

TRANSLATED VERSION

BWV Combustion Technology for Generating Energy from Waste

– Case Study: Reno Nord, Line 4 A High-Efficiency Waste Incineration Plant –

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About Babcock & Wilcox Vølund A/S

Babcock & Wilcox Vølund is one of the world's leading suppliers of equipment and technologies for the conversion of waste and biofuels into thermal energy.

Founded in 1898, the company has its headquarters in Esbjerg, Denmark, and is a wholly owned subsidiary of the Babcock & Wilcox Company (Barberton, Ohio, USA), a subsidiary of McDermott International, Inc. Babcock & Wilcox Vølund has departmental offices in Aarhus and Copenhagen (Denmark), a subsidiary in Paris and a sales office in Taiwan. The company has 430 employees worldwide.

Vølund built its first plant for recovering energy from waste in 1930 in Gentofte, a suburb of Copenhagen. Since then, five hundred lines have been built in seventy countries. Between 2003 and 2006, Babcock & Wilcox Vølund A/S undertook seventeen projects with a combined total throughput of 2,296,000 metric tons per year; some of these projects have now been completed, whilst others are still ongoing.

About I/S Reno Nord

I/S Reno Nord is a Danish municipal authority jointly owned by seven municipalities in North Jutland. It is responsible for handling the waste streams produced by the 225,000 residents of the seven municipalities.

The company was founded in 1978. Its head office and its incineration plant are located in Aalborg.

The incineration plant, which is owned by the municipal authority and located in the eastern district of Aalborg, was built by the company in the period from 1978 to 1980.

The plant is equipped with two Vølund rotary kiln furnace systems, each with a combustion capacity of eight metric tons of waste per hour. The plant supplies thermal energy to the district heating system of Aalborg Fjernvarmeforsyning, the municipal utility company.

In 1989, I/S Reno Nord and I/S Nordkraft, the local electricity supplier, established a joint venture for the construction of a waste-fired combined heat and power plant.

The new waste incineration line, which has a throughput of 12.5 metric tons per hour and provides energy for electricity generation and heating, was put into service in 1991. This line is fitted with a BS-W combustion grate.

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The principal activities of I/S Reno Nord are:

- Waste incineration with energy production
- Operating a regulated waste disposal site
- Operating a recycling facility for building materials
- Sorting discarded refrigeration equipment for reuse
- Sorting electronic waste for reuse.

1. I/S Reno Nord, Line 4

The construction project for a new incineration line, including the schedule and organisational process, is described below in terms of the system concept and general conditions, furnace, boiler and combustion chamber, turbine system, and finally flue gas cleaning system.

1.1 The project

System configuration

In 1999 the governing board of I/S Reno Nord decided to build a new incineration line for combined heat and power generation with a rated throughput of 20 metric tons of waste per hour with a lower calorific value of 12 MJ/kg and an annual volume of incinerated waste of 160,000 metric tons.

The new incineration line was designed to have sufficient capacity to burn the entire medium-term volume of waste produced by the seven municipalities represented in the municipal authority. In addition to fulfilling applicable statutory requirements by a wide margin by considerably reducing environmental pollution, the new system was designed to utilise the latent energy of the waste significantly more efficiently. Figure 1 shows a performance chart.

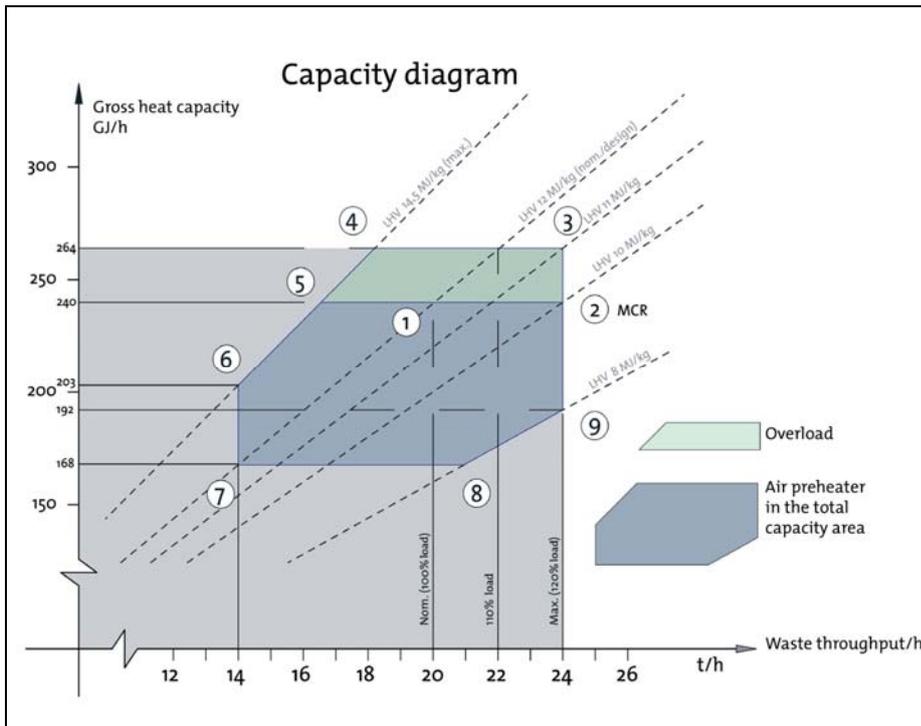


Figure 1: Performance chart

The new incineration line was also designed to be installed in a new building alongside the existing line (Figure 2), with the existing waste bunker being extended such that the same waste handling crane could feed waste to both the old and the new line. The plan called for replacing the two existing waste handling cranes with two new, automated cranes with larger capacity.

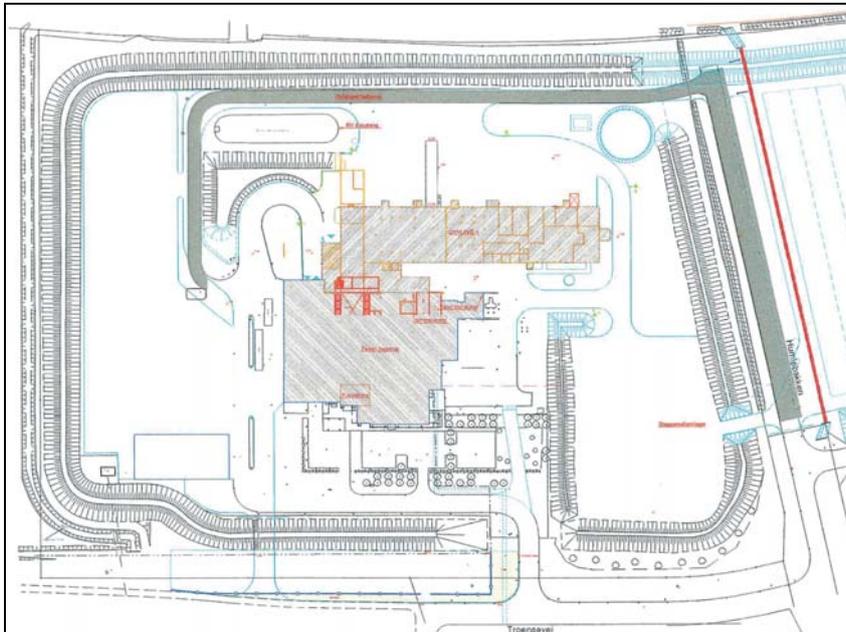


Figure 2: Site plan

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The new line was planned to be constructed as a conventional, grate-fired unit with a steam boiler having three vertical radiant flue gas passes and one horizontal convection pass, consisting of an evaporation tube bank, superheater and economiser. The steam data were specified according to the values of line 3:

Steam pressure: 50 bar (a)

Steam temperature: 425 °C

Feedwater temperature: 130 °C

The turbine specifications called for a design with a swallowing capacity of 120 % of the rated steam generation capacity of the boiler with a 120 % bypass system and equipped with two district-heating condensers for feeding heat into the municipal district heating network of Aalborg.

