Conversion of a traditional coal fired boiler to a multi fuel biomass unit

Technology: Vibration grate & dust burners, Plant: Herning/Denmark/Dong Energy

By

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1. Introduction

Herning Power Plant includes technologies known in the power generation business for the last 30 years. The plant was converted from coal to biomass in a number of steps. The technology changed gradually from being solutions traditionally used in fossil power plants to a technology with a number of features previously known from smaller district heating units, but in this case optimized and adapted to a utility plant scale. The driving factor was an ambitious utility owner/operator. BWE had a relevant reference list with numerous successful plant upgrades from biomass projects with fuels ranging from wood chips, bark, peat, saw mill waste, pellets and straw - including several technical solutions dedicated to these fuels.

Herning Power Plant was originally built in 1982 by BWE as a traditional coal fired CHP unit. The BWE boiler is a two pass drum boiler with a heat input of 288 MW.

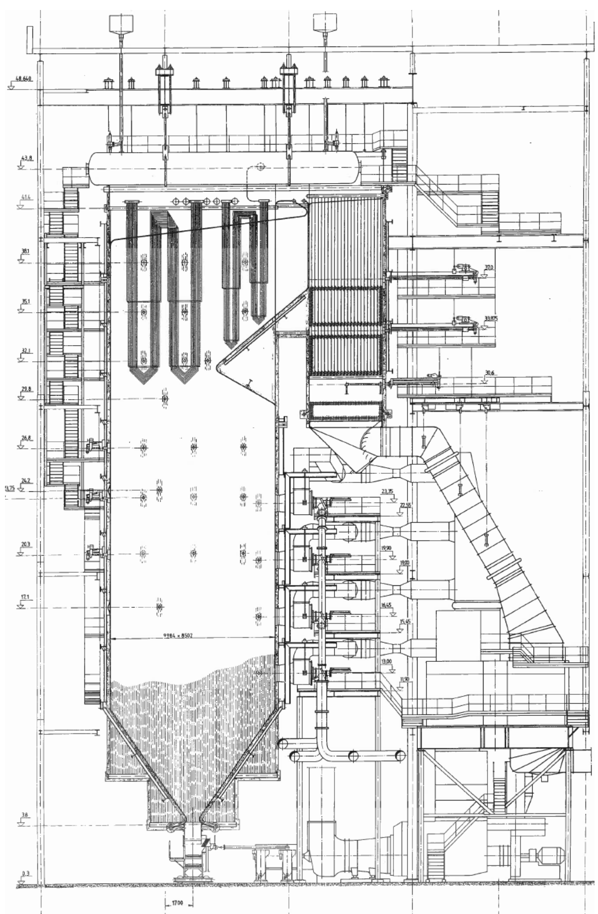

Figure 1

Herning Power Plant in its original layout. Designed and installed by BWE 1982.

Today owned by Dong

2. Herning Power Plant – initial design and conversion steps

As the conversion overview shows the actual system has changed significantly from its original 1982 design for coal firing to the present design including wood chips and pellets.

