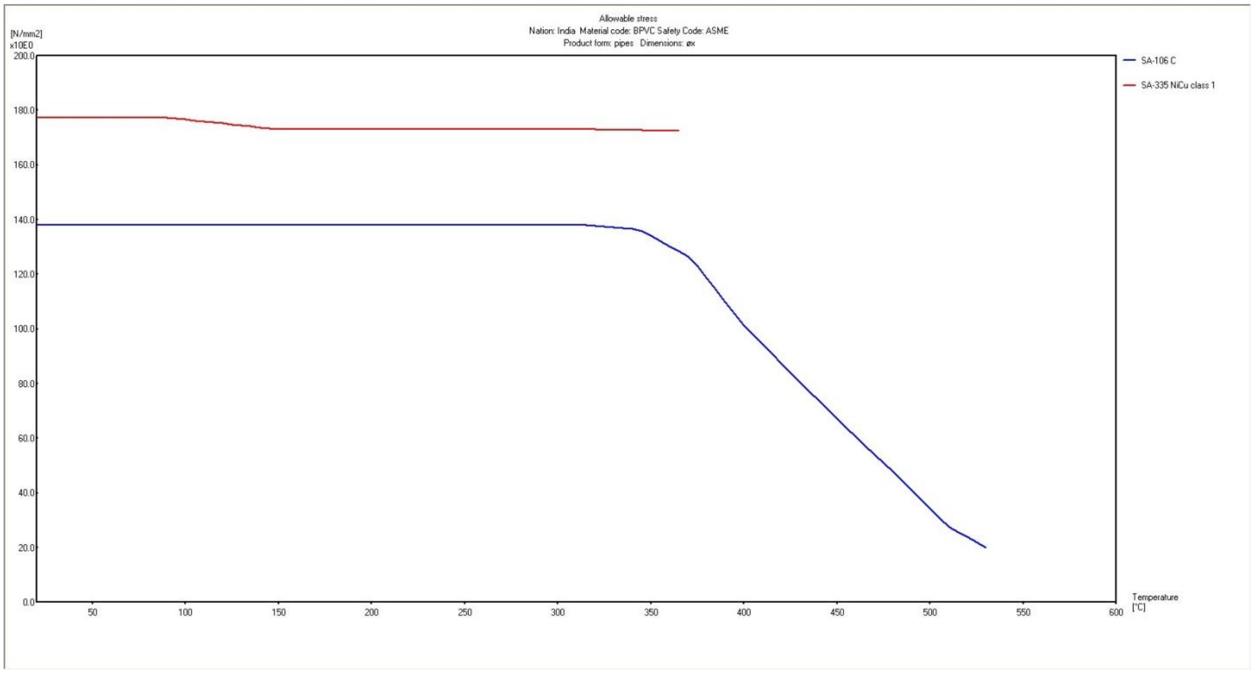

Figure 7:*Allowable stress SA-106 Gr.C and Wb36 ASME Code case 2353*

Return of investment (material cost)

When the total amount of materials for the boiler pressure part is evaluated, it is clear that the extra cost of using USC steam parameters is very limited compared to the total amount of materials for boiler pressure parts (additional cost 6-8%). When the remaining part of the boiler or the plant is also taken into consideration, it is true that the extra cost for an USC boiler is negligible.

Modern USC boilers will have a plant efficiency above 45%. It becomes then clear that the investment will be returned in short time. The coal fired 400 MW USC boiler Nordjyllandsværket designed with double reheat cycle and using cold seawater for condenser cooling was supplied by BWE and has been in operation since 1998 with a proven plant efficiency of 47%.

5. Double reheat

One of the obvious initiatives to increase plant efficiency is to introduce the double reheat cycle. This will increase the plant efficiency by approximately 1%. Two of the 400 MW USC boilers supplied by BWE are designed for a double reheat cycle. When boilers are designed with double reheat, it is extremely important to make accurate boiler calculations and to balance the heat absorption between the two RH parts.

Even with increased cost for the turbine, for additional pipe work and for valve arrangement it might be commercially attractive to design with double reheat cycle in the near future in countries with high electricity costs and emission taxation. Double reheat is a well proven technology to be used in the effort towards the 50% efficiency (LHV).

6. Once trough design

Since 1852, BWE has supplied steam generating plants for industry and power stations. It is thus one of the oldest manufacturers of steam boilers in the world. In 1955 BWE acquired a license for the Benson once-through boiler design and has since then been one of the leading companies for advanced boiler designs.

The tendency in Europe is that all new boilers from 300 MWe and upwards are of the once through design. However, drum type boilers are still in the BWE portfolio since small scale boilers and specially grate fired biomass boilers with heat input 50-125 MW are still of the drum type design.

The well known advantages with the once through boiler design is described below in detail.

First of all once through boilers are not limited in pressure as the drum boilers where circulation is linked to the difference in water and steam density. Thus the plant cycle can be increased by increase of steam parameters above the critical point. The limitation on once through boilers is mainly linked to the selected materials for pressure part and turbine design.