The flue gas cleaning system was specified to consist of a three-section electrostatic filter followed by a three-stage wet flue gas cleaning system along with the associated wastewater treatment plant for the effluent.

An SNCR unit was specified to be used for NO_x removal.

In order to separate ammonia from the effluent of the wet flue gas cleaning plant, the wastewater treatment plant was also specified to include a steam-driven ammonia stripper.

I/S Reno Nord focussed its efforts specifically on obtaining a system that could generate heat and electricity with high efficiency while complying with the latest EU emission regulations.

In addition, emphasis was placed on long-term continuous operation and high availability.

Public tender for line 4

The tender specifications for supplying the machinery and electrical equipment for the new incineration line were issued in March 2001 after the project had been divided into three main lots for tendering, as described below.

Deliverables for construction lot 1:

- Combustion System
- Boiler
- Electrostatic filter
- Steam turbine and generator system, including the steam, condensate, feedwater, and district heating systems
- Electrical systems
- MSR system
- All associated ancillary equipment and fixtures

Deliverables for construction lot 2:

- Wet flue gas cleaning system including a dioxin filter
- Wastewater treatment plant
- Associated electrical equipment
- Associated MSR system (which was subsequently assigned to lot 1)

Deliverables for construction lot 3 (several trades):

- Structure and building

Steel construction for the building was subsequently assigned to lot 1.

Schedule

The schedule described in Table 1 was drafted for the construction project.

Table 1: Construction schedule for Line 4, I/S Reno Nord

	Contract	Actual date
Conditional contract	19.09.2002	
Definitive conclusion of contract by	01.07.2003	
Start of mechanical installation	04.04.2004	
Start of hot testing	01.04.2005	
Start of trial operation	01.08.2005	12.09.2005
End of trial period	01.11.2005	12.12.2005
Provisional acceptance	01.11.2005	22.12.2005
Start of guarantee	01.11.2005	12.12.2005
Definitive acceptance after conclusion of the guarantee period	01.11.2007	12.12.2007

The contract could not be regarded as final until 1 July 2003, since definitive official approval of the project was only obtained at this date.

The start of trial operation was delayed due to a fire in the plant during the hot test. The client accepted the delayed start of the trial period as a consequence of *force majeure*. Although acceptance of the system was delayed relative to the contractually specified date, no contractual penalty was imposed on the contractor; this was largely due to the fact that the system performance complied with the provisions of the original schedule in terms of waste incineration and energy generation throughout the entire period.

Project organisation

The Danish engineering consultancy Rambøll A/S was selected by I/S Reno Nord as the consultant for the client, and in this role it prepared the tender specifications for the machinery and structures.

Babcock & Wilcox Vølund A/S was awarded the contract for executing lot 1 of the construction project, with B+V Industrietechnik GmbH as the subcontractor for the turbine and generator systems, while LAB S.A. was awarded the contract for the flue gas cleaning system.

Contracts for construction lots 1 and 2 were concluded between I/S Reno Nord and a consortium formed by Babcock & Wilcox Vølund A/S and LAB S.A., with Babcock & Wilcox Vølund as the consortium leader.

1.2 System concept

The basic structure of the system is shown in Figure 3. The turbine and generator systems are located in the building below the horizontal boiler section.

In order to achieve high electrical and thermal efficiency, two enamelled and PFA-coated coolers are fitted after the electrostatic filter. They reduce the temperature of the flue gas from 180 °C to 90 °C before the flue gas enters the wet flue gas treatment plant.

The first cooler reduces the flue gas temperature to 120 °C. The energy extracted here is used to preheat the combustion air. Figure 3 shows the link to the air preheater in schematic form.

Heat is transferred to the combustion air by hot water that exits the flue gas cooler at a temperature of 150 °C. The water temperature is reduced to around 40 °C in the first section of the air preheater, from which it is fed to a heat exchanger where it is heated to around 76 °C by district heating hot water before being fed back to the flue gas cooler. As a result, the entire combustion air volume is heated to around 125 °C.

The primary combustion air is heated to around 145 °C in the second section of the air preheater by a partial feedwater stream tapped off from the water emerging from the economiser.

The second cooler reduces the flue gas temperature from 120 °C to 90 °C. The energy extracted here is used to preheat the condensate.

The flue gas cleaning system includes a condensation stage that is chilled by district-heating water.

Overall power and energy generation:

Electricity (gross):	17,918 kW
Heat from district-heating condensers:	43,412 kW
Condensation heat from the flue gas cleaning system	4,000 kW
Condensation heat with the current district heating water return temperature:	7,000 kW max.
Resulting gross electrical efficiency:	27%
Resulting overall thermal efficiency:	98%
Boiler efficiency:	92%

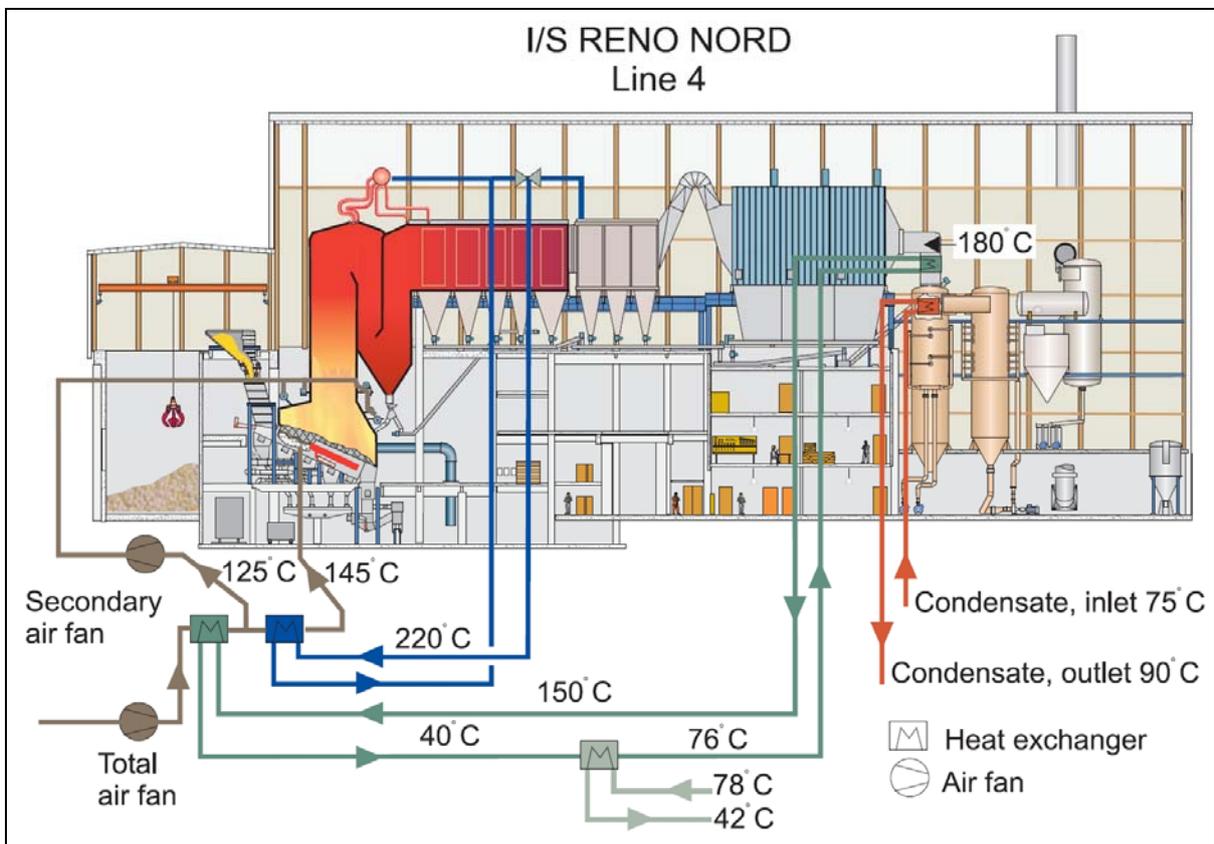


Figure 3: Line 4 system concept, I/S RENO NORD

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Table 2: Incineration line 4, technical data

