Ways to Improve the Efficiency of Waste to Energy Plants for the Production of Electricity, Heat and Reusable Materials

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Abstract

Up to now the emissions of waste-to-energy plants have been of major concern for the operators of waste incineration plants and the public. In Germany the emission standards for waste incineration plants have been very strict for more than 10 years, more stringent than for coal fired power plants, for example. Now the member states of the European Union are following suit with the same standards in accordance with European directive 2000/76/EC on the incineration of waste. Within a couple of years all European waste incineration plants will have to comply with the emission limits of directive 2000/76/EC. There is also legislation in the pipeline restricting landfilling of untreated waste.

In view of the discussions about CO2 reductions the efficiency of today’s Waste to Energy (WTE) plants should be improved, even though – or rather because – waste is regarded to some extent as “green power”. With the same goal in mind the recovery rate of reusable materials from the incineration of waste or flue gas treatment should be improved. This will make it possible to reduce the amount of CO2 generated by the production of these materials from natural resources and to conserve natural resources.

Goals of waste management in Germany and Europe

First of all, waste should be avoided. So when creating a new product one should already bear in mind how it can be produced without generating too much residual waste and also without using too much energy in the production process, which could cause contamination of the environment. And it should also be designed in such a way that the different materials used can be separated easily and thus recycled at the end of the product’s lifetime.

Secondly, clean materials such as glass, paper, leather, scrap metal etc. should be collected separately in the home or within companies to enable these materials to be recycled easily without much effort to separate them from a mixture of different waste types.

Thirdly, waste that cannot be avoided should be treated in such a way as to produce RDF (residue derived fuel) or the waste should be incinerated directly.

From the year 2005 onwards landfilling will only be allowed for pretreated, inert waste to avoid leachates into the ground water or emissions of toxic gases into the atmosphere.

The ultimate goal for sustainable development will be no more landfill!

To fulfill these goals in Europe, a group of experts is working for the European Council on defining and describing the ‘Best Available Technology’. The Waste to Energy plant MVR at Rugenberger Damm in Hamburg, Germany, is one of the examples of the state of the art of modern WTE plants [1, 2].

Description of MVR facility

The plant with a nominal annual capacity of 320,000 metric tonnes went into service in 1999. It was designed to comply with the following guidelines:

- Implementation of state-of-the-art technology
- Maximum energy utilization by cogeneration of electricity and heat
- Recovery of reusable materials from the residues of the incineration and flue gas cleaning processes
- Internal reuse of residues and sewage, no emission of waste water from the incineration and flue gas cleaning process
- Minimization of flue gas emissions as far as is economically acceptable
- Low odor and noise emissions
- Concentration of hazardous pollutants in unavoidable waste fractions

The plant consists of 2 lines which can be operated independently to meet the demand for an uninterrupted steam delivery to a refinery. Each line consists (Fig. 1, 2) of a

- 4-draft vertical boiler equipped with a forward feeding grate with a capacity of 21.5 tonnes/h of waste, producing 68 tonnes/h of steam at 42 bar and 425°C,
- SNCR system for the reduction of NOx,
- 4-stage flue gas cleaning system, consisting of
  - a bag house, operated as an entrained flow reactor with injection of active carbon for the adsorption of heavy metals and dioxins/furans,
  - an acid scrubber with 2 stages to reduce halogens, especially hydrochloric acid (HCl),
  - another scrubber using a lime slurry for the absorption of sulfur dioxide (SO2),
  - a second bag house as a police filter, also operated as an entrained flow reactor using fresh active carbon as adsorbents for any remaining heavy metals or dioxins/furans.

This equipment makes it possible to achieve very low flue gas emissions, as is shown in Fig. 3 in comparison to the limits under European Directive 2000/76/EC, which lays down the same limits as the 17th Ordinance pursuant to the German Immission Control Act (17th BImSchV), and the even lower limits of the operating license of MVR.

Energy production and ways to improve performance

MVR started production of electricity and steam for industrial use in the spring of 1999. During that year and the first few months of 2000 steam delivery was secured by the former oil-fired CHP plant Neuhof, because steam had to be delivered without interruption. In May 2001 that plant was shut down for ever and MVR took over full responsibility, replacing about 75,000 tonnes of heavy fuel oil with waste and a small amount of natural gas (approx. 3% of energy input). Yearly steam demand by our customers is approximately 400,000 MWh/a. As steam delivery has the highest priority, electricity is just a by-product, totaling about 35,000 to 40,000 MWh/a (Fig. 4).

Right from the start of operation the superheaters were affected by corrosion problems. Possible causes were found to be inadequate control of steam temperature and incorrect setting of sootblowers. However, because the depletion rate was unexpectedly high in other areas as well, and since relatively high chlorine levels (approx. 1,500 mg/m³ HCl content of the flue gas at the exit from the steam generator) in combination with relatively low sulfur levels (SO2 approx. 400 mg/m³) were regarded as the cause, the temperature of the live steam was reduced to 400°C as a precautionary measure (design temperature is 425°C).

