Supercritical Boiler

In a pf power plant, power generation cycle efficiency depends primarily on the temperature difference across the steam turbine. Increasing this temperature difference can be achieved by using higher steam temperatures and this leads to higher cycle efficiencies. Generally, the use of higher steam temperatures is also linked to increased pressures to keep the steam volume within manageable limits. When the pressure exceeds 221 bar, the fluid is termed supercritical. The increased pressure also increases cycle efficiency and, although this increase is a second-order effect compared with the effect of temperature, it can still make an important contribution to increasing overall plant efficiency.

The temperature difference can also be increased by reducing the cooling water temperature to the condenser, but this is largely a function of site location and explains why the highest efficiencies are displayed by plant with cold, sea-water cooling such as those on the Baltic Sea. This cooling water effect is the same for subcritical or supercritical power plant. Also, when cooling-water temperatures are too low, losses can increase because of higher steam outlet velocities, caused by too-low condensor pressures.

The boiler at Hemweg 8 is sited in a boiler house with the pressure parts suspended in the boiler structure. The steel structure of the boiler house is also integrated into the boiler structure. The boiler house accommodates the coal bunkers, coal feeders, coal milling plant and the forced draught and primary air fans. To minimise the space requirement, a symmetrical arrangement of the coal bunkers, feeders and milling plant, on each side of the boiler, was chosen. The flue gas ducts, air pre-heaters and electrostatic precipitators (ESPs) are sited outside the boiler house, with the space below the ESPs being used for the fly ash discharge systems. The two induced-draught (ID) fans are housed in a separate building to reduce noise levels at the plant.

The boiler itself was designed for a high degree of operational flexibility in its load regime. This is because Hemweg 8 regularly operates in a daily load following mode and is required to handle a wide range of coal types. This flexibility of design was achieved by careful selection of pressure part materials and by design features that would avoid the use of think-section components in critical areas. In this way, the cyclic stresses that cause fatigue could be minimised, where combination of these with high-temperature creep could shorten the life of these components. The furnace dimensions were chosen to meet the requirements of low-NO_x emissions in the flue gases whilst minimising the amounts of unburned carbon-in-fly-ash.

The boiler is a two–pass Benson boiler, designed by Mitsui Babcock Energy Limited, and constructed by Stork Ketels BV under license. A two-pass boiler arrangement was chosen for the Hemweg plant because it offered a number of benefits, including the following:

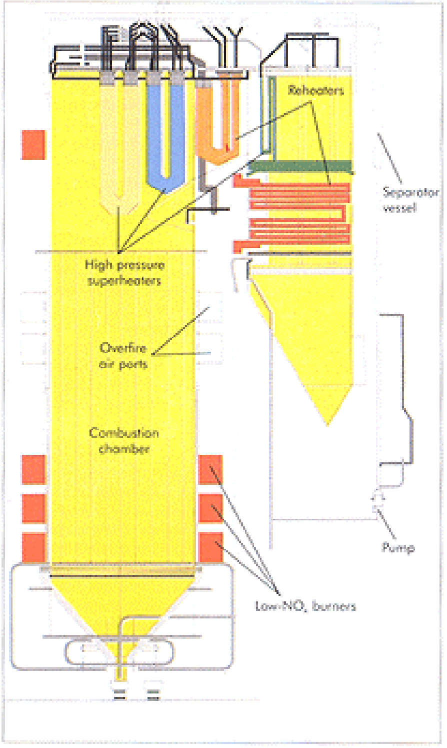
- boiler design would reduce the capital cost of plant foundations
- the vertical superheater tubes that this design allows would produce lower ash-slag adhesion
- no high-temperature tube bank supports would be necessary
- the pipework between the boiler and steam turbine would be shorter, due to the reduced boiler height.

The boiler steam conditions (260bar, 540^0 C/568^0 C) selected were regarded as 'state-of-the-art' in Europe at the time the boiler was ordered.
Although steam conditions in Europe and Japan have since increased to 300bar, 600^0 C/610^0 C, the steam conditions at the Hemweg 8 plant remain at the frontier of pf boiler technology in developing markets in Asia.

