Waste Is Innovation: Amsterdam’s High-Efficiency Waste Fired Power Plant

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EXECUTIVE SUMMARY

The Afval Energie Bedrijf (Waste and Energy Company of the city of Amsterdam) is building world’s first Waste Fired Power Plant® (WFPP®). This is a new facility designed to transform waste with a high-efficiency into sustainable energy and high quality building materials.

Technical principle of the WFPP
The basic technical principle of the WFPP is the same as that of the existing Waste-to-Energy Plant. Waste is burnt on a grate, with the heat released being used to produce steam, which then passes through a turbine generator to produce electricity. Due to major improvements the WFPP has a net electrical efficiency of 30%, the existing plant 22%. These improvements are:

- High thermal capacity which have the added advantage that unavoidable differences in the composition of the waste being burned have barely any effect upon the overall incineration process.
- Air injection at different stages to have little excess air as possible and to achieve maximum efficiency.
- The high-efficiency boilers are designed for steam parameters of 440°C/130 bar and an increase to 480°C is intended. Because of the high pressure which is the result of this the boiler draughts and the membrane walls under the brickwork are lined with Inconel®. This high-quality nickel-chrome alloy enables higher steam temperatures to be reached without causing increased corrosion.
- Reheating the steam with a steam-steam heat exchanger, as done in nuclear power plants. The steam emerging from the high-pressure turbine is reheated and then fed to the low-pressure turbine.
- Because of the superheating which takes place during the process, the steam turbine has been designed with separate high and low-pressure sections. Between the two turbines is the generator. A gearbox between the high-pressure section and the generator allows the high-pressure rotor blades to move faster, thus increasing energy efficiency.
- To ensure the maximum possible electrical efficiency, condensate preheating is completed in six steps: ECO 3, 0.6-bar preheater (optional), grate cooler, 4-bar preheater, ECO 2 and degasser.
Flue gas cleaning
Another important part of the process is the cleaning of the flue gases. The flue gas that has passed through the particle filter is re-circulated as secondary air. This limits production of nitrogen oxides. The flue-gas cleaning system has been specifically designed for selective product separation. For the pre-separation of fly ash, an electrostatic filter has been fitted after the boiler outlet. Combined with the boiler’s two-way ash conveyance system, this ensures that the maximum amount of fly ash can be reused.

A fabric filter is used to remove the last particles. Fine powdered blast-furnace coke is blown in as the adsorption medium for this filter. Limestone is added to this injection to eliminate the risk of fire and explosion.

High-quality building materials
The WFPP produces high-quality building materials. Instead of road-building materials, high-quality clean sand and gravel will be produced as raw materials for use in the production of sand-lime bricks and concrete. Iron and non-ferrous, semi-precious and precious metals are recovered from the bottom ash using advanced techniques from the mining industry. Patents for increasing this metal recovery from waste are obtained. The water evaporation in the quench ensures that the bleed from the hydrochloric acid washer is concentrated to a 10% solution for the salt fabrication.

INTRODUCTION
The Afval Energie Bedrijf (AEB) is a city of Amsterdam public utility company. This means that it operates as an independent business, but with the local authority as its sole shareholder. Since 1993 AEB has run a Waste-to-Energy Plant in the city’s western port district. At present it has a processing capacity of approximately 850,000 tonnes of urban waste per year.

That plant was a success from the day it opened. In business terms, but more especially in respect of its technology and environmental performance. The atmospheric emissions from the stack are (far) below the Dutch limits which are the most stringent in the world. AEB is now building upon that success by expanding its waste-processing capacity with a new high-efficiency Waste-to-Energy Plant, the Waste Fired Power Plant (WFPP). The driving force behind this development is the ambitious mission statement of the Afval Energie Bedrijf: Maximise use out of waste. This means:

To be the best in processing waste materials, with a focus upon generating the maximum benefit and the highest possible environmental yield from waste at the lowest possible cost, creating added value for all our stakeholders. We achieve this thanks to the support and dedication of all our staff, in an atmosphere of mutual respect. In short, we make the most out of waste.