Simultaneously attempts were started to counteract the high corrosion rate in the areas affected by the sootblowers by coating the tubes. Some tubes were cladded with Inconel 625, some were electrolytically coated with pure nickel or with an alloy of Ni-Co-Si-carbide. The thickness of the coating was approximately 1 to 1.5 mm (Fig. 5).

The alloy coated tubes started to fail after approx. 15 months, but the results of the nickel-coated tubes were very encouraging [3]. Analysis of ash deposits on the tubes (Fig. 6, 7) shows that because of the coating there is practically no iron or chlorine in the deposit of the nickel-coated tubes. This could indicate that a chemical barrier to high-temperature corrosion caused by chlorine has been found.

It was also clearly visible from dismantled tubes that removal of the coating (nickel) takes place only in the region affected by the sootblowers. The extent of material erosion decreases with the distance from the sootblower and thus with the kinetic energy of the steam jet blowing onto the tubes. Tubes installed in the second layer (Fig. 8)
also display uniform removal of the nickel coating in the 3 to 9 o’clock position, because the gap between the tubes below enables the steam jet to cover that area too. There is no measurable reduction of the nickel coating on any surfaces not affected by the sootblowers.

Electrolytic coating with nickel offers some advantages over other materials and coating technologies:

- non-porous layers without any mixing with the base material due to heat input (e.g. cladding)
- stress-relieved application of the coating material
- good adhesion, subsequent cold forming is possible within usual limits after application of the coating
- coating may be applied in variable thickness
- highly complex shapes and surface structures can be coated

Last, but very important:

- The resistance to high temperatures is very good.

And this raises hopes of improving the efficiency of WTE plants in the future. At MVR we have replaced 3 critical packages of superheaters (Fig. 9) in one line with nickel coated tubes in the year 2002 and will change the same in the other line this year. Afterwards we will be able to raise the temperature of the live steam to 425°C again and soon after perhaps to 450°C, the maximum allowable with the present equipment. By these measures we will be able to increase production of electricity by about 4%. This could be further improved by another 2 to 3% if we could raise the steam pressure to about 50 bar (from 42 bar), but only detailed calculations will show whether this is possible with our equipment.

With nickel coated tubes new WTE plants could be designed to more conventional steam parameters like 520°C and 100 bar, raising the efficiency in producing condensing power from about 20% today to 30% [4].

To reach that goal better protection of the water walls in the first draft of the furnace is also necessary. Cladding with Inconel 625 has reached its limits at today’s steam parameters and problems with refractory materials are a never-ending story in Germany. First tests with a nickel-coated water wall at another plant have been very encouraging. Tests will go on at MVR beginning in May to elaborate the basic technology for more efficient WTE plants.

The application of electrolytically coated tubes has been patented. Nickel is very expensive and thus the costs for protecting critical areas of WTE steam generators (superheaters, water walls of the first draft) will rise. But not more than 5% on a first estimate, and this will be a good bargain in view of the higher revenues for the generated power. And this will also help the environment, because the more energy can be recovered from waste, the more fossil fuels can be saved.

Treatment of Residues

But waste incineration should not only be regarded in terms of the transformation of waste to energy: good waste management should also include treatment of the residues of incineration and flue gas treatment for reuse in different applications.

Bottom Ash

With good combustion control and a focus not only on maximum waste incineration but also on low carbon-content in the bottom ash, one can produce a very good construction material from the bottom ash. If sintering of the bottom ash is achieved on the grate the leachates of the bottom ash are comparable to molten bottom ash and also to some natural materials. If surplus water is added to the bottom ash extracting device (Fig. 10), the salt content of the bottom ash can be reduced by more than 50%.

At MVR we use water from the Elbe river for scrubbing the bottom ash, the salt content of the water limiting the reduction of chlorides in the leachate according to the German leachate test DE-SV 4. In addition biological tests confirm that no harmful contamination to water has to be feared from bottom ash treated as we do at MVR. It is also very important, even though this aspect has more of a psychological touch, not to add anything else to the crude bottom ash, like fly ash or riddlings, because such components may contain contaminants.
After scrubbing we treat the bottom ash further by taking out metals (scrap iron and non-ferrous metals), crushing large chunks and reducing unburned particles by sieving and wind sifting. According to German regulations the processed slag then has to be stored for at least 3 months before being used as a construction material. As a result of cooling and scrubbing the bottom ash with water, new chemical reactions are started leading to reformation of some minerals with a higher specific volume. After intermediate storage we put the slag through the whole treatment again to further reduce the content of metals and get a better grain size distribution in accordance with regulations.

We take great pains in processing the bottom ash in this way, but the result is worth the trouble. From about 90,000 tonnes/a of raw slag we produce about 80,000 tonnes of a sand-like mineral mixture which can be used e.g. for road construction. Furthermore, about 8,000 tonnes/a of scrap iron are recovered and sold to steel mills. And about 800 tonnes/a of chrome steel and non-ferrous metals like aluminum and copper can be returned to the materials cycle and used again.