The boiler is operated in modified sliding pressure mode where the turbine inlet pressure is controlled to a level that varies with the unit load. Lower pressures at part load enable savings in feed pump power to be realised and throttling losses in the turbine control valves to be minimised. For start-up purposes and low load operation, the boiler has a circulation system incorporating two 100% circulating pumps.

Below~85% boiler load, steam conditions become subcritical. The boiler is operated in pressure slide until~42% load. Boiler operation from 42-100% load is at sliding pressure with open control valves to the steam turbine without throttling losses. Below 193kg/s steam, the boiler is operated in circulation mode at 110bar.

A schematic of section through the boiler



In the combustion zone of the boiler, the membrane well is spiral wound, utilising smooth-bore tubing. This inclined-tube arrangement reduces the number of parallel paths compared with a vertical-wall arrangement and therefore increases the mass flow of steam/water mixture through each tube. The high mass flow improves heat transfer between the tube metal and the fluid inside to maintain adequate cooling of the tube metal despite the powerful radiant heat flux from the furnace fireball. In the upper furnace area, the heat flux is much lower and the transition is made to vertical tubing, via a transition header.

At full load, the boiler produces 550kg/s of steam, with a boiler outlet pressure of 260bar. Table 2 shows the main boiler operating parameters.

The boiler is equipped with three superheaters with interstage spray-type attemperators and two reheater banks (although the cycle is a single reheat one). The economiser is a horizontal, multi-loop bank with extended surface tubes.

The primary superheater is arranged as one horizontal and one vertical bank. The secondary platen is a single-loop pendant bank and the final superheater is also a single-loop pendant bank. At the boiler outlet, the live steam temperature is 540^{o}C.

Table 2. Boiler operating parameters

Nominal boiler rating (Mw_e)		
Coal		630
Natural gas		650
Boiler operating conditions		
Main steam output (kg/s)		550
Superheater outlet pressure (Mpa)		26.0
Superheater outlet temperature (°C)		540
Reheater outlet temperature (°C)		568
Feed water temperature (°C)		291.4
Coal data	**Design**	**Range**
*NCV (MJ/kg)	26.97	24-30
Ash (%wt)	12.09	6-16
Moisture (%wt)	7.6	6-15
Sulphur (%wt)	0.48	0.3-15

*NCV = net calorific value

The boiler reheater system is arranged in two stages: primary and final. The primary stage comprises two horizontal banks and the final reheat stage is a folded-loop pendant bank located in the vestibule of the boiler. At the boiler outlet, the reheat steam temperature is 568°C.

Although the superheater and reheater stage is similar to that of a two-pass subcritical boiler design, the increase in pressure and temperature requires either thicker sections or higher-grade components. Generally, the latter solution is chosen in order to minimise fatigue damage and reduce weight. For Hemweg 8, extensive use was made of 12% chrome tubing in the high-temperature superheater and reheater. Modified 9% chrome pipework was used to connect the boiler to the turbine where necessary.

The boiler sootblowing system comprises 107 blowers activated by a programmable logic control (PLC) system incorporating user-programmable software. Bottom-ash removal is by a scraper chain conveyor beneath the furnace and a hydraulic transport system to a bottom ash filtration reservoir.

The boiler flue gas exit temperature is~350°C. The flue gas is cooled down to 130°C in the rotating air pre-heaters.

Steam Turbine

From the boiler outlet, steam is delivered to the high–pressure (HP) turbine section of the plant via two live steam lines.

The 680MW_e steam turbine, supplied by ABB, consists of a single–flow HP section, a dual-flow intermediate-pressure (IP) section three dual flow low-pressure (LP) section and the generator.

Steam is supplied to the HP section via four control valves and two emergency stop valves. The HP section itself is designed with a double shell casing and one extraction point for feedwater preheating. The steam supply to the IP section is via two combined control and emergency stop values. The three dual-flow LP sections are also designed with double shell casing. The shafts of all the turbine sections are made by welding forged disks together, which results in a compact shaft design. The condenser of the main turbine consists of six modules, connected to the exhaust steam ducts of the three LP sections and supported on the building foundations by springs. Each condenser module has an intake and outlet water box, which means that, for both cooling water intake and outlet, there are six pipes in all, each of which can be shut off individually. Each condensor is operated at a pressure of-35mbar.