Business Units
AEB is divided into a number of business units, and also participates in a joint venture. At the heart of the business are the existing Waste-to-Energy Plant and the new WFPP. Other units are the Hazardous Waste Depot, the Regional Sorting Station for appliances and the so-called Waste Collection Points, where hazardous and recyclable waste is collected. The joint venture is called Westpoort Warmte BV, in which AEB works closely together with the energy company Nuon. The joint venture supplies heat to customers in Amsterdam’s western port district called Westpoort.

Technological Innovations
In tandem with the development of the WFPP, AEB has been working on a whole series of technological innovations. One major success has been achieved with a pilot plant that uses waste residues to produce salt for road de-icing. This greatly reduces the amount of unusable residues. A 50 ton/h pilot plant for bottom ash produces clean sand and aggregate from bottom ash. Iron
recovered and the amount of aluminium, zinc, copper and other precious and semi-precious metals recovered will be tripled! The wet process is protected by a patent held jointly by AEB and Delft University of Technology. AEB has also patented a number of other innovations.

Environmental Certificate
AEB has been awarded a so-called ‘Green-declaration’ for the new WFPP. This environmental certificate entitles banks and their clients to tax advantages when investing in the plant. In the framework of the Dutch Carbon Dioxide Reduction Plan the WFPP has been granted for financial support under the Environmental Quality Electricity Production Act so, each megawatt hour of electricity will qualify the plant for a ten-year fixed allowance per kWh. In addition, significant European grant aid has been received under their Energy, Environment and Sustainable Development Programme.

HISTORY

AEB’s new high-efficiency Waste Fired Power Plant is the latest step in the long history of waste processing in Amsterdam. Since 1919, waste that cannot be reused has been incinerated in furnaces. The steam produced was transferred directly to the Municipal Electricity Corporation’s power station next door.

Fifty years later, in 1969, the old Waste-to-Energy Plant no longer met the standards of the day and its capacity was insufficient. So a new plant was built with a dust separation.

AEB’s current Waste-to-Energy Plant in Amsterdam’s western port district entered service in 1993. In terms of capacity, technology and environmental awareness, this represented another huge leap forward. This plant has a net electrical efficiency of more than 22%. Thanks to an effective approach to reduce discharge of dioxins and other toxic substances, it was the first new built plant in the Netherlands to comply with the then new emission regulations. Today the plant processes some 850,000 tonnes of urban waste and 100,000 tonnes of sewage sludge each year. And next to 150,000 GJ district heating, it delivers 530,000 MWh of electricity to the national grid annually.

The Fourth Generation

Our society is quickly developing a sustainability awareness. This assessment led AEB to the conclusion that, instead of being only a clean solution to get rid of waste, conventional Waste-to-Energy should be adapted to the aim of really maximizing the recovery of energy and materials. The frame of mind for fourth generation Waste-to-Energy (-and-Products) is ‘design for output’. The result of this new paradigm is a Waste Fired Power Plant achieving a 30% net electrical installation efficiency. Bottom ash will be washed to produce clean sand and aggregate and to maximize recovery of metals.

The first WFPP is going to extend rather than replace the existing Waste-to-Energy Plant in Amsterdam. From 2007, the Waste-to-Energy Plant and the WFPP will operate in parallel, both under the name of AEB. Their total processing capacity will be 1.5 million tonnes of waste and sewage sludge a year.
THE WASTE FIRED POWER PLANT

The basic technical principle behind the WFPP is the same as that of the existing Waste-to-Energy Plant. Waste is burnt on a grate, with the heat released being used to produce steam, which then passes through a turbine generator to produce electricity.

Another important part of the process is the cleaning of the flue gases and the recovery of the bottom ash. The main difference between the current plant and the WFPP is in their respective net electrical efficiencies: 22% at the existing plant, compared to 30% at the new one. This chapter explains how that significant improvement has been achieved.