Waste silo	Capacity	12,500 m ³
	Number of dumping bays	5
Waste handling cranes	Quantity	2
	Grab volume	8 m ³
	Type	Fully automatic
	Supplier	Kone Cranes
Combustion System	Throughput	20 t/h
	Grate type	BS-W, air cooled
	Grate length	9.9 m
	Grate width	9.1 m (usable width 8.8 m)
	Supplier	Babcock & Wilcox Vølund A/S
Boiler	Boiler wall protection	Inconel / refractory
	Burners	Oil, 2x 25 MW
	Thermal energy input	66.7 MW
	Steam generation	22.2 kg/s
	Steam pressure:	50 bar (a)
	Steam temperature:	425 °C
	NO _x reduction	SNCR
	Supplier	Babcock & Wilcox Vølund A/S
Turbine/generator	Output	17.9 MW
	Temperature / pressure	422 °C / 48 bar
	Supplier	B+V Industrietechnik GmbH
District heating condenser	Output	43 MJ/s
	Temperature	38 °C / 78 °C
	Supplier	B+V Industrietechnik GmbH
Dust removal	Type	Electrostatic filter
	Number of fields	3
	Capacity	Less than 10 mg/Nm ³
	Manufacturer	Alstom
	Supplier	Babcock & Wilcox Vølund A/S
Flue gas cleaning	Flow	112,000 Nm ³ /h
	Type	Wet flue gas cleaning
	Components	Quencher, acid scrubber, limestone-based alkali scrubber, HOK-based dioxin scrubber, venturi scrubber with agglomeration filter, exhaust blower
	Condensation stage	Direct cooling with district heating water Heat generation for district heating: 4 MJ/s
	Supplier	LAB S.A.
MSR system	Manufacturer	ABB
	Supplier	Babcock & Wilcox Vølund A/S
Chimney	Height	75 m
Building	Dimensions (L x W x H)	115 x 25 x 45 m
Consultants	Principal consultant	Rambøll A/S
	Architect	C. F. Møller

Combustion System

Feeding system

The key objective in feeding the furnace is to supply exactly the right amount of fuel to the grate necessary to achieve stable combustion and energy generation.

The feed rate must be constantly and continuously adapted to the transport capacity of the grate in order to obtain a uniformly distributed layer of fuel on the grate and thus achieve uniform energy generation. Consistent feeding in this manner ensures minimal environmental pollution, especially as it fosters optimally controllable combustion.

The feed hopper of the Reno Nord system is designed to avoid blockages as much as possible in order to ensure a continuous inflow of waste to the water-cooled feed chute. Three sides of the hopper are vertical to prevent the formation of bridges in the waste material in the hopper. The feed system is shown in Figure 4.

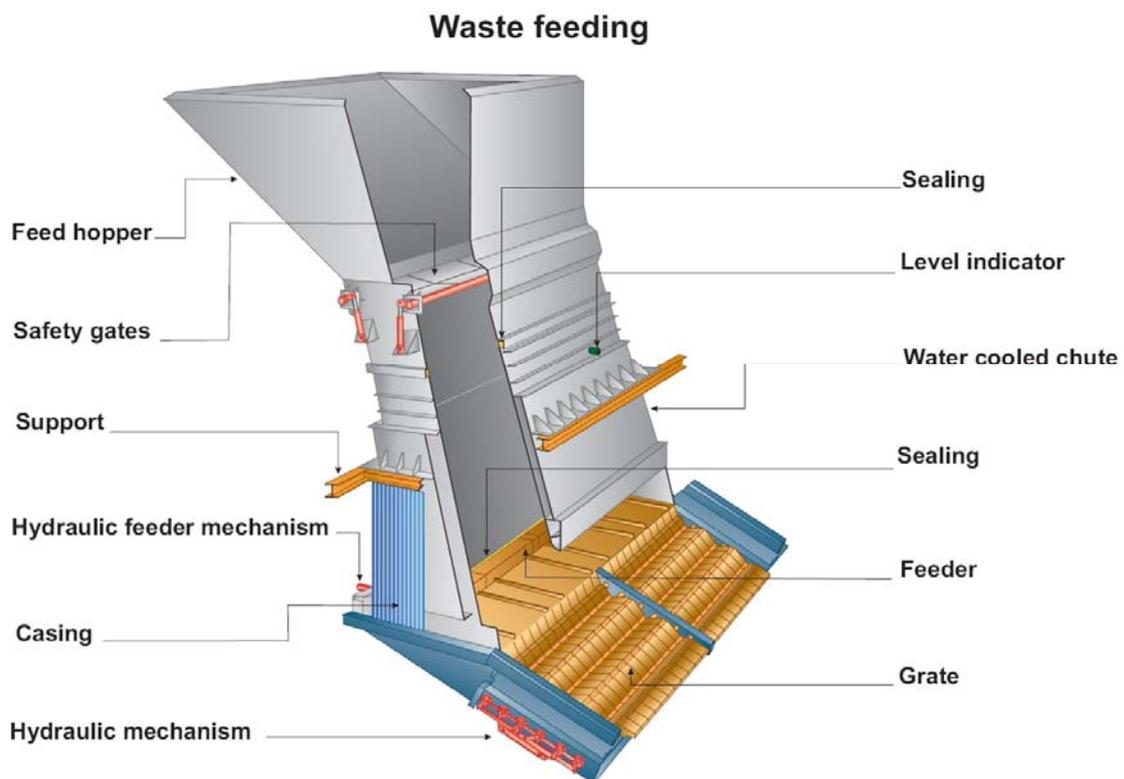


Figure 4: Feeding unit

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The inner surfaces of the hopper are lined with sheet-steel wear panels.

All structural loads are transferred from the hopper to the crane deck. As the junction between the feed hopper and the feed chute is not rigid, the thermal expansion of the hot combustion chamber does not affect the load transferred to the crane deck. The junction between the hopper and the chute is sealed by a dust-proof flexible connection.

There are two hydraulically actuated safety hatches between the hopper and the chute. In normal operation, they are open and lie flush against the front and rear walls of the lower part of the hopper. When actuated, the hatches close to seal the opening between the hopper and the chute.

The hatches can be closed in the event of a fire in the chute. The hatches close automatically if there is an electrical power failure.

The feed chute carries the waste from the feed hopper to the waste feeder. In addition, the chute acts as a storage area for the waste before it catches fire on the grate. The chute is made from thick steel plate with water cooling in order to withstand the effects of strong heating. Although the cooling load is minimal in normal operation, the constantly circulating cooling water is intended to prevent possible overheating. The heat extracted by the chute cooling water is fed to the district heating system.

The chute is attached to the combustion chamber and is shaped like a slender funnel with its wide end facing the combustion chamber. This prevents the waste from getting stuck after it has passed through the narrow end at the top.

The waste is fed to the grate by a hydraulic waste feeder at a variable speed corresponding to the energy generation. The continuous, slow forward motion of the waste feeder at a variable speed corresponding to the energy generation results in a consistent, continuous flow of waste supplied to the grate.

The waste feeder is located at the bottom end of the feed chute, where it feeds the waste slowly to the first section of the grate. The waste feeder consists of several feeder rams, with each ram driven by a hydraulic cylinder.

The hydraulic-fluid volume control system ensures that the feed rams move forward synchronously at variable speed. The waste feeder is made from thick sheet steel in order to withstand the mechanical effects of the waste materials. In addition, the leading and trailing edges of the waste feeder are fitted with replaceable sheet steel wear plates.

The sides of the lower part of the chute is fitted with cast-iron wear plates in the operating area of the ram feeder.

Each feed ram is air-cooled and has two cooling air inlets to ensure adequate cooling of the ram. This advanced channel system for the rams is also of a robust construction to enable the rams to withstand the impact of heavy objects landing in the empty chute.

The replaceable cast-iron wear plates on the sides of the chute are designed to prevent the feed material from jamming between the outer rams and the chute walls.