Furthermore when a drum boiler is designed to operate close to the critical pressure, the split between the evaporator and the super heater becomes a challenge. If no special designs are introduced, the evaporator part of the boiler often becomes too large since the membrane walls of the first pass all are designed as evaporator.

When the boiler has to be designed for and is to operate with a variation of coal types available on the market, the sizing of the evaporator becomes critical. The different coals result in different heat absorptions and for drum boilers the evaporator is fixed.

Once through boilers are more flexible with respect to heat absorption since the evaporation fully takes place in the furnace and superheating starts already in the membrane wall.

Benson minimum

Below a certain load called the Benson minimum load it is necessary to maintain sufficient flow through the evaporator by forced circulation.

The forced circulation is established by a circulation system working either via dedicated boiler circulation pump (BCP) or via circulation through FW-tank / deaerator and FW-pumps.

The Benson minimum load is normally at 35 % boiler load depending on the design of furnace membrane wall. A proper boiler design includes correct decision on number of parallel tubes, pitch and inner diameter of membrane wall tubes.

In circulation mode (<35%) the water and steam leaving the evaporator is separated in the cyclone separators and the water is lead to the level vessel. From the level vessel the water goes to the circulation system.

Minimum boiler load

Recently utilities have required boilers able to operate at low load condition and ready to follow the electricity demand quickly increasing the load. Subsequently it has therefore become essential to keep the boiler in operation during night and weekends at low load condition.

Min. boiler load on coal without support firing is typically possible down to 25% boiler load depending on coal composition and mill design.

Load jump and load change rate

The drum type boiler has a certain amount of energy accumulated in the large portion of water in the evaporator and drum. Load jumps can therefore be performed by reducing pressure and release more steam to the turbine.

The amount of water in the once through boiler is very limited however load jumps can easily be made by well known and proven methods. Load jumps can be executed via bypass of HP preheaters, LP preheaters or condensate stop depending on the cycle arrangement. Planned load jumps can be executed via pre throttling of either HP or IP turbine valves by operating the boiler in modified sliding pressure mode as described below. The once through boiler with a BWE combustion system can easily follow a load change rate of 5%/min (in the range from 40-90% boiler load).

7. Optimized combustion system

The complete coal firing systems consist of BWE Low-NOx burners, over burner air (OBA) and over fire air (OFA) systems, see Figure . The system is well proven and since 1990 more than 500 of BWE coal, bio dust, oil or gas burners have been commissioned world-wide. BWE has developed a tangential firing technique using circular burners and air staging. By inclusion of OFA, this system is extended to in-furnace air staging resulting in reduced NOx formation. The complete BWE coal firing system with tangential firing is used in the latest USC boilers in Denmark for a fuel range including coal, oil, gas and biomass.

Air staging

The principle of air staging means applying just enough air to make the combustion stable but not enough to allow the nitrogen to be oxidised to NO and NO2. The NOx formation is governed by local furnace parameters such as gas-temperature and composition, and in low-NOx burner designs the combustion air is controlled so that a staged mixing of fuel and air takes place. The result is a long flame where zones with simultaneous high temperature and high air-fuel ratio, are avoided.

By implementing low-NOx burners alone the NOx level can be reduced by 40-50%, compared to traditional "high NOx" coal burners.

The combustion system is composed by five air flows, see Figure and Figure. The three co-axial burner air outlets are:

1. Primary air (PA: The primary air and conveying air for the pulverized coal)
2. Secondary air (SA)
3. Tertiary air (TA)
4. Over burner air (OBA: The air nozzles above each burner)
5. Over fire air (OFA: The air nozzles above the burner zone)

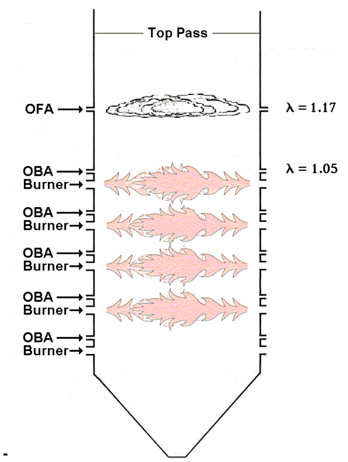

Figure 8: *To the left: BWE coal firing system with low-NOx burners, Over Burner Air (OBA) and Over Fire Air (OFA). Excess air is typically increased from just above stoichiometry to* λ *= 1,15 – 1,17 by use of OFA. To the right: two off 69 MW BWE low-NOx burners with OBA in a T-fired boiler.*