Thermal Capacity
The existing Waste-to-Energy Plant has four incineration lines. The WFPP has two. Its thermal capacity of each boiler is 93.3 MW, and their minimum throughput is 33.6 tonnes per hour. In other words, these are very big incineration lines. This volume has the added advantage that unavoidable differences in the composition of the waste being burned have barely any effect upon the overall incineration process. Variations in the make-up of the waste are "absorbed", enabling the boilers to operate consistently and, therefore, without malfunction.

Incineration Grates
The hoppers which feed the incineration line are filled using cranes. The waste passes through a shaft onto a hydraulic dosing ram, which distributes it over the incineration grate. Here the waste is actually burned, on a moving horizontal grate with water cooling. That cooling is part of the water-steam cycle, ensuring that no heat is lost.

Air Injection
Achieving maximum efficiency means having as little excess air as possible. To combine this with effective incineration of the waste and obtain thoroughly burnt flue gas and bottom ash, the air is injected in stages. The primary combustion air is fed in from underneath the grate onto the bottom layer of waste. The temperature can be set by preheating the air in each grate zone individually. Flue gas that has passed through the particle filter is recirculated as secondary air, or "recigas". Large nozzles are used to make sure that the flue gas is mixed properly. This results in a lower temperature and more even heat transfer. Adding the low-oxygen recigas limits production of nitrogen oxides. Finally, tertiary air provides a second mix, this time with oxygen from the air. This ensures that good incineration remains possible at an excess oxygen level of just 6%.
High-efficiency Boiler
The high-efficiency boiler has three empty draughts and one horizontal one with tube banks for the superheaters (the so-called OVO’s) and economisers (ECO's). To achieve maximum possible reliability and the desired excess capacity, the furnace is spacious, with large surfaces, and flue-gas velocities are low – as is the critical flue-gas temperature before it reaches the first OVO banks. The lower temperature and flue-gas speed slow the build-up of dirt in the tube banks. This increases reliability.

In designing the horizontal draught, it was borne in mind that the superheater tube banks must be replaceable in their entirety. Consequently, changing a complete bank takes just 72 hours, which enhances the boiler's uptime. The superheater can thus be regarded as a normal replaceable part.

Figure 2: Process scheme WFPP

Inconel®
Because of the high pressure, the temperature of the membrane walls inside the high-efficiency boiler reaches some 340°C instead of the usual 270°C.

For this reason, the entire first and second boiler draughts are lined with Inconel®, as are the membrane walls under the brickwork. This high-quality nickel-chrome alloy enables higher steam temperatures to be reached without causing increased corrosion.

There are no unnecessary ignition or support burners. But, when first lit, the boiler is preheated using hot feed water, primary air and recigas. This is to avoid condensation in the fabric filter. No burners are needed for start up, simple ignition of waste is sufficient.

Raising The Steam Temperature To 480°C
The high-efficiency boiler has been designed for steam parameters of 440°C/130 bar. The design includes an empty space between the superheater and the ECO section. This can be used to add an extra tube bank so as to achieve an even higher steam temperature than the current maximum. An increase to 480°C is intended. This could further increase the WFPP's electrical efficiency in the future.

Reheater
The WFPP's high efficiency is primarily the result of reheating. This process is common in many power plants, but this is the first time it has been applied to waste incineration. Difference is that reheating is not done with a flue gas heat exchanger but with a steam-steam heat exchanger, as is done in nuclear power plants. The steam emerging from the high-pressure turbine is reheated and then fed to the low-pressure turbine. Each boiler has its own reheater. This enables the most effective possible response to its individual operating conditions. For the reheating, saturated steam from the same boiler's drum is used. The condensate is fed straight back from the reheater into the boiler drum.
Figure 3: Outline steam reheating

**Turbine Generator And Main Condenser**
There is only one turbine generator set. Because of the superheating which takes place during the process, the steam turbine has been designed with separate high and low-pressure sections. Between the two turbines is the generator. A gearbox between the high-pressure section and the generator allows the high-pressure rotor blades to move faster, thus increasing energy efficiency.