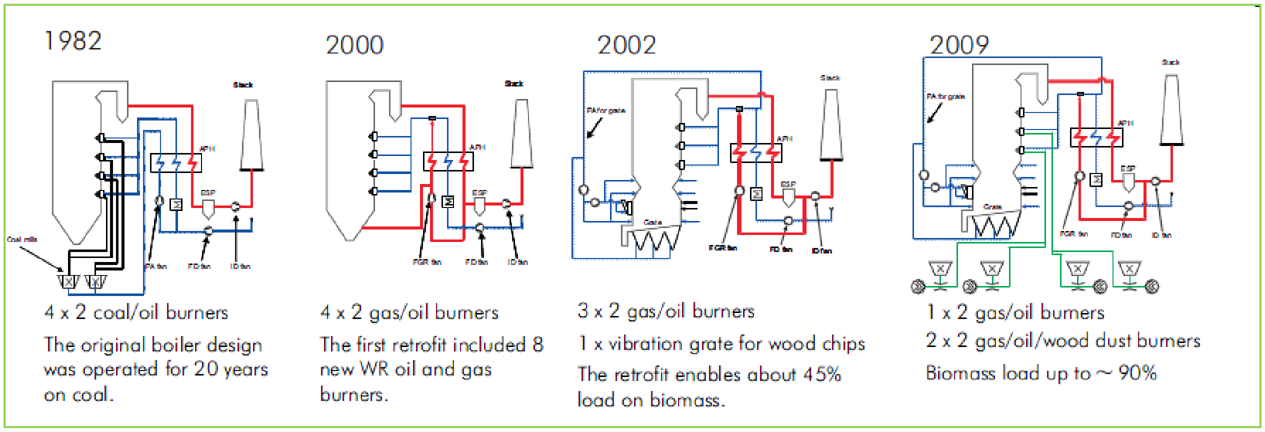

Figure 2

Conversion overview and CO_2 reduction				
Year	**1982**	**2000**	**2002**	**2009**
Coal (max)	100%	-	-	-
HFO	100%	100%	78%	78%
N-gas (max)	-	100%	100%	100%
Wood chips (max)	-	-	45%	45%
Wood pellets (max)	-	-	-	43%
Optimized CO_2 emission at 100% load [kg CO_2/GJ]	95	57	31	6.8*

**The 6.8 kg CO_2/GJ is only applicable due to 10% co-firing with N-gas when load is 100%.*
Table 1

2000: Coal → N-gas (plant age: 18 years)

During the first conversion the plant owner took the initial step to update the plant. This was a way to utilize Danish N-gas from the North Sea, reduce emissions and maintenance costs.

2002: N-gas → N-gas + Wood chips (plant age: 20 years)

In December 1999 Denmark had the worst storm in 100 years and vast forest areas with spruce were practically laid down on the mainland peninsula Jutland. In 2000 BWE presented various studies to the plant owner on the redesign of Herning Power Plant for wood chips firing – having in mind that the storm felled trees would gradually lose value by just lying on the ground. The owner awarded a contract to BWE for the conversion of the plant to co-firing of 130 MW from wood chips on a water cooled vibration grate.

The vibration grate design was based on the experience from numerous plants in Sweden, Denmark, Czechoslovakia, England and Spain. The main features for the complete conversion were:

- Weighing station
- Log chipper station
- Chips barn
- Conveying belt
- Boiler house indoor dosing system (BWE)
- Spreader system (BWE)
- Vibration grate and drive (BWE)
- New Combustion air system (BWE)
- New pressure part - hopper design (BWE)
- New slag scraper and ash/slag handling (BWE)

2009: N-gas → N-gas + Wood chips + Wood pellets (plant age: 29 years)

As a result of the increased focus on carbon neutral power production within the power generation business and in society in general, Dong Energy awarded a contract to BWE for the conversion of the 2 lower burner levels for pulverized fuel (PF) biomass combustion based on wood pellets – a total of 4 burners.

The design was based on the general experience from the BWE burner development program in the 1980-1990's and a specific experience from indirect firing with peat in Sweden. The main features for the conversion at Herning Power Plant were:

- Pellets reception building
- Air suspended conveying belt
- Reuse of existing bunker
- Dosing system
- Milling system

- Conveying air blower
- Conveying piping (BWE)
- Multi fuel burners for Wood dust, N-gas, HFO (BWE)

3. Plant data

- Manufacturer: BWE
- Design: Top suspended boiler, natural circulation
- Year of construction: 1982: Coal/HFO
- 1st conversion: 2000: N-gas/HFO
- 2nd conversion: 2002: N-gas/HFO/Wood chips
- 3rd conversion: 2009: N-gas/HFO/Wood dust/Wood chips
- Electrical output: 95 MWe (gross)
- Heat output for Herning: 174 MW
- Steam data: 525°C/118bar
- Grate capacity: 130 MW (45 %)
- 6 burners on N-gas: 6x48 MW= 288 MW (100%)
- 6 burners on HFO: 6x37.5 MW= 225 MW (78%)
- 4 burners on wood dust: 4 x 31.3 MW= 125 MW (43%)
- Grate + wood dust burners: 255 MW (88%)
- Wood chips consumption: 260,000 ton/year
- Wood pellets consumption: 75,000 ton/year (reported in 2010)

4. Woody fuels

Wood pellets:

With the increasing demand for wood pellets, manufacturers are enlarging the production capacity. Many forests are located in mountain and rocky areas and it is highly uncertain that these areas can be converted to farmland. Consequently, the fuel does not compete with products for animal or human food.