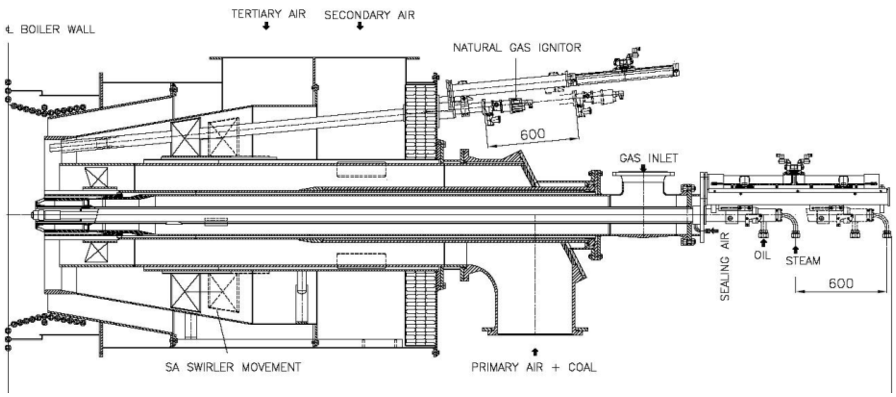

Figure 9: *BWE low-NOx corner burner with central gas lance, oil lance and three axial airflows: primary (PA), secondary (SA) and tertiary (TA). Suitable for multi fuel design.*

The use of circular burners provides an annular airside protection against CO corrosion of the furnace walls in contrary to traditional jet burners in tangentially fired systems. This protection is enhanced by the use of the over burner air (OBA) nozzles which maintain a layer with higher stoichiometry close to the walls.

For in-furnace air staging, the overall air-fuel ratio in the burner zone is reduced to just above stoichiometry ($\lambda \approx 1.05$) which results in an even better NOx-performance. Finally, the principle of air staging is extended to the whole furnace by use of over fire air (OFA). With both low-NOx burners and OFA, the NOx level is typically reduced by 60 to 70% compared to a high NOx combustion installation.

8. T-firing – front / opposed

When the T-fired furnace is considered in a cross section, it is obvious that there are no dead corners. On the other hand it is clear that front and opposed fired boilers will have dead corners at the outer burners close to the side walls.

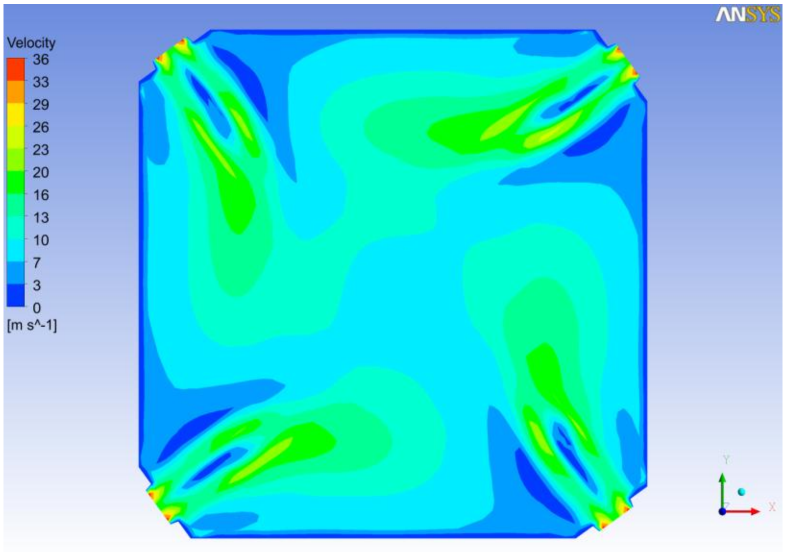

Figure 10: *CFD calculation of a 660 MWe tangentially fired USC boiler.*

It is therefore possible to operate the T-fired boiler with lower air excess without the risk of CO corrosion at the membrane walls. BWE designs T-firing system for coal combustion with air excess down to λ 1,15.

BWE combustion system for T-firing will have over burner air (OBA) injected just above each burner. The OBA is part of the air staging and contributes to a reduction of NOx formation. Furthermore the OBA ensures sufficient oxygen content along the membrane wall and in this way protecting the membrane walls against CO corrosion. No CO corrosion is reported on T-fired boilers with a BWE combustion system installed.

The T-firing concept results in a very uniform flue gas temperature profile at the outlet of the furnace. The temperature imbalance in the first heating surfaces caused by the flue gas profile is therefore reduced significantly. In USC boiler design this is essential since the materials operates in the creep range where the allowable stress is dropping fast when the temperature is increased.

Front, opposed or even worst box type boilers will have high temperature peaks in the flue gas temperature profile at the furnace outlet resulting in temperature peaks in the superheater banks.

By T-firing it is possible to operate with longer flames and without swirl in tertiary air sectors of the burner. Front and especially opposed fired boilers are very sensitive to variation in the coal composition and the related shape of the flame. Often it is required with heavy swirl in order to reduce the flame length. In opposed fired boilers the flames will meet at the middle of the furnace and generate NOx.

9. Fuel flexibility

Co-combustion

Co-combustion of biomass and coal in utility boilers is a proven technology by BWE. A heat input of 10-15% on biomass is possible and it is still possible to use the fly ash for cement production. The biomass can be straw, wood chips or wood pellets.

Co-combustion of biomass is carried out through the PF coal burner by installing a centre lance injecting biomass divided into fine particles to the furnace.

As for biomass, RDF (Refused Derived Fuel) can be injected into the furnace via an inner tube in the centre of the PF burner.