Steam extraction before the reheater, at 14 bar, is used for steam tracing and to preheat the primary air in the first zone. Steam drawn off from the turbine, at 4 bar, is used to heat the primary air in the second and third zones. If the turbine is not operating, this steam can be produced from high-pressure steam by using reducing stations. The turbine is fitted with extractors for all required pressures: that is, nominal values of 14, 4 and 0.6 bar. The outlet pressure to the condenser is 0.030 bar.

**Water-steam Cycle**
To ensure the maximum possible electrical efficiency, condensate preheating is completed in six steps: ECO 3, 0.6-bar preheater (optional), grate cooler, 4-bar preheater, ECO 2 and degasser. ECO 3 and ECO 2 make use of residual heat from flue-gas cleaning, whilst the grate cooler takes heat from the waste incineration bed, which can vary widely. The separately deployable 4.0 bar condensed-steam preheater absorbs these fluctuations and ensures a controlled temperature of entry into ECO 2; this to prevent corrosion. This method of heating condensate minimises the use of steam extraction for the deaerator.

**Flue-gas Cleaning**
It was not the very strict emission limits under Dutch law which were used to define the design specifications for the flue-gas cleaning system. Instead, the AEB looked at the already excellent operating parameters of its existing Waste-to-Energy Plant. It was that performance which had to be surpassed. So, as in the current plant, full use is made of the selective non-catalytic reduction (SNCR) technique to reduce nitrogen oxide levels. Rather than steam, diluting water and compressed air are used as the media for ammonia injection.

The flue-gas cleaning system at the WFPP has been specifically designed for selective product separation. For the pre-separation of fly ash, an electrostatic filter has been fitted after the boiler outlet. Combined with the boiler's two-way ash conveyance system, this ensures that the maximum amount of fly ash can be reused.

**Fabric Filter**
A fabric filter is used to remove the last particles. Fine powdered blast-furnace coke is blown in as the adsorption medium for this filter. Limestone is added to this injection to eliminate the risk of
fire and explosion. It also forms a filtering layer on the filter bags. This method ensures that the dioxins and furans are separated right at the beginning of the flue-gas cleaning process. The heavy metals content is also reduced. So products from the wet flue-gas processing can be reused.

As in the existing plant, after the fabric filter a flue-gas heat exchanger (ECO 2) is used to preheat the condensate. Underneath this is a so-called "quench", where the hot flue gases are cooled to saturation point.

**Salt Production**
The water evaporation in the quench ensures that the bleed from the hydrochloric acid washer is concentrated to a 10% solution for the salt fabrication.

The next steps in the cleaning process are the hydrochloric acid and sulphur dioxide washers. These remove the acid constituents and ammonia from the flue gases. The hydrochloric acid washer uses a so-called packed bed which captures the acid remaining in the flue gas after the quench.

The sulphur dioxide washer is an open type washer, with limestone added as a neutraliser. The sulphur dioxide reacts in the washer to a gypsum slurry. A centrifuge then separates this to create a dry product which is removed and recycled as a building material.

The amount of residue that has to be dumped after the complete cleaning process is less than 1% of the total volume of waste incinerated.

**Heat Exchanger**
After the sulphur dioxide washer comes a separate fine washer. This also acts as a heat exchanger. It consists of a packed bed over which water circulates. A water-water heat exchanger, ECO 3, cools the washing fluid. The cooling causes the condensation of water in the saturated flue gases, further reducing emissions. The recovered heat is used to preheat the condensate. By sub cooling the flue gases, the fine washer and ECO 3 produce virtually pure condensation water which can be reused in the flue-gas cleaning process, most notably in the hydrochloric acid washer and the quench. At a later stage, it could well form the basis for demineralised water products. The plant produces no waste water at all. All the water released is reused in other stages of the process.

**Induced Draught Fan**
Finally, the purified flue gas is extracted by an induced draught fan. This runs "wet" in the saturated flue gases which pass the emissions monitoring equipment on their way to the chimney. The plume which eventually emerges is virtually free of hazardous substances. In fact, it is nothing more than a cloud of clean water vapour.