Wood pellets are a refined product with a relatively high density, and even for intercontinental transports, freight costs are reasonably low. Handling is very easy and can be carried out with many types of conveyor systems. Wood pellets are the basis for the wood dust which is the final stage of the fuel for the burners. The equipment for milling pellets and dosing dust is quite complex and energy consuming.

Not all wood pellets meet the highest standards, but generally the typical characteristics of wood pellets are as stated in Table 2.

Wood Chips:

The price for each GJ is lower for wood chips than for wood pellets, but the fuel requires a more complex handling system all the way from unloading to fuel feeding. In addition the combustion system cannot be optimized to the same low air excess as systems for dust firing. A sufficient dosing accuracy can be performed with relative simple means. Obviously, the base material is wood, but like pellets the wood chips can be of varying qualities – ranging from the best wood chips manufactured exclusively from pure virgin wood to wood chips only from roots and branches or waste wood. A variation is wood chips manufactured solely from a few years old shoots from willow (Latin: Salix). Such fuel contains a large share of cambium (last year's growth) which means high contents of various salts, including potassium. At the same time a criticism could be that Salix is normally grown in farmland type environments.

Not all wood chips meet the highest standards, but generally the typical characteristics of wood chips are as stated in Table 2.

Design fuel:

For the design of a flexible system with sufficient capacity, it is recommended that the design basis is a complete specification of the fuel/fuels.

Standard specifications for woody fuels:

Since 2005 CEN TS 14961 "Solid biofuels – specification and classes" is the guidance. A Working Group is presently preparing prEN 15234-1 which is intended to cover fuel quality assurance. The standard is expected to be issued within 2011 (prEN indicates a draft standard).

Comparison table of fuels:

	Wood chips	Wood pellets	Coal	N-gas
Mass density [kg/m³]	300	650	800	0.8
Typical size [mm]	<10x20x50	∅6, L=12	30	-
LCV [MJ/kg]	10	17	24	48
Humidity [%]	40	8	12	-
Ash content [%]	1-2	0.5-1	10	-
Bulk [characteristic]	Bridge building	Free flowing	Bridge building	-
Price [Euro/GJ]	4	8	3	11
Energy density [GJ/m³]	3	11	19	0.04

Table 2

Please note that all values are typical values. Prices are volatile and the N-gas price in Denmark is politically fixed to the oil price.