BS-W waste incineration grate

The incineration grate is a conveying device that transports the ignited fuel from the waste feeder through the combustion chamber to the ash extractor located below. During the transport process, the fuel is mixed and combustion air is added. Volatile materials are released into the combustion chamber, while bound carbon compounds are burnt on the grate.

Line 4 is fitted with a BS-W Mark 5 air-cooled grate, which is also suitable for conversion to water cooling if desired. The grate, which consists of two parallel grate lanes, each with a width of 4.4 metres, is divided lengthwise into four sections.

The BS-W Mark 5 grate incorporates the results of 40 years of development experience. The proven, air-cooled W grate is ideally suited to waste incineration, in particular due to its very high combustion efficiency with high energy utilisation and low environmental pollution.

The Line 4 grate is prepared for conversion to water cooling if this proves to be necessary in the future.

The patented water-cooled Mark 6 grate has demonstrated a service life of approximately 32,000 operating hours in the prototype version and around 32,000 operating hours in commercial use (up to 2006).

The Mark 6 grate is characterised by its suitability for burning waste materials with high calorific content, and it can be fully combined with the air-cooled Mark 5 model, which yields an unrestricted design scope for varying the proportion of air-cooled and water-cooled grate areas.

The BS grate system can handle all types of unsorted solid waste and can be used for combined fuelling with biomass.

Grate operation

The grate resembles a set of stairs. The individual elements – the grate bars – are arranged in alternating horizontal and vertical orientation. The grate bars are in turn fitted to shafts so the bars of two adjoining shafts can join to yield a continuous grate surface.

The structure of the grate is shown in Figure 5.

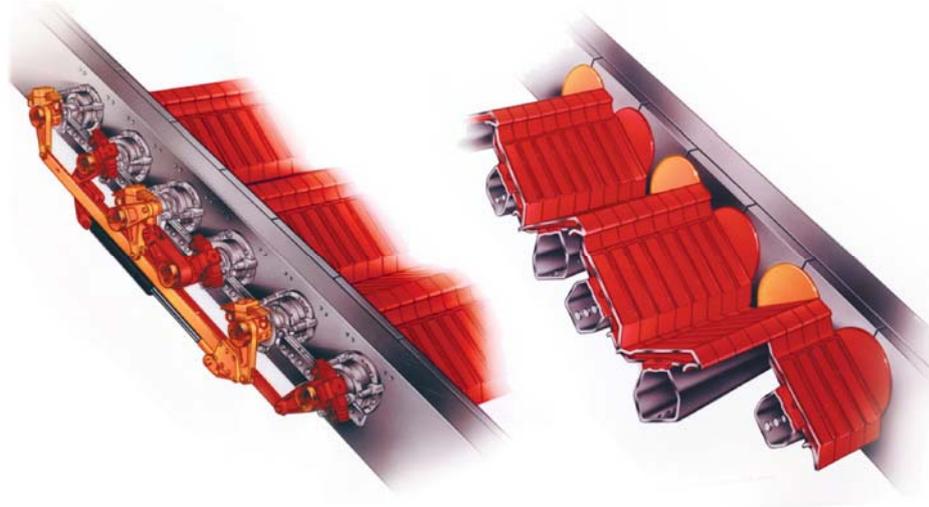


Figure 5: BS W MARK 5

When the shafts rotate by 60 degrees in opposite directions as the grate moves, the orientation of the grate elements changes between horizontal and vertical.

This alternating orientation of the elements from horizontal to vertical or vertical to horizontal creates a wave-like motion in the lengthwise direction. This motion optimises the mixing and distribution of the waste on the grate bed to ensure proper drying, transport, and combustion.

The drive mechanism (Figure 6), which is located outside the combustion chamber, allows a gap of around 2 mm to form between the grate bars of two adjoining shafts while the grate is moving, and the combustion air is fed through these gaps.

The grate motion keeps the air gaps constantly clean and free of particulate matter. There is no physical contact between the grate bars of two adjoining shafts during grate motion.

On the sides each grate shaft is limited by a rotary disc, which, in combination with the side covers of the grate, forms a flat side wall that allows the grate to expand freely in this region. All grate elements that are exposed to the combustion chamber have cooling flanges on the rear surface.

A grate consists of modules that can be combined to form grates of various lengths and widths.



Figure 6: The drive mechanism outside the combustion chamber

The maximum width of a grate lane is 4.8 metres. Larger grate widths can be obtained by arranging several lanes side by side. There is no limit to the number of grate sections that can be combined, and thus no limit to the length of the grate. The grate is oriented at an angle of 25 degrees to the horizontal.

Each grate section can be operated at an independently variable speed according to the required energy generation. Each grate section is equipped with a complete drive mechanism, including a double-acting hydraulic cylinder. This drive mechanism also ensures that the width of the gap between the grate bars of two adjoining shafts remains constant during grate motion.

BS Mark 5 air-cooled W grate

Process advantages:

- The minimal, well-defined air gap area is approximately 1.5 to 1.8 percent of the configured grate area. This limits the volume of grate riddlings and thus the amount of unburnt material below the grate. This in turn results in particularly efficient air distribution above all areas of the grate sections.
- As a result of good mechanical turning of the waste on the grate, all of the waste material is exposed to radiant heat from the combustion chamber and combustion air. Combined with the efficient distribution of the combustion air, this ensures controlled, effective combustion that yields very low CO and TOC values at the steam generator outlet and stable energy generation.
- The primary air supply for the Mark 5 grate is close to the stoichiometric ratio. This results in low temperatures in the waste layer on the grate, which in turn reduces slag agglomeration and minimises the accumulation of encapsulated residues of combustible components. This yields good combustion characteristics and finely granulated slag.
- The slow, continuous motion of the grate generates very little dust and fly ash in the flue gas stream.

Mechanical advantages:

- There is no physical contact between the moving parts of the grate. This reduces wear and minimises mechanical forces on the grate.
- Locating the drive mechanism and grate bearings outside the perimeter of the furnace protects them against soiling by grate riddlings, melted metals, and liquids.
- The air gap between the side plates and the adjacent grate bars remains constant regardless of thermal expansion of the grate shafts.
- The moveable side seals track the lateral expansion of the grate.

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- The grate components are machined to tight tolerances to ensure optimal primary air distribution.

In addition to the process advantages directly associated with the incineration of waste materials with high calorific content, the patented Mark 6 grate (Figure 7) enables full integration with the air-cooled Mark 5 grate (BS-W grate). It provides unrestricted design scope for choosing a grate bed, especially since the air-cooled or the water-cooled version, or a combination of the two can be used because the water-cooled grate has the same motion geometry as the air-cooled version and the water-cooled grate bars have exactly the same geometric form as the air-cooled bars. A water-cooled grate thus offers the same process advantages and mechanical advantages as an air-cooled grate.

The water-cooled grate bars are formed and machined as hollow sections with channels that allow the cooling water to be fed to the areas with the highest heat loads. The large volume of water circulating through the individual grate bars keeps the temperature difference along the length of the individual grate bars low, which minimises the risk of local overheating.

Each grate section has its own water circuit, which is designed for a maximum operating pressure of 10 bar and a maximum operating temperature of 120 °C. The temperatures of the cooling water circuits are regulated to achieve a constant grate exit temperature. As a result, the temperature difference varies along the length of the grate. The maximum temperature difference is 25 °C.