The cooling water is taken from an intake channel outside the harbour area and is mechanically cleaned in three identical cooling-water plants. Because of the long distance between cooling–water inlet and outlet no warming up of the inlet cooling water occurs. During wintertime recirculation of a part of the outlet is possible to prevent ice formation. Cooling water temperatures vary from 0-24^{o}C through the year.

The generator consists of stator and rotor. The stator housing is a welded construction in which the stator segments are suspended and secured. The rotor is a single-piece forging with slots milled during manufacture to accommodate the rotor winding. The rotor winding and stator core are cooled with hydrogen.

The auxiliary electrical power system has a high degree of redundancy. During normal operation, this is supplied from the generator via two station transformers. During start-up and shutdown, the auxiliary system is supplied from the local grid via a 150/50/10kV transformer. The transition between the two is carried out by two high-speed-switching devices which are also used in the event of power supply failure to switch to 'start-up' mode so that a controlled shutdown can be achieved without risk of damage. During plant maintenance, the 10kV plant can be connected to the local 10kV power supply. To secure safe and reliable start-up of the plant in the event of complete loss of power, the emergency supply system consists of two redundant emergency power generators.

NO_x Control

The supercritical boiler has 36 low-NO_x burners, located in three rows of six burners in each of the boiler front and rear walls in an opposed arrangement. To maximise NO_x reduction, the combustion is two-stage with 24 after-air ports positioned in two rows of six on the front and rear walls of the boiler, situated directly above the burners. This type of burner system design, together with optimisation of furnace dimensions, achieves very low NO_x concentrations in the flue gas. The performance specification for NO_x emissions is 300mg/Nm^3. Actual yearly average emissions of NO_x from the plant are 260-280mg/Nm$^{3.}$

Particulates Control

Fly ash is separated from the flue gas in tow ESPs, supplied by Rothemuhle. Particulate collection efficiency is 99.9% with the discharge from the ESPs being conveyed pneumatically to silos.

SO_2 Control

The FGD Plant, is a wet limestone system, supplied by Hoogovens Technical Services Energy and Environment BV.

Flue gas from the ESP plant passes upwards through the FGD absorber, where the entire cross-section is sprayed with limestone suspension in four vertical stages. This removes at least 88% of the SO_2, together with some remaining fly ash, chlorides and fluorides. During the process, the flue gas is cooled to 50^{o}C. To prevent the temperature dropping below dew point and to eliminate the risk of any resulting corrosion, the cleaned flue gas is heated by 10^{o}C before entering the stack.

FGD plant with absorber and flue gas reheater

The SO_2 removed form the flue gas reacts with the limestone to form a gypsum suspension. This suspension is collected in the FGD absorber and is returned to the spraying stages by recycle pumps. The gypsum suspension can also be diverted to a separate tank when inspection of the FGD absorber is required. The concentration of the suspension is controlled by adding fresh limestone and extracting some of the gypsum as a suspension. This suspension is then subjected to further treatment as described in a later section of this brochure discussing management and utilisation of plant residues.

OPERATION

The boiler installation and auxiliary systems have been designed with a high level of automation to allow operation by as small a team as possible. This includes the use of a boiler control system to start up the installation.

A total of 75 operators and five shift-leaders are employed to operate the three power plants in the Amsterdam cluster. Hemweg 8 can be operated with a minimum of five people per shift. A two-shift team (10 field operators and one shift leader) handles the logistics on weekdays.

Main Operational Features

The operational flexibility of supercritical power plant is regarded as being a major benefit. There is no loss of flexibility in moving from subcritical to supercritical conditions and, in some respects, the once-through boiler design is more flexible than drum boiler designs. This is because, to control metal temperature differentials in thick-section components such as the drum, temperature control at start-up and during ramping is more critical.