5. BWE water cooled Vibration Grate

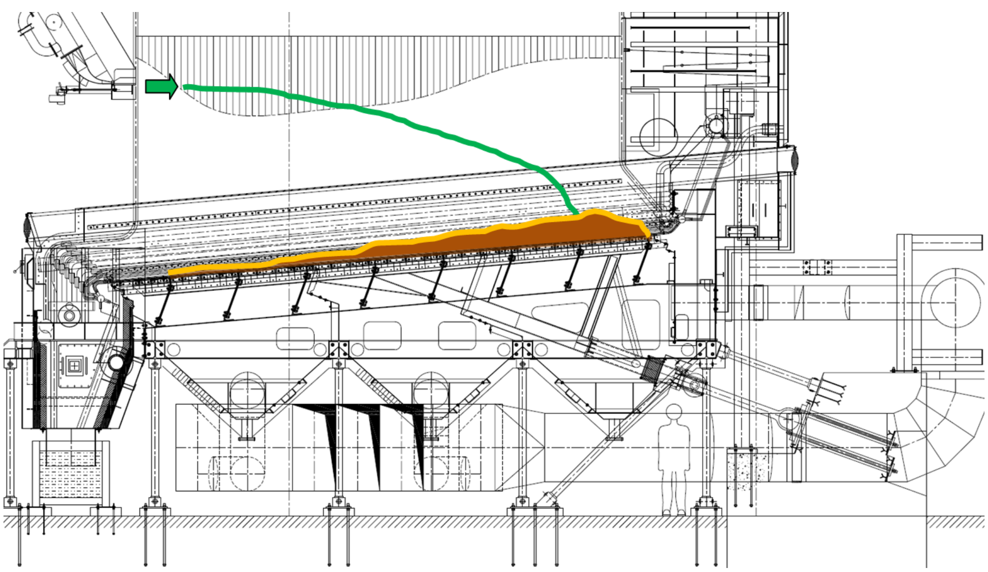

Figure 3

The BWE water cooled Vibration Grate with an effective area 8 x 9 m for the top suspended boiler. The grate has pendulum column support. The grate offers a possibility for use of a wide range of wood chips in different qualities. Further the grate serves as post combustion of possible unburned particles dropping down from the PF dust burners.

The vibration grate offers very low maintenance costs and provides high availability. The design is somewhat complex, especially with regard to the interface to the top suspended boiler. The boiler at Herning Power Plant is with natural circulation, and consequently the grate is a part of the evaporator system.

BWE employs engineers who have designed vibration grates since the end of the 1980's. Most vibration grates have been designed specifically for the individual plant. However, a few designs have been produced in high numbers.

At Herning Power Plant, the lower burner level and the hopper section of the existing hanging boiler were cut away and replaced with a new lower part with interface to the standing grate including the following main features:

- Connection tubes to the downcomers from the drum
- Expansion tubes to connect for 150 mm vertical expansion
- Spreader openings in front wall
- Slag hopper
- Boiler/grate/slag hopper surrounding expansion joint
- Openings for combustion air nozzles

The grate for this project was designed with a number of specific characteristics, including:

- 12 individually controlled air zones
- 6 spreader openings
- 4 grate sections with a balanced operation like the pistons of an inline 4 cylinder engine
- Each section having a membrane with holes in the fins for primary air
- Flex tubes between stationary headers and grate
- Expansion tubes between stationary outlet header and the boiler rear wall
- Stationary membrane between the grate and boiler side wall/bottom header

The Herning Power Plant water cooled Vibration Grate – various data:

- Number of modules: 4
- Width: 9,000 mm
- Length: 8,000 mm

- Number of spreaders: 6 individual
- Grate surface: Evaporator membrane
- Concrete foundation for drive: 200 tons
- Holes for PA in membrane fins: 40,000 pcs
- Stroke: 10 mm
- Frq. of operation: 7.5 Hz with VSD
- Sequence of operation: 3 s/180 s (typically)

The function of a vibration grate

The wood chips are continuously being fed onto the grate by a pulsating spreader system sending the wood chips from the front wall openings to land on the grate in the upper zone near the rear wall. The pulses are generated by boosted combustion air with a pulsating pressure. The grate is inclined to a low angel still allowing it to be a part of the evaporator system without the risk of steam stagnation and overheating of the membrane. The vibration drive is operating intermittently; typically with one vibration sequence every 2-5 minutes. The vibration ensures a mixing of wet and dry fuel and coke. In addition the vibration generates a transport down the grate from the heating/drying zone to the area where the main combustion takes place, further down to the zone where the coke glows out and finally to the cooling zone before falling into the slag hopper. As a practical alternative to a large number of controlled air zones, a system with air distribution based only on a predesigned hole pattern is often recommended.

Various mechanical features

The grate is exposed to all the traditional mechanical stress, wear and tear:

- Thermal expansion and loads from this
- Dynamic movements and loads from this
- Self oscillation
- Wear and tear from the abrasive ash and slag and the fuel itself
- Air tightening

To control all these issues, many special designs are applied including:

- The flex tubes have a self oscillation frequency approx. 3 times higher than the grate's vibration frequency. Furthermore, the flex tubes are calculated according to the rules of PED (Directive 97/23/EC) and associated requirements.
- The tubes in the membrane have additional wall thickness as allowance for wear and tear.
- At the lower end of the grate on the pressure part, the tubes are additionally reinforced to withstand the heavier erosion from the slag and ashes.
- In the intermediate lines between the moving grate sections, special spring supported seals are mounted. These are wear parts with 2 years' lifetime.
- Circumferential air tightening plates and web expansion joints.