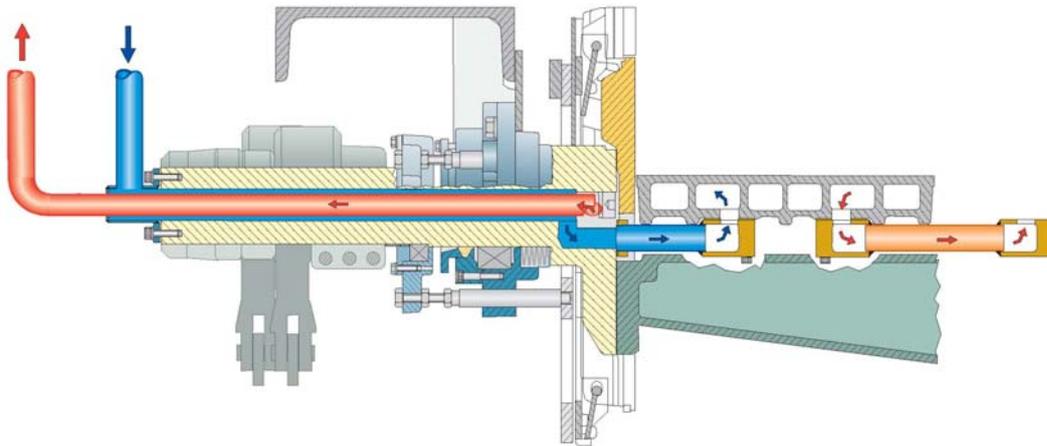


Figure 7: BS W Mark 6 water-cooled grate

The cooling circuit is designed for maximum heat flux from the hot flue gases. Normal heat flux is in the range of 15 to 20 kW per square metre. In normal operation, all of the transferred energy can be fed back into the combustion process because the energy can be used to heat the combustion air. This means that steam generation efficiency and electricity generation can be maintained by using a water-cooled grate.

Each cooling circuit is equipped with circulation pumps, a flow meter and energy meter, a pressure expansion tank and a heat exchanger. The energy received from the grate is used to heat the combustion air in the heat exchanger. To enable all shafts to be controlled to achieve uniform throughput, each grate shaft is fitted with a combined throughput indicator and meter.

The cooling water inlet and outlet of each shaft are formed by two concentric tubes fitted to the end of the shaft. These tubes carry the water through a fixed tubing system in the middle of the shaft to the individual grate bars, which are arranged sequentially. After passing the grate bars, the water is also fed back through the tubing system embedded in the grate shaft under the grate bars. Standard steam hoses are used to carry the water from the fixed tubing system outside the furnace to the shafts, which rotate through an angle of 60 degrees.

The hoses are located outside the furnace to avoid exposing them to hot ashes, melted tin and aluminium, etc., which could damage the hoses. This design avoids any sort of hoses inside the furnace.

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BS Mark 6 water-cooled W grate

Process advantages:

- Grate bed cooling is independent of the combustion air, so the air supply can be adjusted to achieve optimal combustion
- Optimal combustion air distribution allows excess air to be minimised, with a corresponding reduction in flue gas volume
- Minimal corrosion due to low grate element temperatures
- Constant, high water circulation through the individual grate elements prevents local boiling
- All energy obtained from grate cooling can be transferred to the primary air
- Low temperature difference over the grate results in low thermal stress

Mechanical advantages:

- Cooling water enters and exits the grate via the shaft ends with tubing connections to the centre of the shaft
- No fragile hose connections below the grate
- No grate damage due to temporary cooling failure

Combustion air system

The entire volume of the combustion air is drawn equally from the waste bunker and the boiler house by a total air fan. This fan is controlled by a variable-frequency drive. From the fan, the air is routed to an air preheater consisting of two sections.

The entire volume of the combustion air is heated to 125 °C in the first section of the air preheater.

The primary air is further heated to 145 °C in the second section of the air preheater by a partial feedwater stream tapped off from the water emerging from the economiser.

After emerging from the air preheater, the primary air is distributed by a duct system to the individual hoppers under each grate section.

The air volume is measured using venturi tubes and fed to the individual grate sections via the control dampers in the individual supply ducts. These dampers are controlled by the combustion controller so the air supply to the individual grate sections can be controlled independently.

After the secondary air emerges from the preheater at 125 °C, its pressure is increased by a fan controlled by a variable frequency-drive. The fan maintains a constant pressure in a manifold, from which the air is distributed to the individual rows of nozzles.

The air supply to the individual rows of nozzles can be measured using venturi tubes.

VoluMix

This technology involves injecting secondary air into the combustion zones in many places at different angles and velocities (Figure 8). The flow fields include dual rotating vortices in the after-combustion chamber (ACC). The vortex method guarantees thorough mixing of the gases, ensures long retention times and complete CO combustion, and makes it possible to achieve fast O₂ control and uniform flue gas temperatures, even in the corners of the pass.

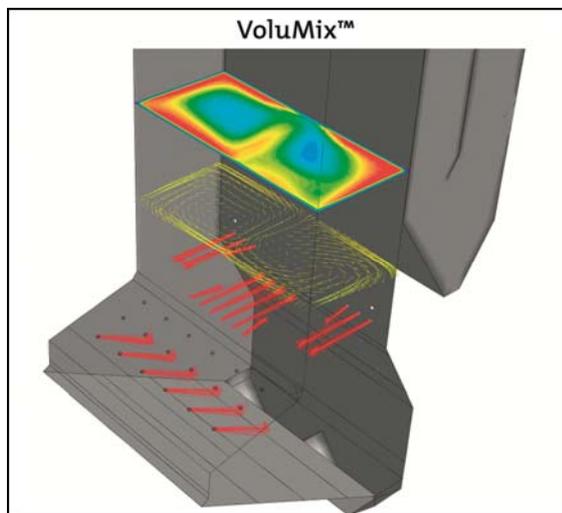


Figure 8: VoluMix

The positioning of the VoluMix nozzles is important for achieving a specific flue gas flow pattern in the after-combustion chamber. Several structural requirements are critical for the placement of the nozzles.

The front nozzles on the ceiling of the combustion chamber are arranged to push the hot gases over the middle grates up in the front of the combustion room to accelerate the drying of the incoming waste. The nozzles fitted on the rear wall help create turbulence at the entrance of the after-combustion chamber and aid the extraction of hot combustion gases from the middle of the grate back to the rear wall. Several rows of nozzles are located at the entrance of the after-combustion chamber. This creates a large region with favourable turbulence conditions.

Counterflow nozzles are positioned to achieve excellent mixing, provide oxygen and ensure the right turbulence conditions for full CO combustion. Although many design objectives could be stated here, the main focus is on achieving the maximum foreseeable service life, low emission levels and high thermal efficiency. These objectives lead to a set of requirements for the flow characteristics:

- Thorough mixing in the combustion chamber
- Low peak temperatures in the combustion chamber in order to minimise thermal NO_x formation
- Staged combustion
- Avoidance of localised overheating in the combustion chamber and boiler, since overheating can accelerate corrosion processes
- Creation of turbulent conditions in the first flue gas pass in order to optimise complete combustion
- Uniform temperature and velocity distribution in the flue passes in order to maximise heat transfer and retention time
- Avoidance of particle impact in the wall areas in order to minimise corrosion and erosion.

The implementation and arrangement of the VoluMix nozzles is based on an analysis of the combustion and CFD flow modelling. This method makes it possible to achieve extremely low CO levels – an indicator for combustion quality – under commercial operating conditions.

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Excess air

The Vølund System boiler design with staged combustion, central or parallel flow in the furnace, FGR etc. makes it possible to operate the incinerator with a low excess air ratio, which yields a low O₂ level of 4 to 5% (wet) with low CO emissions and no CO corrosion.

Cooling air

The cooling air serves to cool the grate bars and the waste feeder.

The majority of the cooling air is not included in the combustion process. A small portion of the cooling air acts as combustion air as a result of being fed along the edges of the grate to cool these parts of the system.

Grate riddlings, bottom ash and ash

Grate riddlings

There are two discharge hoppers with cleaning doors below each grate section, which serve to receive the grate riddlings and supply the primary air. Each hopper is fitted with a duct with a dual-flap lock section and connected to a pair of vibratory pipe conveyors that transport the grate riddlings to a set of wet bottom ash extractors. The grate riddlings are received and transported in a hermetically sealed system to prevent objectionable dust emissions.

Bottom ash

The bottom ash hoppers connect the furnace to the wet bottom ash extractors. The bottom ash tipped off the end of the moving grate falls through the bottom ash hoppers into the wet bottom ash extractors. There are two hoppers and two wet bottom ash extractors.

The bottom ash hoppers are made from sheet steel, and the upper part has a refractory lining to withstand the effects of exposure to the strong, variable heat of the bottom ash.