Multi fuel concept

The BWE combustion system and BWE burners can be designed suitable for a multi fuel concept. The standard PF burner as presented in the section above can be designed with an inner gas and simultaneously an inner HFO/LFO oil lance. The combustion system can be designed for 100% coal, 100% oil and 100% gas firing. In this way the fuels can be changed quickly and it is also possible to operate with different fuels on different burner levels. The 400 MW multi fuel USC boiler Avedøreværket Unit 2 has 4 burner levels each designed for coal, oil and gas.

Furthermore the normal pulverized fuel system can be used for biomass firing. Wood pellets are simply grinded in the mills and combusted via traditional PF coal burners. This concept is implemented on the multi fuel USC boiler Avedøreværket Unit 2 where a heat input of 0,7x800MJ/s corresponding to 36 kg/s on wood pellets is proven.

Besides the utilities other industries like the steel industry is demanding new boilers designed with multi fuel firing systems able to utilize the waste lean gasses from the steel mills in order to improve the plant profitability and avoid unnecessary loss of energy. BWE is fully capable of meeting the demand and is presently supplying flexible multi fuel fired boilers in India.

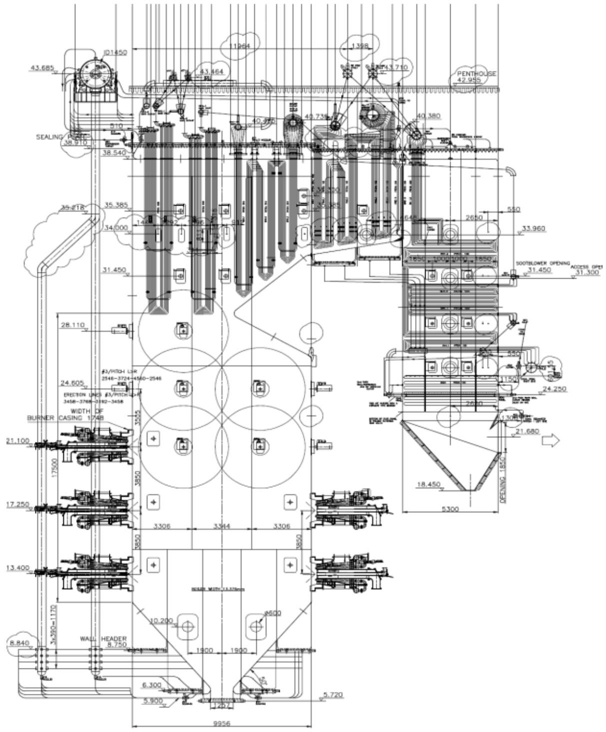

Figure 11: *2 x 150 MWe multi fuel (coal, lean gas, oil) fired drum boilers for steel plant in India.*

10. Single train – double train

There is a tendency to design new utility boilers in Germany and Denmark with single train flue gas path and mono components. For many years BWE has implemented the design with only one APH. Based on operation experience the availability of these plants is very high. All critical components like bearings can be designed for a high life time (APH bearing typically for 200.000h).

The single train mono components concept is used for plants up to 800 MWe and is recommended for modern boiler design.

	Single train mono component	**Double train**
FD fan	1	2
PA fan	1	2
APH	1 (with two drives)	2
ID fan	1 or 2 *	2
Dampers	none	approximately 16

		(with sealing air)
Duct work	reduced	complicated
Pressure loss flue gas	low	high
SCR	1 x 100%	2 x 60% (two set of ammonia injection)

*If the high starting current is unacceptable, two fans can be installed still in a single air / flue gas path design.

Figure 12: *Comparison table single train / mono component versus double train*

For the double train solution, the equipment and the duct system are arranged as two parallel flue gas paths. The components are normally arranged in a way that makes it possible to run the boiler at 60% load with one of the FD-fans out of operation.

For the single train solution, the equipments and the duct system are arranged as a single flue gas path with no damper exposed to flue gas.

Advantages and disadvantages single train

The main advantages of the single train design are:

- Lower cost due to reduced number of components.
- Lower APH leakage rate (reduced from 8% to 6%)
- Less power consumption
- SCR design 100% (not 2 x 60%)
- No temperature imbalances
- No dampers in the main flue gas path

The disadvantages are:

- Higher starting current on FD- and PA-fan
- Higher load on single steel columns APH / SCR area

Single train APH design

Below is a table of comparable APH designs for single respectively double train on a 660 MW boiler.

	Single train	**Double train**
No of APH	1	2
Type	Quad sector	Tri sector
Rotor diameter	23,44 m	16,11 m
Total air leakage	29,2 kg/s	38,7 kg/s
Total weight	1890 tons	1910 tons

Availability USC single train

The single train / mono component concept has been used for a number of boilers for more than 20 Years. The 400MWe USC boiler at NJV Denmark runs since 1998 with a very high availability.´

Year	Availability	Note
2004	93,7%	Damage due to sootblowing
2005	95,7%	Thermo well replacement
2006	88,0%	Turbine breakdown
2007	99,5%	

Figure 13: *Availability Nordjyllandsværket 415 MW USC. The availability is calculated exclusive of planned maintenance.*

When calculating the availability factor of single train mono component configuration, it can be proven that the total availability of the boiler is higher than for double train and redundant systems since the risk of failure is reduced significantly.