Figure 4

Workshop assembly of tightening plates.

6. BWE Vibration drive

The vibration drive is mounted on a heavy concrete foundation. The design of the drive includes features for thermal movement of the flanges on the grate. The frequency of operation is adjustable within a specific range by a variable speed drive (VSD). As a vertical acceleration on the grate surface of approximately 10-11 m/s² is required for transport of fuel along the grate, the frequency needed is related to the general geometry of the grate. The design resembles that of the crankshaft and the piston rods in an inline 4 cylinder engine. The masses of the grate sections moved back and forth are approximately 5 tons pr section and for the chosen design type, the drive unit needs to be of a heavy and robust construction. In order to obtain acceptable low bearing forces, the drive unit includes a flywheel which evens out the angular velocity of the drive shaft by accumulating the kinetic energy of the grate sections being moved back and forth in a linear movement.

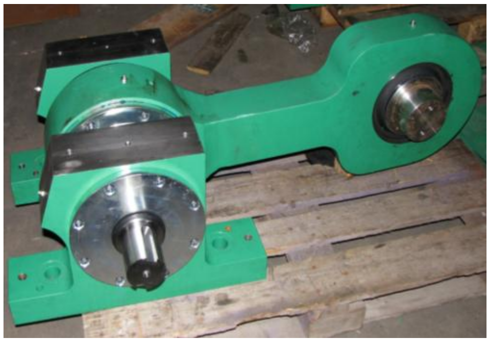

Figure 5

Ready to ship drive rod module –

here 1 out of 4 is shown.

The design of the heavy concrete foundation is an integrated part of the BWE grate design and the only design feature left to civil works is to make the detail drawings including steel reinforcement. The design of the concrete foundation, the drive unit and the connection to the grate flange is carried out in such a way that the drive unit can be mounted relatively late in the erection sequence maintaining the possibilities for alignment and adjustments needed. The drive consists of 1 motor unit and 4 rod modules.

7. Boiler design

The most stable start and operation of a vibration grate is obtained when the grate is an integrated part of the evaporator. As the very heavy and robust grate, drive and concrete design needs to be supported directly on the foundation, special attention is required for the connection of the grate pressure part to the boiler.

By having the grate surface to be a part of the evaporator with its membrane, a suitable surface temperature is achieved. (For other systems the alternatives for cooling can be feed water or separate cooling circuit. The alternatives for the grate surface are casted elements)

8. Dosing system for wood chips

The complete system includes a log chipper and a large wood chips barn. This was outside the BWE scope. The BWE scope had its terminal point at the outlet from the belt conveyor coming from the wood chips barn. At this point a distributor screw supplies 2 silos each approximately 100 m^3. These silos are equipped with reclaimer screws each supplying a distributor screw which again feeds 2x3 buffer/dosing screws. From the 6 individual dosing screws, the wood chips are led to the wood chips chutes feeding the spreaders. The design of the chutes is delicate as the wood chips need to hit the spreader table well distributed and not concentrated on one side of the table.

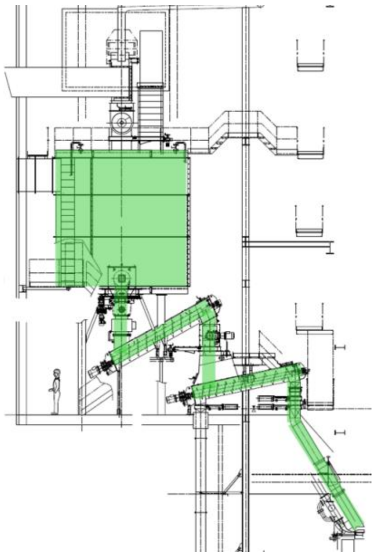

Figure 6
An additional bay at the boiler house for wood chips dosing.