The wet bottom ash extractors receive the hot bottom ash from the furnace. The bottom ash is cooled in a water bath, which also prevents penetration of outside air via the wet bottom ash extractors.

The bottom ash is removed by a hydraulically driven ram. The ram operates automatically using an adjustable pulse generator, and its motion shoves the bottom ash onto the transverse vibratory conveyor.

The transverse vibratory conveyor carries the bottom ash to a rubber conveyor belt that transports the bottom ash out of the boiler house.

Ash

The boiler ash is collected in the second and third boiler passes and the horizontal convection pass by chain scrapers and transported to the ash silo. The ash from the electrostatic filter is also stored in this silo.

The ash is removed from the silo in dried form so that it can be transported in tankers to the waste disposal site.

Boiler and combustion chamber

Vølund Systems Boiler

For many decades, Babcock & Wilcox Vølund has been active in the design and construction of a broad range of water-tube boilers designed for firing with oil, gas or solid fuels.

Its range of boiler products includes:

- steam boilers for saturated or superheated steam
- hot-water boilers
- waste incineration boilers for use with waste-fired power plants and gas turbines.

The structural design normally consists of a four-pass boiler with two options for the final pass. The function of Vølund Systems Boiler includes:

- integration of the furnace, after-combustion chamber and boiler
- optimal flue gas flow through the system
- uniform temperatures and heat loads
- minimised risk of corrosion
- good near complete-combustion characteristics with low CO and TOC levels
- optimised, integrated SNCR for NO_x reduction
- very low NO_x emission
- generation of hot water, steam and/or electricity.

Radiation is the primary heat transfer mechanism in the first two or three passes. In the final pass, heat is transferred predominantly by convection. The convection pass of a boiler is characterised by the manner in which energy is transferred from the hot flue gas to the water or steam, with the primary mechanism here being convective heat transfer. In the case of boilers for generating energy from waste, the flue gas temperature at the inlet of the convection pass is typically less than 700 °C in order to minimise corrosion and the fouling of the superheaters by ash deposits.

The heating surfaces are usually cleaned by soot blowers or rapping devices, depending on the arrangement of the individual surfaces. The convection pass is normally located immediately ahead of the economiser, which also has a convection heating surface.

Combustion chamber design

Due to the interaction between the direction of flue gas flow and the direction of the waste feed over the grate, the furnace geometry is exceptionally important for the optimisation of the combustion process. Very broadly speaking, there are three different arrangements for the furnace and boiler:

- Counterflow: the gas flow and waste feed are in opposite directions
- Central flow
- Parallel flow: the gas flow and waste feed are in the same direction.

The combustion chamber of Line 4 is built as a central-flow furnace (Figure 9).



Figure 9: Combustion chamber with central-flow firing

The Vølund central-flow design:

- integration of the furnace, after-combustion chamber and boiler
- optimised flue gas flow through the system
- uniform temperatures and heat loads
- minimised risk of corrosion
- good water circulation
- ideally suited to volatile fuels with high calorific value.

The central-flow furnace and boiler with a large radiant section, which also serves as the after-combustion chamber, is the optimal solution for industrial waste with high calorific value.

It allows the volatile components of the fuel to be fed to the after-combustion chamber and enables relatively fast complete combustion of these components. The released energy is absorbed by the boiler. In addition, the boiler can absorb a large part of the radiant heat from the furnace. Another factor is that a slightly higher flue gas temperature in the radiant section automatically results in a higher surface heat load. Although this involves the use of smaller radiant heating surface, it makes them more efficient.

The side walls and ceilings of the combustion chamber are water-cooled and consist of membrane tube walls. The side walls are lined with Inconel, and the ceilings are lined with refractory. The operational and environmental advantages of this sort of solution arise from the fact that the system can be operated with a relatively low amount of excess air without producing excessively high combustion temperatures.

Water-cooled wear surfaces fashioned as membrane tube walls are used for the junction between the boiler and the grate, in particular because these walls follow the slope of the grate and rest on the grate, which allows the top supported boiler to extend downwards behind the wear surfaces. The wear surfaces are Inconel clad and are fashioned as a pair of vaporiser heating surfaces, which obtain their supply water from the two main down comers. Riser tubes run from each of the heating surfaces to the steam drum.

The water-cooled wear surfaces were developed primarily for use with relatively large top supported boilers in order to reduce the surface area formed by uncooled refractory material in furnaces used to generate energy from waste materials.

This uncooled refractory material has the disadvantage that it regularly leads to the formation of large slag deposits, which in some cases can cause operational malfunctions in the system. Baked-on deposits on the side walls of the combustion chamber can interfere with the transport of waste material on the grate and thus considerably impair the combustion process. In the worst case, the result is a full operational outage. Consequently, reducing the amount of refractory material has the advantage of reducing maintenance costs and increasing availability.

Boiler

The boiler for Line 4 is built as a four-pass boiler with three radiant passes and a horizontal pass with an evaporation heating surface in front of the superheater and an economiser. The boiler is designed to operate with natural circulation.

The radiant passes are implemented as a top supported assembly, while the convection pass with the superheater and economiser is implemented as a bottom supported assembly.

The boiler is conservatively designed with a large heating surface in order to achieve long-term continuous operating periods without undesirable deposition of ashes during the operating period.

At the request of I/S Reno Nord, the boiler was designed such that the system can be operated with an excess air factor of 1.8, which corresponds to an oxygen concentration in the flue gas of 9.3% by volume (dry).

The after-combustion zones are located in the first radiant pass of the steam generator.

The after-combustion zone is lined with refractory material. Secondary air nozzles are located in the front and rear walls at the entrance of the first boiler pass, and secondary air is injected via these nozzles at high velocity.

Two modulating start-up / auxiliary light-oil burners are located at the beginning of the first flue duct. Each burner has a capacity of 25 MW. These are located on the sides of the first pass, with the refractory lining formed with suitable allowance for the burner cones.

Ceramic burner head covers are used to avoid the need to withdraw the burners from the combustion chamber when they are not in use.

Nozzles are also fitted at two levels on the side walls of the first flue pass in order to inject an ammonia solution for NO_x reduction.

The rest of the first pass and part of the second pass are lined with Inconel.

Hanging membrane walls are located in the third pass to ensure adequate reduction of the flue gas temperature before the entrance of the convection pass.

The hanging membrane walls can be cleaned with steam soot blowers to ensure that the required flue gas temperature of 620 °C before the superheater can be maintained.

An evaporating heating surface is located ahead of the superheater.

The superheater is divided into three sections, with water injection provided between superheater 1 and superheater 2 and between superheater 2 and superheater 3 (the last superheater) for regulating the steam temperature.

Pneumatic rapping devices are used to clean the superheater sections during operation.

A horizontal economiser is used here. The economiser is designed such that part of the feedwater stream can be bypassed to a heating surface in the steam drum and returned to the economiser in order to maintain a flue gas temperature of 180 °C at the economiser outlet during the entire operating period between manual cleaning. The economiser is cleaned during operation by pneumatic rapping devices.

Turbine system

The turbine system was supplied by B+V Industrietechnik GmbH.

The turbine is designed for a swallowing capacity of 120 % of the nominal steam generation. The rated power of the generator is 17.918 MW. The turbine system is fitted with a bypass system for receiving the full volume of steam.

The turbine is equipped with a control stage followed by five sections divided into twenty-two stages with reaction blades.

The turbine system has two condensers cooled by district-heating water: one for high pressure and the other for low pressure.

The turbine is equipped with uncontrolled steam extraction for condensate preheating via a heat exchanger and an uncontrolled extraction for heating the feedwater tank.

The condensate is preheated in two stages. The first preheating stage uses heat from the second stage of the flue gas cooler. Following this, the condensate is further heated by extracted steam in a separate heat exchanger before being pumped back into the feedwater tank, where it is maintained at a temperature of 130 °C.