The APH is equipped with two 100% drives. The two drives can be in operation simultaneously. In case one drive fails, the other will take over.

Layout single train

The single APH is typically arranged at elevation +35 m. A single centre column is positioned at the centre line boiler supporting the main APH rotor bearing. Due to the large diameter of the APH rotor, the APH casing is supported on beams outside the footprint of the boiler itself.

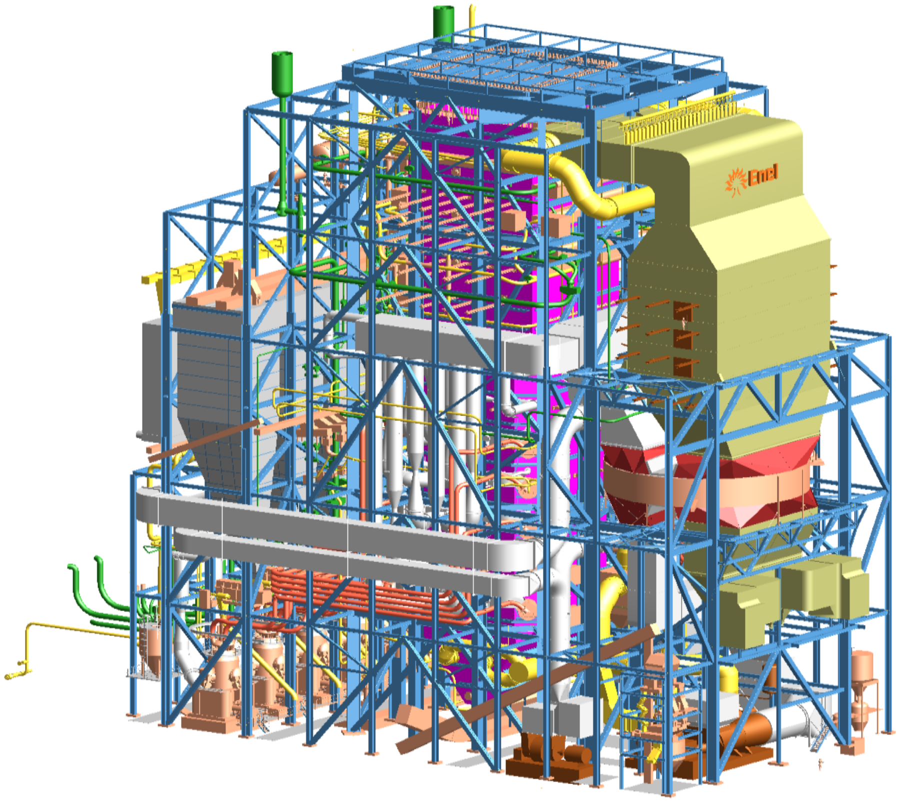

Figure 14: *Plant layout PortoTolle 3 x 660 MW USC single train.*

Typical Electrical load 660MW single train

When single train / monocomponent design is applied, the electrical system must be designed to meet the required electrical load. For a 660 MW plant the typical electrical installation will be:

- FD-fan motor size: 3500 - 3800 kW, 745 RPM
- PA-fan motor size: 3850 - 4000 kW, 1000 RPM

Together with the single APH concept, it is suggested to have two main drives for the APH. On top of one of the drives, an AC emergency drive will be placed. The Emergency drive is connected to the emergency diesel generator.

- Main drive 1	(electrical)	1 x 22 kW
- Main drive 2	(electrical)	1 x 22 kW
- Emergency drive	(electrical)	1 x 5.5 kW
- Emergency drive	(pneumatic)	1 x service air supply - 375 m3/h at 7 bar

11. SCR

The installation of an SCR has become mandatory in many countries. It is therefore essential to keep the SCR in operation in the whole load range typically from 25% to 103% boiler load.

Obviously the operation requirements for the SCR have an influence on the boiler design.

The acceptable flue gas temperature window for a proper SCR operation is from 315 to 400 °C. Short time operation (2-3 hours) below the 315 °C is acceptable if the temperature is increased above 350 °C afterwards.

Previously boilers have been designed with an SCR bypass used during start up. The “No SCR bypass” concept is based on a full flow through the SCR during start up. All BWE reference plants and recently built coal fired plants in Germany are designed without any SCR bypass.

12. Split ECO

The tower type design makes it easy to arrange a split economizer.

A split economizer is divided into two separate heating surfaces located before and after the SCR plant in the flue gas stream. The feed water is first lead to the economizer located between the SCR plant and APH and from here it is led to the economizer in the boiler top. The total heating surface of the two economizers is sized to maintain the same heat absorption as for the basic design with a single economizer.
The split of the heating surface is chosen to ensure the best possible operating conditions for the SCR plant over the entire operating range of the boiler. The acceptable flue gas temperature window for proper SCR operation is from 315 to 400 °C.

The split ECO will lead to a high reduction of the boiler steel structure and a reduction of the membrane walls by about 1.5 m.