9. The wood chips spreader

The spreader is an old and proven design. In this case the wood chips fall down to the spreader table through the wood chips chute passing a flap gate which closes if there is no material flow as a back fire protection. The falling wood chips are blown onto the grate surface by a pulsating air flow coming through an adjustable gab behind the spreader table. The main part of the wood chips will land on the grate surface near the rear wall. The very finest dust particles start drying, heating up and ignite in the air. The spreader table is equipped with an easy to replace wear plate and the spreader table angle is adjustable.

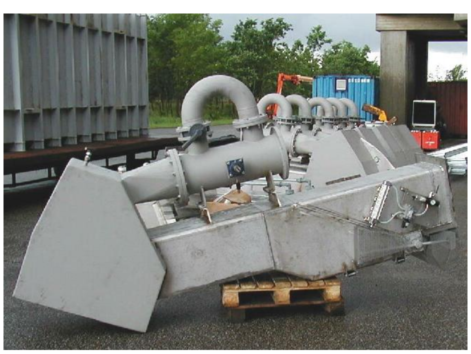

Figure 7
6 pcs. BWE wood chips spreader ready for installation.

10. Dosing/milling system for wood pellets

The dosing/milling system was installed by the client. The system included a dosing system in the bottom of the existing coal bunker, 4 disc mills and 4 blowers for conveying air for each burner.

The dust pipes and the burners were designed for a dense air/fuel mix compared to traditional roller mills. The low air/fuel ratio was chosen in order to obtain a better overall efficiency as this would keep down the amount of cold air by-passing the APH.

Some of the characteristics of grinded wood pellets are due to the nature of the fibers and the relatively coarse particle size distribution (PSD). This means that an even flow is only possible with increased conveying air velocity compared to the velocities known from coal dust feeding. Coarse particles are not easy to handle in any combustion system and a disc mill does not grind the pellets base particles much. A disc mill only crushes the pellets to the particle size they had before they were pressed into pellets. Disc mills are not developed for further grinding and for the actual use at Herning Power Plant relatively high maintenance cost have been reported.

If a better PSD is required and if further focus is on increasing the plant efficiency by bringing the cold conveying air amount down, the following points need to be studied:

- Installation of a hammer mill with adjustable grinding performance
- Installation of a blower with adjustable performance
- Mill wear part life time
- Dust pipe design
- Burner design
- Conveying air temperature

It should be noted that a hammer mill with an adjustable grinding performance is likely to be a hammer mill with an increased capacity. By installing a finer screen in order to obtain a better PSD, the power consumption increases. Larger size hammer mills only affect operational costs if the power is actually consumed e.g. by installing a finer screen or increasing the through-put. Wear part life time is related to power consumption, so a larger hammer mill which is not utilized to its full capacity gives longer life time of wear parts.

An oversized blower with VSD can be employed to adjust to optimal air velocity in the conveying pipes in order to obtain the best possible evenness of transport of the dust.

11. BWE Circular multi fuel Low-NOx burners

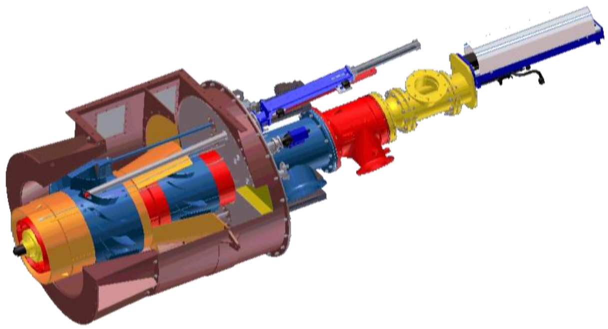

Figure 8

The BWE Multi fuel low NOx burner.

The burner design is in line with the BWE burner development program which has its origins many years back in time. The main features of the burner are:

- Circular design
- Adjustable swirl of SA and TA by electrical actuators
- A central retractable HFO oil lance with steam atomization
- A Retractable gas igniter/pilot burner
- A coaxial/central N-gas lance
- A PF sector for wood dust
- In-burner mixing with adjustable hot-PA flow
- A Flame holder
- 2 sets of flame scanners

12. Air distribution

Operating a combined grate and dust fired unit puts high requirements to the fuel and air systems. Air flows to the grate operation and dust burners operation are separate. The grate operation would be at the level of $\lambda=1.3$ and the dust burners operation would be at the level of $\lambda=1.17$.