Flue gas cleaning

The first stage of the flue gas cleaning system consists of a three-field electrostatic filter made by Alstom. The dust concentration after the filter is 10 mg/Nm^3 with a flue gas oxygen content of 11% by volume (dry). The low dust volume arises from the fact that the dust concentration at the inlet to the scrubber must be kept as low as possible due to regulations regarding the introduction of heavy metals into wastewater.

The electrostatic filter is followed by a wet flue gas cleaning system supplied by LAB S.A.

The LAB flue gas cleaning system employs a unique process to remove ammonia, hydrogen chloride, sulphur dioxide, hydrogen fluoride, mercury, heavy metals, dioxins and solid particles from the flue gases of waste incinerators. The flue gas cleaning system also includes an ammonia stripper to remove ammonia from the wastewater before it is fed to the wastewater treatment plant. The stripper was supplied by Rauschert Verfahrenstechnik GmbH.

Principal components of the flue gas cleaning system:

- The first stage is an open spray scrubber. Here the flue gas is cooled to approximately $90 \text{ }^\circ\text{C}$ by a water spray at the inlet of the scrubber. The primary components removed in the first stage are ammonia, hydrogen chloride, and mercury. Limestone slurry is used as the active medium.
- The second stage is also an open spray scrubber, which primarily serves to remove sulphur dioxide. Limestone slurry is used as the active medium.
- The third stage consists of two parts: an open part equipped with the patented LAB G nozzles, and a second part with a filling of solids. This stage is intended to remove dioxins and furans. It uses the patented Dedioxlab wet catalyst process.

In order to extract energy from the flue gas and condense the water vapour in the flue gas, the water circuit of the scrubber includes a heat exchanger that transfers the energy in the process water to the district heating network.

Sodium hydroxide is added in the third stage. It enables a quick response to sulphur dioxide peaks and simplifies any adjustments that may be necessary. Hearth furnace coke is injected in the third section to remove dioxins and furans.

- The fourth stage consists of the agglomeration filtration modules (AFMs), which remove the remaining dust particles.
- This is followed by the wastewater treatment plant and ammonia stripper, which removes the ammonia emissions washed out of the flue gas.
- The limestone silo and the limestone pre-treatment system.
- The gypsum handling system.
- The storage container for hearth furnace coke, the pre-treatment system and the spray injection system.

2. Operational Experience – Performance

Following the description of the system concept, here we briefly describe the initial operating results and compare them with the values specified in the guarantee. The time frame here is the first year of operation or the trial operation period.

2.1 Actual performance versus guaranteed values

In connection with the three-month trial period before the provisional acceptance, functional tests and provisional trials were planned in order to demonstrate that the system was able to fulfil the provisions of the guarantee in terms of operational performance and environmental compatibility. The system had to attain at least 300 hours of continuous operation during the test period. The results were reported on the basis of the operational data obtained using the MSR system. An independent measuring laboratory was engaged as an unbiased party to perform the emission measurements on the flue gas and wastewater. During the 300-hour test, bottom ash and ash samples were also taken within 12 hours for TOC analysis.

The target values specified in the guarantee and the actual measured values are listed for comparison in Table 3.

The guarantee stipulates that the variation in steam generation must be kept within a range of plus/minus 10% of the nominal steam generation.

Figures 10 and 11 show the measured variation in the steam flow and the CO and O₂ concentrations.

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Table 3: Target values specified in the guarantee and the values actually achieved

	Unit	Measured value	Guarantee value
Energy input	GJ/h	243.69	240.00
Volume of waste	t/h	21.72	14–24
Calorific value	kJ/kg	11,277	8–14.5
Steam flow	kg/s	22.55	22.42
Steam temperature at the turbine	°C	422	422
Steam pressure at the turbine	bar (a)	48	48
Electricity generation	MW	17.956	17.918
Internal electrical consumption			
Furnace and boiler	kWh/h	819	730
Turbine system	kWh/h	171.4	256
Flue gas cleaning	kWh/h	720	980
Total electrical power consumption	kWh/h	1,710.4	1,966
Overall system	kWh/h	2,332	
Percent relative to fuel heat input	%	3.5	

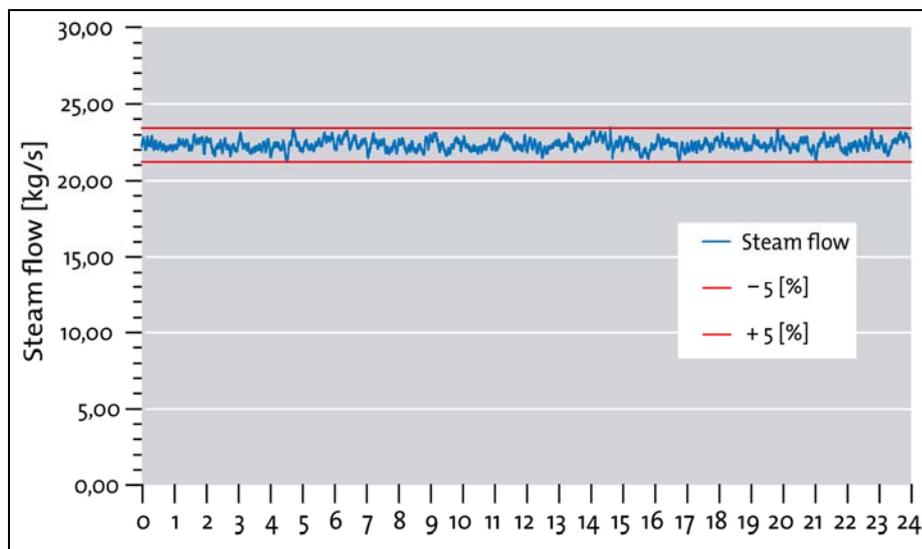


Figure 10: Normal variation in steam flow

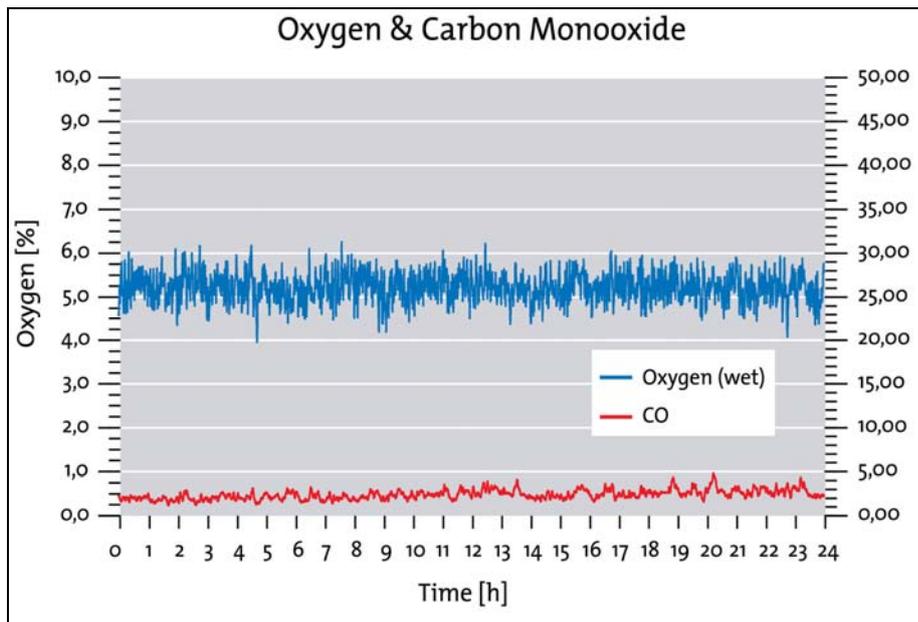


Figure 11: Normal variation in O₂ and CO content

Table 4: Environmental data

	Unit	Measured value	Guarantee value
Bottom ash and ashes			
Loss on ignition of bottom ash	% of TS	2.3	Less than 3.3
TOC of bottom ash	% of TS	0.27	Less than 2.0
Loss on ignition of boiler ash	% of TS	2.9	Less than 5
Loss on ignition – total ash	% of TS	5.4	
TOC of ash	% of TS	0.11	Not available
Flue gas emissions			
Particulate matter			
After electrostatic filter	mg/Nm ³	1.6	10
In chimney	mg/Nm ³	0.21	10
HCl	mg/Nm ³	0	5
HF	mg/Nm ³	Less than 0.1	2
SO ₂	mg/Nm ³	7.4	20
Hg	mg/Nm ³	0.0028	0.05
Cd and Tl	mg/Nm ³	Less than 0.0001	0.05
Total Sb, As, Pb, Cr, Co, Cu, Mn, Ni and V	mg/Nm ³	Less than 0.009	0.5
CO	mg/Nm ³	Below detection limit	50
The normal curves for oxygen and CO are shown in Figure 11.			
NO _x	mg/Nm ³	150	200
TOC	mg/Nm ³	Below detection limit	10
Dioxin and furan	ng I-TEQ/Nm ³	0.013	0.1

Treated wastewater

The wastewater streams are treated in the wastewater treatment plant to the point that they fulfil the statutory requirements for direct discharge of treated wastewater into the Limfjorden water body.