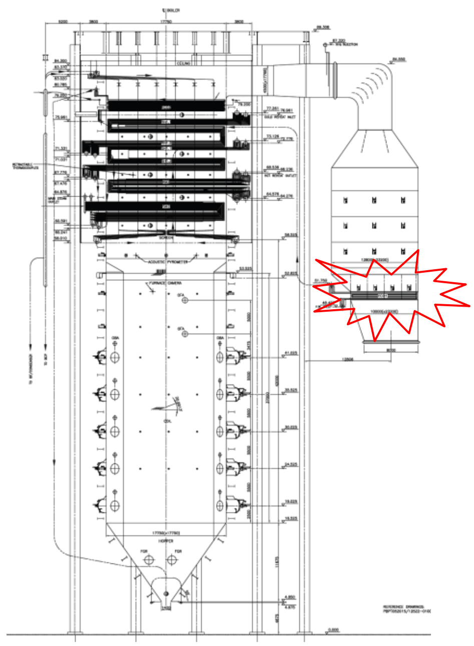

Figure 15: *Section view boiler pressure part Porto Tolle 3x660MW arrangement of split ECO*

13. Controlled safety pressure relief systems (CSPRS)

Preferably hydraulically operated safety valves are used to protect the high pressure part as well as the re-heater in power stations. In comparison to the use of spring loaded safety valves, the number of installed components can be reduced drastically by the use of combined bypass and safety valves.

Controlled pressure relief	Traditional safety valve arrangement
• 100% HP combined bypass units with safety function Hydraulic Spring loaded (two valves) • 116% RH safety valve Hydraulic Spring loaded (two valves)	• 80% HP-bypass valves (two valves) • 23% HP vent valves (two valves) • Shut off valves in front of HP-bypass (two valves) • 103% HP spring loaded safety valves (two valves) • 100 % RH spring loaded safety valves (two valves) • 40% RH vent valves(two valves)

Comparison table CSPRS versus traditional system

A modern boiler is typically equipped with following valves:

- 100% HP Hydraulic Spring loaded bypass units with safety function (two valves)
- 100% + 16,5 % RH Hydraulic Spring loaded safety valves (two valves)

The schematic arrangement is shown on the diagram below. With this design there will always be sufficient flow through the reheater. The RH safety valves will be designed for 100% flow from the HP- part plus a spray water flow of e.g. 16,5%.

The span between normal operation pressure at MCR 103% and the set pressure of the safety valves can be used for overload operation. By having combined HP-bypass and HP safety valves, the whole span can be used.

It is normally foreseen that the LP-bypass valves at the turbine will have a capacity of 60-70%. (in general not included in the boiler scope). At turbine trip the RH safety valves will open. The boiler load will be reduced down to 60-70 % load. The RH safety valves will then be closed and the full RH flow will pass through the LP-bypass valves.

The HP-bypass and the RH safety valves will be designed for three type of operation:

- Safety relief (opening time < 2sec.)
- Quick opening (opening / closing time 5sec.)
- Control (opening / closing time 15-20 sec.)

The safety relief control unit will open the valves at the set pressure as if they were simple spring loaded safety valves. The hydraulic relief system is in line with EN Code 12952-10.

The "quick opening function" relieves the pressure at low load and part load when the sliding pressure is exceeded by a certain margin. In this way the quick opening function avoids stagnation in the steam flow which is essential for the sufficient cooling of the super heaters and reheaters.

The "control operation mode" is used for pressure and flow control during start up conditions. By continuous boiler operation after a turbine trip, the HP-bypass valves are controlled so that the boiler pressure is controlled and follows the sliding pressure curve.

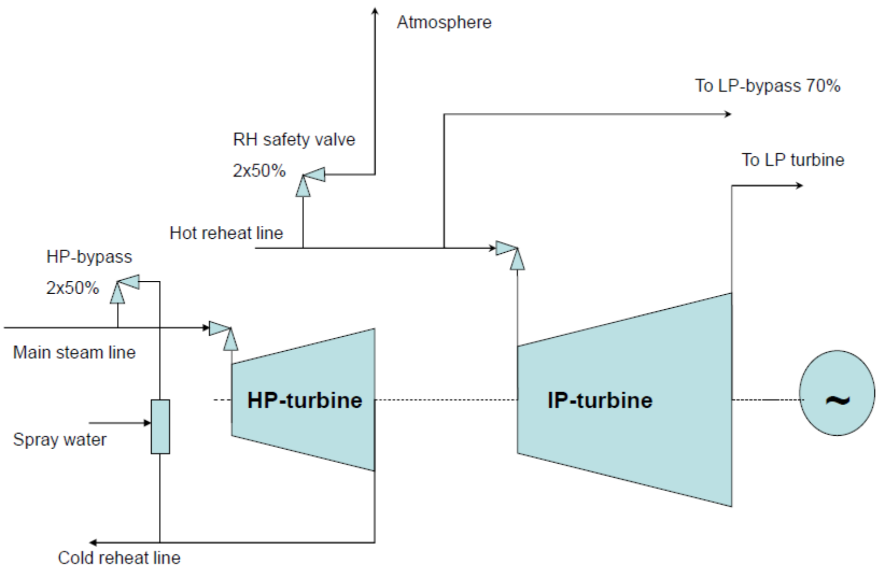

Figure 16: *Schematic arrangement of HP-bypass and RH safety valves*

The safety valve design described is in line with the references of BWE and in line with the design of new USC boilers in Northern Europe.