Grate:

The grate PA is introduced to the combustion zone through the many small holes in the fins of the grate membrane. The rest of the combustion air for the wood chips combustion is introduced through a number of jet nozzles as SA/TA at the boiler noses and below these and a part is introduced as spreader air.

PF burners:

The dust burners are equipped with individual ducting, measuring and control of conveying and combustion air for each burner. The combustion air is divided into 3 flows: PA, SA and TA. The PA flow together with the conveying air would normally account for 20% of the combustion air and the remaining part is introduced as SA and TA – with an air-split based on the load. (The conveying air for the dust is not preheated and accounts for approximately 5-8% of the combustion air for the PF burners).

13. Material selections

Reliability and long life time are ensured by numerous initiatives. For the burners all furnace near parts and parts until approximately 1000 mm behind the burner outlet are of high or ultra high temperature resistant steel. Rolled parts are made of ultra high temperature resistant austenitic steel with high exfoliation temperature. Various casted parts exposed to wear and ultra high thermal radiation will have a very high Cr and Ni content. For wear parts at lower temperature levels alternative material selection is possible and often clients have special requirements or preferences such as e.g. casted design, Hardox plates, overlay welding with Chromium Carbide or glued-on ceramic linings.

14. Combustion air and emissions

Vibration grate

Many factors are important to obtain stable and low emissions. The vibration grate must have effective air tightening so that the combustion air leakage at corners and joints are as low as possible. The air flow from the air box to the grate surface must be adjusted correctly or designed correctly so that the main zones are fed with the optimal air flow for the drying zone, the combustion zone and the burn out zone. For the grate combustion, the PA is the air lead to the air box. The SA will be introduced to the combustion zone through a number of nozzles evenly distributed on the front and rear wall noses. Nozzles are orientated and have air velocities such as to intrude the combustible gasses in a curtain like pattern. There are 2 levels of nozzles at both front and rear wall. A certain small amount of combustion air is lead to the furnace at the spreader and below the spreaders.

Dust burners

By having multiple controlled airflows and swirls, the burners can be adjusted to a stable flame. With burner tip temperature surveillance, 2 sets of flame scanners per burner and inspection glasses at the side walls near the burners and directly at the rear wall, the sufficiently attached flame can be observed. The SA-turbulator and the TA-turbulator can shape the flame which also is an indication of the degree of internal recirculation and the mixing velocity of combustion air and fuel.

Emissions

The plant can operate with NOx emissions down to 210 mg/Nm^3(dry, 6% O_2). The CO emission will fluctuate a bit mainly due to the grate vibration sequences. The typical CO emission hourly average will be in the range of 50-100 mg/Nm^3.

From January 1, 2016 the new Industrial Emissions Directive (IED) will replace the Large Combustion Plant Directive (LCPD). As a consequence there will be a tightening of the allowable emissions of NOx, SOx, and dust.

Referring to IED, Annex V, Part 2 specifically for units with a heat input exceeding 300 MWt, the emission limits will be 150 mg/Nm^3 (dry, 6% O_2) for NOx, 150 mg/Nm^3(dry, 6% O_2) for SO2, and 20 mg/Nm^3(dry, 6% O_2) for dust.

If typical pellets are used, FGD will not be needed, and an optimized ESP should also be able to meet the limitation on dust. For NOx some reduction would be required, and depending on the specific project it must be evaluated if SNCR is needed or if a simple SCR should be applied.

In case of retrofit it is often a challenge to find a correct location of NH_3 injection and residence time for nitrogen formation.