2.2 The first year of operation

Line 4 was shut down in August 2006 to carry out the annual inspection. At that time, the system had accumulated approximately 8,000 operating hours since its commissioning in the summer of 2005.

Some planned and unplanned downtimes occurred during this operating period.

An inspection of the combustion chamber, boiler and gas cleaning system pursuant to the terms of the guarantee was carried out in early December, coinciding with the conclusion of the three-month trial period and the start of the two-year guarantee period. No boiler cleaning was performed during this shutdown.

A total system outage occurred in January 2006 as a result of a fault in the 150-kV electricity grid, which led to the boiler being boiled dry, but without any significant damage. The down time was approximately 36 hours.

A shutdown of approximately nine days was scheduled in February 2006 for the replacement of the generator bearings. During this shutdown, changes were also made to the boiler water level regulation system, and the ash conveyer was remodelled.

The system had to be taken out of service in March due to an accumulation of ash in the bottom hoppers of the electrostatic filter. There was another downtime due to a fault in the high voltage unit of one field of the electrostatic filter.

Aside from these down times, in approximately 8,000 operating hours during the completed operating period the system achieved contractually compliant performance with respect to waste incineration and energy generation while conforming to the environmental protection regulations.

The following table presents comparative operational data for the combustion system and boiler before and after manual cleaning.

This data is based on the operation reports stored in the MSR system and the environmental reports, in particular for 27 July 2006 (before cleaning) and 27 August 2006 (after cleaning). The plant was shut down immediately after 27 July 2006, and on 27 August 2006 it had been operating for approximately fourteen days after being put back into service for waste incineration.

As can be seen from the situation before cleaning, the flue gas temperature before SH 2, the first superheater in the flue gas flow path, was 585 °C, compared with a requirement of 620 °C maximum.

Table 5: Comparative operational data

	Unit	27.07.2006	27.08.2006
Boiler load	%	102.5	102.1
Combusted volume	kg/h	21,119	22,227
Lower calorific value	MJ/kg	11.1	10.5
Temperature before EVAP	°C	606	510
Temperature before SH (max.)	°C	620	620
Temperature before SH 2	°C	585	500
Temperature before SH 3	°C	529	446
Temperature before ECO 3	°C	320	293
Temperature after boiler	°C	180	180
Flue gas pressure before EVAP	Pa	59	60.3
Flue gas pressure before ECO	Pa	-153	-68.1
Flue gas pressure after ECO	Pa	-304	-196.6
Feedwater temperature	°C	131	131
Feedwater flow	kg/s	22.58	22.564
Feedwater pressure	bar	79.5	82.2
Main steam flow	kg/s	22.277	22.309
Main steam pressure	bar	47.708	47.402
Main steam temperature	°C	423	417
Steam temperature before SH 2	°C	363	349
Steam temperature after SH 2	°C	409	390
Steam temperature before SH 3	°C	380	389
Water injection flow	kg/s	1	0
Feedwater temperature before ECO	°C	134	165
Feedwater temperature after ECO	°X	226	215
Steam pressure	bar (g)	55.9	56.2
Hot-water system flow	kg/s	7	6
Temperature before hot flue gas cooler	°C	75	75
Temperature after hot flue gas cooler	°C	155	155
Flue gas temperature before flue gas cooler	°C	182	179
Condensate temperature after flue gas cooler	°C	93	92
Flue gas pressure after flue gas cooler	mbar	-21	-17
Flue glass flow in chimney	m ³ /h	169,437	169,345
Flue gas temperature in chimney	°C	65	65
Oxygen in chimney	Vol % (dry)	6.8	6.4
District heating energy	MJ/s	45.6	44.9
Generator	MW	17.3	17.2

The measured flue gas temperature at the top of the second flue gas pass, at the transition between the first and second flue gas pass, was 717 °C before cleaning, compared with a specified maximum value of 900 °C.

As can also be seen from the table, on 27 July the flue gas temperature after the boiler was 180 °C, compared with a specified value of 180 °C.

The feedwater temperature before the economiser was 134 °C on 27 July, compared with a prior feedwater temperature of 131 °C. This means that feedwater was still being circulated through the heating surface in the steam drum in order to heat the feedwater to 134 °C. Consequently, the flue temperature was still being regulated by means of the feedwater.

The feedwater temperature after the economiser was 226 °C.

On 27 August, with a clean boiler, the feedwater temperature before the economiser was 165 °C and the temperature after the economiser was 215 °C.

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The measured pressure at the flue gas side before cleaning was -304 Pa on 27 July.

The pressure measured at this point on 27 August was -197 Pa. It thus increased by 107 Pa after approximately 8,000 operating hours.

During the inspection of the heating surfaces of the boiler before cleaning, it was found that the flue gas passage was largely unobstructed in the entire convection section. No signs of blockage between individual rows of tubes were found anywhere.

During the inspection, incipient corrosion effects were seen in the second boiler pass on the boiler wall between the first and second pass after the Inconel cladding. It may thus prove necessary to extend the Inconel cladding further downward in the second pass.

In light of the above, it can be stated that the system fulfils the requirement of an operating period of 8,000 hours between manual cleaning.

During the first year of operation, it was found that the noise level in the vicinity of the flue gas cooler exceeded the allowable value of 80 dB(A). Further investigation of the problem indicated that the high noise level was most likely due to flow-related acoustic interactions in the flue gas cooler. In the light of this finding, calculations were carried out which led to the installation of two diverter plates between the lower row of tubes, extending downward into the transition piece between the flue gas cooler and the quencher at the inlet of the scrubber. Although this reduced the noise level, it still did not fulfil the guarantee value. Possible options for resolving this problem are currently being studied in order to enable the system to comply with the guaranteed noise level.

3. Summary

The waste technology concept of Babcock & Wilcox Vølund A/S is based on the platforms of BS Technology and Vølund Systems. The BS Technology platform was used for Line 4 of I/S Reno Nord. The following results can be achieved with systems based on this technology along with the BS-W Mark 5 or Mark 6 combustion grate:

- Waste flexibility
- High energy efficiency
- Consistent, stable energy generation
- A uniform, efficient combustion process that ensures very low CO values and minimises the amount of non-combusted organic compounds in the flue gas
- A high degree of burn out of bottom ash and ash
- Long operating times and high availability

For I/S Reno Nord, the key focus in the construction of Line 4 was the use of safe, reliable and proven technology in combination with high energy efficiency and long continuous operating intervals, while complying with the stringent environmental protection requirements specified for Line 4.

The results achieved after approximately one year of operation confirm that these requirements have been fulfilled.

The described system configuration, with a spacious combustion chamber lined with Inconel with restricted use of refractory lining and a boiler with a low flue gas temperature before the superheaters, designed on the basis of conservative estimates, combined with the option of upgrading part of the grate bed to use water cooling, makes the system ideally suited to the incineration of waste with increasingly high calorific value.

At the same time, the results achieved confirm that high electrical efficiency can be attained using proven technology without recourse to extreme steam conditions, which yields a considerable reduction in operational risk.