Pipe layout

The pipe layout will be simplified due to a reduced number of branches of safety, bypass and vent valves. The amount of piping on a 660 MW unit will be reduced by approximately 50 tons of pipes and 6 large Tee-pieces all in P92.

The HP-bypass valves are connected closely to the main steam line and in this way kept at sufficient temperature. The two HP-bypass valves will always operate in parallel avoiding temperature imbalances between the left and the right side of the boiler outlet.

The RH safety valves will be equipped with exhaust pipes and silencers.
Only the RH safety valves require a small bore heating line.

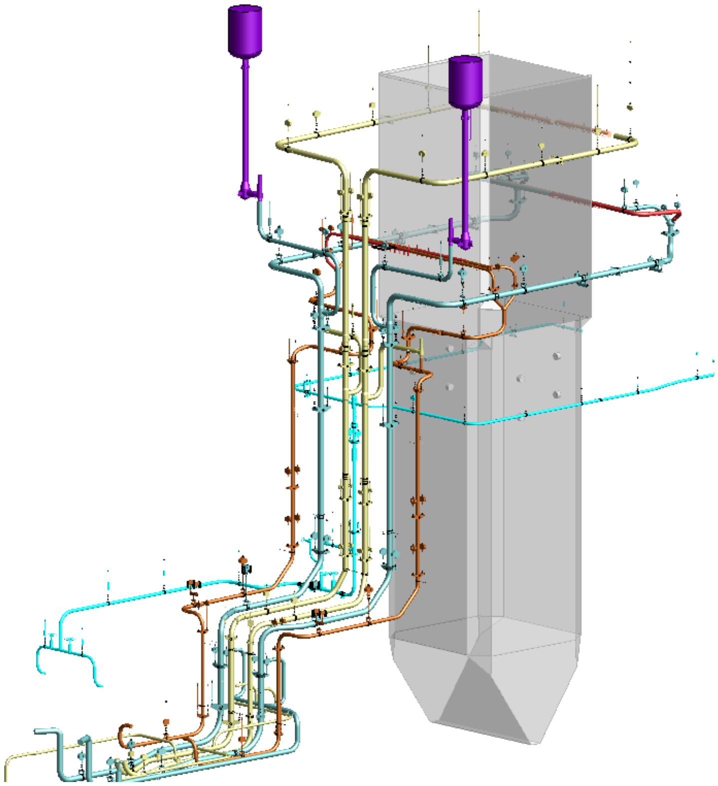

Figure 17: *Layout HP piping Porto Tolle 3 x 660 MW*

14. APH sealing system

Reduced APH leakage is vital for a proper operation of the boiler and to improve boiler efficiency. One step is the single train / mono component design as described above. Another step is to install an improved APH sealing system with reliable sensors.

The BWE APH has a number of upper and lower radial seals. Each radial seal consists of two plates hinged together. Each radial seal control consists of one actuator, one distance sensor and one mechanical safety device.

The control of the sealing system is integrated in a local control panel with a PLC. The gap distance between the radial seal plate and the APH rotor as measured by the distance sensors is compared with the desired distance stored in the controller (PLC), and action is taken to correct any deviation. Each radial seal is controlled individually.

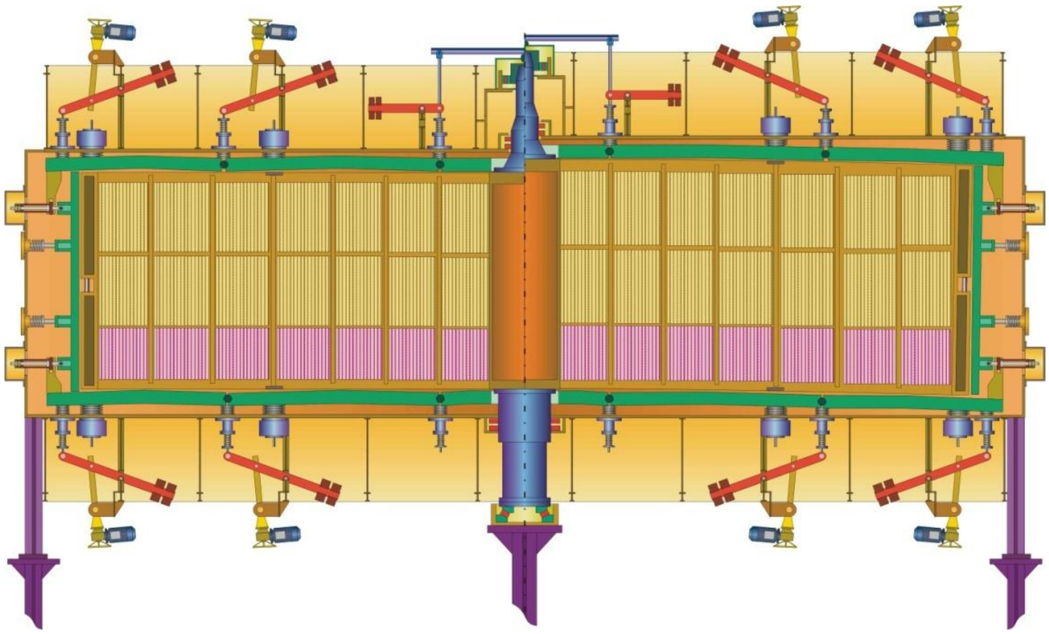

Figure 18: *Principle for APH sealing system (left side cold condition, right side hot condition)*