15. Bio conversion overview

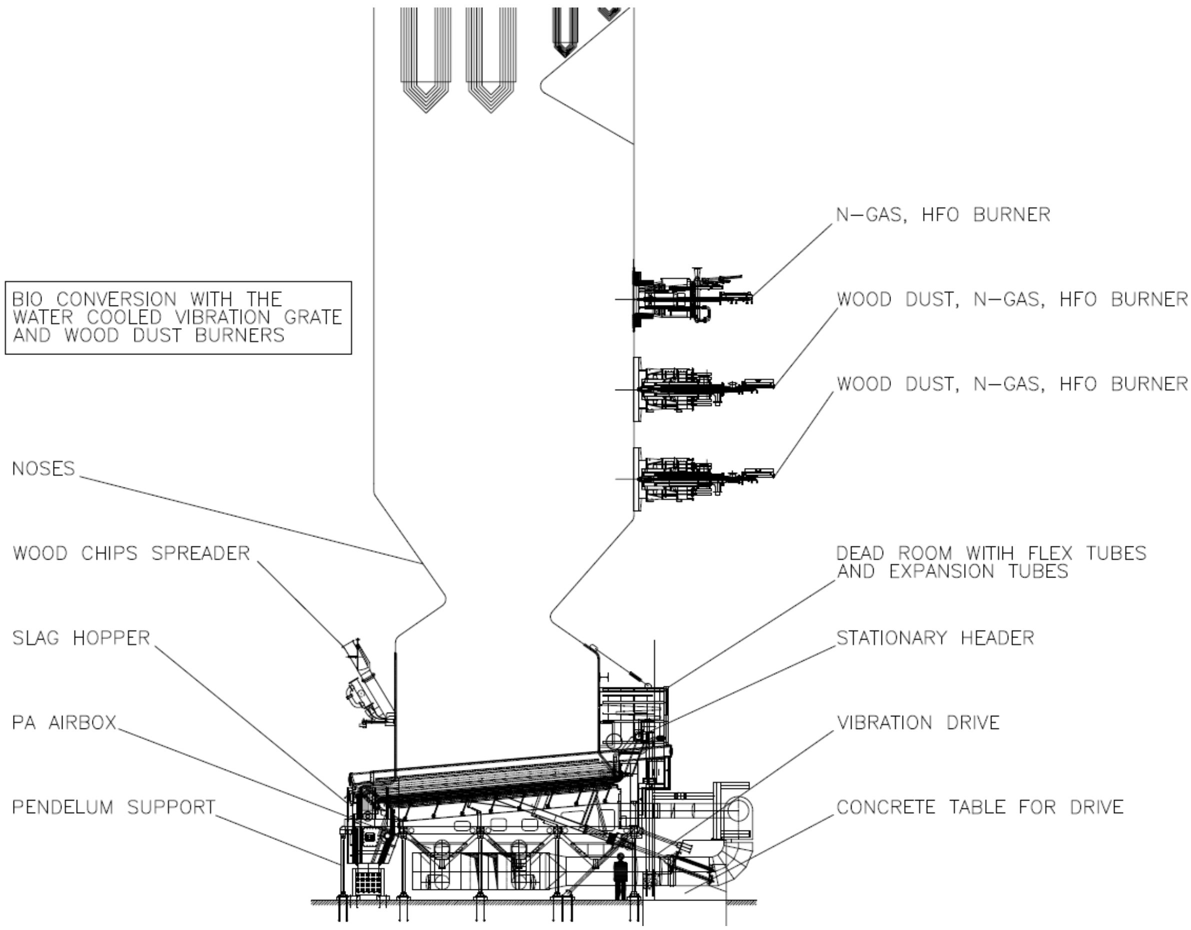

Figure 9

16. Balancing of heat uptake

It is well known that most types of biomass in substitution of fossil fuels will change the fouling and slagging situation of the heating surfaces. For a new boiler this can be handled through proper design but for at retrofit this needs to be controlled by various initiatives or combinations of initiatives:

- In case of retrofit the thermal input can be reduced
- Increase sootblower and cleaning system
- Introduce additives
- Adjust heating surfaces and water injections

The optimal solution to be chosen depends on many plant characteristics.

For Herning Power Plant, BWE designed and installed an additional by-pass economizer in the ducting between the boiler and APH. This additional heating surface can adjust the flue gas temperature to the APH inlet which again provides the correct temperature to the ESP and the stack.

This solution was possible as the ID fan capacity and attemperator ejection capacity were sufficient.

This new eco by-pass was also equipped with rotating sootblowers.