**Bottom Ash**
The bottom ash produced during the incineration of waste drops down the slag shaft into a water-filled deslagger. Each grate has three of these. The ash is then prepared for reuse by a slag reprocessing facility. Instead of road-building materials, high-quality clean sand and gravel will be produced as raw materials for use in the production of sand-lime bricks and concrete. Iron and non-ferrous, semi-precious and precious metals are recovered from the bottom ash using advanced techniques from the mining industry. Patents for increasing this metal recovery from waste are obtained.
**Cooling Water System**
The main cooling water system supplies the main condenser and, when necessary, the emergency condenser. The water is drawn from the nearby harbour and is filtered before being pumped to the condenser.

**Traffic Congestion**
The new high-efficiency Waste-to-Energy Plant will lead to larger quantities of waste being processed. To prevent this causing more traffic on the roads, a proportion of that waste will be shipped to the plant by barge, packed into specially designed bales. Other measures are also being taken to prevent congestion. For example, increasing the capacity of dustcarts and loading them more efficiently. The shipment of waste by rail will continue, too, and the existing railway link can be extended if necessary.

**Location**
It is important to remember that the cost-effectiveness of a WFPP depends on many factors. The most important of these is its location. In Amsterdam, this is almost ideal. The plant's proximity to the port paves the way for the delivery of waste by water, and provides a source of cooling water. The presence of link roads and a railway makes the site easily accessible. And the nearby built-up areas facilitate the sale of district heating, whilst the sewage treatment plant next door enables direct intake of sewage sludge.

**THE FUTURE**
TheWFPP does not stand in isolation. It can best be regarded as the powerhouse for a series of activities related to recycling materials and the production of energy from waste. Sustainability and environmental responsibility are the first priorities in all of these. But economics is also important. By encouraging various companies based close to the plant to co-operate with each other, efficient interaction in respect of waste, energy, recycling and, above all, expertise is fostered. The process to generate this synergy is currently being set in motion in a systematic way, under the title Eco-Port® Amsterdam.

**Environmental Teamwork**
Eco-Port® Amsterdam consists of a series of projects, which interact with one another in a variety of ways. One important element is the municipal sewage treatment plant next door to the WFPP. Collaboration with the City of Amsterdam's Water and Sewage Department, with the modern sewage treatment plant on the adjacent site, increases efficiency. It supplies biogas that the AEB uses to generate sustainable electricity and district heating. Some of that is then returned to the sewage works. 100.000 ton/year of sewage sludge plant are being co-incinerated in the existing Waste-to-Energy Plant. AEB returns heat and power to the sewage treatment plant.

AEB itself operates the Hazardous Waste Depot, facility for dismantling electrical and electronic equipment, the salt factory and the slag reprocessing facility.

**Pilot Plants**
Pilot plants also have a role to play in the Eco-Port® concept. For example, the pilot plant producing road salt from flue-gas residue. Such a factory has the potential to develop into a fully fledged production facility. Also important is the facility which produces non-ferrous metals and building materials like sand and gravel from the bottom ash left over after waste incineration. The businesses that process chemical waste and recycle appliances are very much part of the same picture, too. What they can recover is reused and what they cannot is sent to the WFPP to be turned into energy. For the Amsterdam and the AEB, Eco-Port® represents a future offering good development opportunities for a whole range of sustainability-related initiatives.
CONCLUSION

As a result of its long experiences with Waste-to-Energy Plants, and with the development of the WFPP in particular, the AEB recommends that the highest possible electrical efficiency be sought when building such facilities. In other words, you should opt for Waste Fired Power Plants. This new generation of Waste-to-Energy plants ensures a significant improvement in environmental performance, an ambition that has shown a very positive effect upon public support. The higher investment costs involved may seem problematic at first sight, but they are recouped by shorter licensing procedures and the additional yields in the form of sustainable electricity, building materials and metals.

ACKNOWLEDGEMENTS

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Basis of design


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