BWE has developed a very reliable sensor for the APH sealing system. The sensor can be installed in hot flue gas condition and does not need any external cooling system.

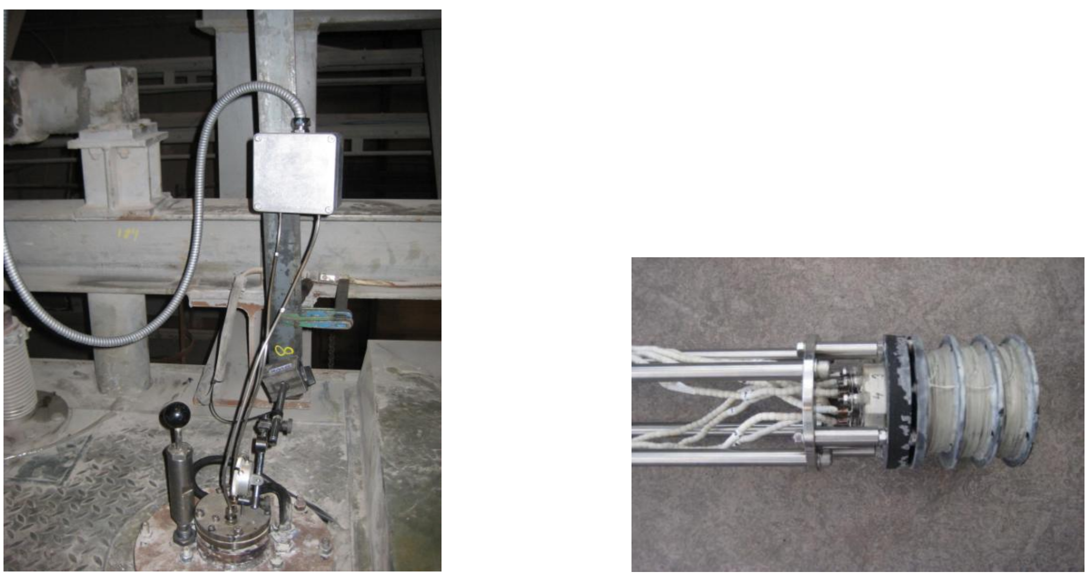

Figure 19: *APH sensor*

The BWE sensors are installed in APH and GGH at new built power plant and retrofitted into a number of existing boilers including Avedøreværket Unit 2 (APH), Fynsværket Unit 7 (APH), Nordjyllandsværket (APH), Brindisi South Unit 4 (APH), Torrevaldaliga North (APH), Fusina (APH), Jorf Lasfar (GGH), Honam (GGH).

15. Next steps in modern boiler design

The next steps in the modern boiler design is to increase steam parameter further. Studies performed in the late 90’s showed that an increase of steam temperatures up to 650 °C is not possible with the known martensitic steels (P91 &P92) for headers and steam piping.

Instead the use of nickel alloy materials as alloy 174, 263, 617 and 740 is required. Since these materials have very good creep properties (creep strength is not limiting the design stress at temperatures below 650°C), it is therefore natural to take a large step up to700 °C steam temperature. Some of the relevant materials are tested under the COMTES 700 program. Early results of the manufacturing and operation test show that the machining, bending and welding of high nickel alloy materials are highly challenging and cracks are observed. High temperature pre-weld heat treatment is probably needed. Furthermore, the price for nickel alloy steels is in the range of ten times higher than for austenitic steel used today.

Technically, a 700 ° C boiler design is presently not realistic and commercially it seems more attractive to improve the present design based on the 600/610 °C boiler concept aiming at 50% plant efficiency by use of low mass flux vertical evaporator tubing, double reheat and flue gas heat transfer system (condensate and feed water heating by further flue gas cooling).

16. Conclusion (BAT)

The use of BAT (Best Available Technique) is becoming a future political demand. BAT conclusions stating the achievable emission limits and efficiency will become benchmark for the power industry. Using BWE technology it proven that boilers can be reliable operated with steam parameters up to 600 / 610 °C using well known materials and plant efficiencies of 46-48 % (LHV, EN) can be achieved.

The boiler Technology is heading towards achieving 50 % rankine cycle efficiency. This article elucidates the intricate points related with various technological improvements in boiler component design adopted by BWE towards achieving this goal. With ongoing programs on superior metallurgy in place in near future, BWE is fully geared up to maximize the bottom line for their customers. Furthermore, the world is also benefitted with cleaner and greener environment.