**Hydrochloric Acid**

Halogen, especially hydrochloric acid, are eliminated from the flue gases by scrubbing in an acid scrubber. At MVR, instead of neutralizing the crude acid and disposing of the salts in landfill together with fly ash, a special unit (Fig. 12) is used to transform the crude acid into a commercially salable product (HCl) [5, 6]. We produce about 4,000 tonnes per year of 30% hydrochloric acid of high quality and purity, comparable to any other technical hydrochloric acid on the market (Fig. 13). The residues from this process are about 1,200 tonnes/a of a 20% solution of various Na and Ca salts, which can be used for refilling exploited salt caverns, but only if the heavy metal concentrations are below the concentrations of the natural salt!

**Gypsum**

By injecting active carbon, most heavy metals and dioxins and furans are extracted from the flue gas in the first bag house before desulphurization. Because of this – as is the case with hydrochloric acid – the gypsum produced in the desulphurization stage of the flue gas cleaning system is of a very good quality and purity (Fig. 14), comparable to natural gypsum or gypsum produced by the desulphurization process in coal fired power plants, which is also recycled in Europe.

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**Fly ash**

We are still working on solutions acceptable to industry and the public for reusing boiler fly ash and fly ash from the bag house. Boiler fly ash looks very much like fine sand. It is hardly contaminated, because it is extracted from the process at temperatures above 300°C. Filter fly ash is heavily contaminated with heavy metals and dioxins/furans (up to 1000 ng/kg). Because of this it is considered the main waste stream MVR has to dispose of, although it currently accounts for less than 1% of the waste input. But we are already doing research on recovering some of the heavy metals for industrial purposes!

**Economic aspects**

The way waste is treated at MVR is relatively expensive. The total investment was approx. 225 million dollars (without interest during the construction phase), equivalent to approx. 700$/(tonne/a), which by German standards 5 years ago was relatively low. About 10% was needed to develop the site, i.e. build a tunnel (400 m long), for the steam pipe, which is about 2 km long! The site was not safe from high tides, so we had to raise the ground level by about 2.5 m and we also had to build a new quay wall, about 250 yards long. There was no connection to the sewer system, so we had to build a pumping station and the tubing to the next gully several hundred yards away. The connection to the electrical grid was not as easy as we had thought with a 110 kV line almost crossing the site. All this money could have been saved if a site just 2 km further east had been accepted by the local community! Now all the people of Hamburg are having to pay a higher price for incineration.

Capital costs account for the main share (about 60%) of our yearly expenses (Fig. 15). Only a small amount (about 15%) is covered by revenues from the products sold such as steam, electricity, scrap metals, gypsum and hydrochloric acid. Unfortunately energy is not worth much in Germany at this moment, and energy from WTE plants is not considered green power either, even though about 60% of the waste consists of renewable fuel (wood, paper, etc.). The rest of the revenues has to come from the tipping fee, which at about 130$/tonne is below the average for Germany, but above the average for the Hamburg area. Without capital costs the tipping fee could be reduced to about 40$/tonne.
We believe, though, that the tipping fee is acceptable in comparison to other commodities we take for granted or regard as necessary in our daily life (Fig. 16). In Germany, for example, each person produces about 200 to 250 kg waste per year. A family of four thus produces about 1 tonne of waste every year. For collecting and disposing of that waste the sanitation department of the city of Hamburg collects about 200$ from a family of four. The costs for each of the commodities included in Fig. 16 will vary from state to state, but that will not produce much change in relative costs. Even with tipping fees of over 100$/tonne, the cost of keeping our cities and our environment clean does not appear too high with regard to sustainable development of mankind.

Summary

Efficient waste management will play an important role in sustainable development of human society. Natural resources can be saved by producing residues with a quality comparable to industrial or natural products in a waste incineration plant. MVR is setting an example of a high rate of material recovery from waste incineration or subsequent flue gas cleaning. By means of a newly developed method of electrolytic coating of tubes the efficiency of recovering energy from waste can be improved considerably in the future. Thermal treatment of waste is more expensive than simple mass burning of waste, but this would seem to be an acceptable and necessary step towards sustainable development of our society.

References


Fig. 1: Cross section of steam generator at MVR

Fig. 2: Flue gas cleaning system at MVR
Fig 3: MVR specific flue gas emission values
Fig. 4: Steam and electricity by MVR Jan. 2000 until Dec. 2002

Fig. 5: Tube coated electrolytically with nickel
Fig. 6: REM analysis of fly ash deposits on 15Mo3 tube

Fig. 7: REM analysis of fly ash deposits on Ni-coated tube
Fig. 8: Sootblower-induced removal of Ni-coating from a tube in the second tube layer

Fig. 9: Steam generator with superheaters susceptible to corrosion
Fig. 10: Integrated scrubbing of bottom ash

Fig. 11: Bottom ash processing
Fig. 12: HCl-rectification unit

Fig. 13: Comparison of hydrochloric acid produced by MVR with HCl according to European standard EN 939
Fig. 14: Comparison of MVR-gypsum with gypsum from desulphurization of coal fired power plants and natural gypsum.

Fig. 15: Expenses and revenues

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Fig. 16: Annual costs of different commodities of a family of 4 in Germany, 2002