Plant Monitoring and Control

Automatic control is carried out using ABB's PROCONTROL P digital process control system, which controls all aspects of the process using a hierarchical structure. Process control cubicles and operating panels have been sited at selected locations in the plant, eg in the plant logistics building, the FGD plant and the coal-and ash–handing silos, the ensure close proximity to the process to be controlled. A range of modifiable user programmes, stored in EEPROM technology, provides enhanced user-friendly performance. In both the FGD plant and the logistics building, there is a separate control room provided with a process control console linked to the main system using fibre optics. The FGD plant control room was used during commissioning and is not currently in use.

Design of the control room and plant management and monitoring systems is based on ergonomic principles. These systems give operating staff targeted access to all the important process data required. An alarm hierarchy is used where the plant management system display messages according to their level of priority and in the correct time sequence to enable rapid assessment of any process malfunctions.

Plant Maintenance and Monitoring

The plant was designed to comply with the customer's requirement for a scheduled shutdown for inspection and maintenance purposes, once every two years. The mean time between failures for each of the components matches this interval. Currently, considerable effort is being made to increase this interval to three years.

Service personnel are assisted by a plant diagnostics system that includes automatic analysis and reporting of the entire instrumentation and control system. This ensures rapid fault detection and leads to reduced repair time. Since 1998, the Hemweg 8 plant has achieved a high availability, reaching a maximum availability of 95.9% in that year.

Management and Utilisation of Residues

The benefits of maximising the utilisation of power station residues are well recongnised, and considerable care is taken at Hemweg to optimise boiler combustion conditions to produce high-quality fly ash and bottom ash.

The fly ash from the ESPs (~120,000t/y) is conveyed pneumatically to silos where it is loaded into lorries or ships. Both systems are equipped with facilities for both wet and dry ash handing. As an alternative, the fly ash can be loaded into storage silos, equipped with similar handling facilities. On-line measurement of unburned carbon (UBC) and daily sampling are used to control fly ash quality. The main market is the concrete industry as cement replacement.

Bottom ash (17,000t/y), removed from the base of the boiler, is transported by a hydraulic transport system to a filtration reservoir, consisting of three basins where it is dried out on a filter bed. The filter bed is cleaned with rinsing water and compressed air. When this treatment is complete, the ash is either loaded into lorries or into storage. The bottom ash carries a quality mark with a product certificate, 'E bottom ash', which guarantees that it can be used in environmentally friendly and economic applications, whether integrated in road foundations or in civil engineering works.

All the bottom ash is sold and this is used mostly in road construction. The rinsing water is recycled in the bottom-ash system and excess water, due to a continuous fresh supply, is re-used as supply water for the FGD plant.

Considerable effort is also made to maximise the utilisation of FGD residues. Reacted limestone slurry from the FGD plant is dewatered in hydrocyclones and centrifuges to produce a gypsum powder of <5% residual humidity and >95% purity. The plant produces ~ 60,000t/y of high-grade gypsum, all of which is sold to the building construction industry for the manufacture of gypsum blocks and boards. The high quality of the gypsum produced is achieved by careful pH control and continuous extraction of wastewater to reduce contamination and control the levels of chloride in the suspension. The water from the limestone dewatering process is recirculated back to the FGD system. A multi-stage wastewater treatment system is also used to remove dissolved heavy metals and floating particles.

Measures have also been taken to reduce pollution by storing coal on concrete impermeable to water and by collecting and purifying seepage water before recycling.

PLANT PERFORMANCE

Since it first came into full operation, the commercial and environmental performance of the Hemweg 8 supercritical plant has been excellent and has either met or, more often, exceeded expectations. Table 3 summarises some of the key performance indicators for the plant.

PARAMETER	**PERFORMANCE**	
	Target	**Actual**
Cycle efficiency LHV (%)	42	42
Availability (%)	85	92
Unburned carbon (%)	5	3.5
Emissions		
Particulates (mg/Nm^3)	20	1.5
SO_2 (mg/Nm^3)	400	160
SO_2 removal (%)	88	91
NO_x (mg/ Nm^3)	300	270

Reference:
Super Critical Boiler Technology At Hemweg Power Station
Best Practice Brochure - 003