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Gaseous emissions from waste combustion

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Abstract

An overview is given on methods and technologies for limiting the gaseous emissions from waste combustion. With the guideline 2000/76/EC recent European legislation has set stringent limits not only for the mono-combustion of waste in specialized incineration plants but also for co-combustion in coal-fired power plants. With increased awareness of environmental issues and stepwise decrease of emission limits and inclusion of more and more substances into the network of regulations a multitude of emission abatement methods and technologies have been developed over the last decades. The result is the state-of-the-art waste incinerator with a number of specialized process steps for the individual components in the flue gas.

The present work highlights some new developments which can be summarized under the common goal of reducing the costs of flue gas treatment by applying systems which combine the treatment of several noxious substances in one reactor or by taking new, simpler routes instead of the previously used complicated ones or – in the case of flue gas desulphurisation – by reducing the amount of limestone consumption.

Cost reduction is also the driving force for new processes of conditioning of nonhomogenous waste before combustion. Pyrolysis or gasification is used for chemical conditioning whereas physical conditioning means comminution, classification and sorting processes. Conditioning yields a fuel which can be used in power plants either as a co-fuel or a mono-fuel and which will burn there under much better controlled conditions and therefore with less emissions than the nonhomogeneous waste in a conventional waste incinerator.

Also for cost reasons, co-combustion of wastes in coal-fired power stations is strongly pressing into the market. Recent investigations reveal that the co-firing of waste can also have beneficial effects on the operating behavior of the boiler and on the gaseous emissions.

1. Introduction

In Germany, a feeling that the chemical industry was a threat to the environment came up in the public during the seventies of the last century. In Hamburg we had in 1979 the "Stoltzenberg Scandal" because residues were found to be carelessly stored on a former chemical production site. The residues included even war gases from World War I. It was followed in the early eighties by the "Böhringer Scandal" about ground water contamination by an insecticide production plant. A culmination was reached in the mid eighties with the "Georgswerder Scandal". Georgswerder is the name of a disposal site which was built according to state-of-the-art technology in the early sixties. During over 25 years both municipal and chemical wastes were received and stored in large basins. The scandal came up when liquid residues with high contents of Dioxins and Furans

were discovered in the ground of neighboring gardens. In the eighties and nineties the government of Hamburg spent over 70 million Euros to encapsulate this disposal site (Fig. 1).

During the last 20 or 30 years the environmental consciousness has strongly increased in all parts of our industry. The motto is now to avoid or to minimize the amount of wastes by adapting suitable process routes. If waste disposal cannot be avoided the requirement of the German TASi regulation [1] is that only chemically inert material should be brought to the disposal site. The best way to make the waste inert is the thermal treatment. The most widely practiced method of thermal treatment is incineration. In the chemical industry waste that has to be thermally treated is not only coming directly from the production plants but also in the form of sewage sludge from the company-owned waste water treatment plants. These wastes are currently burnt mostly in specialized incinerators on the sites of the chemical production plants.

The present paper will deal with the gaseous emissions from waste combustion and highlight some current developments in the field.

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Fig. 1. Georgswerder – a former disposal site (photo courtesy FHH Hamburg, Behörde für Stadtentwicklung und Umwelt).

2. The legal framework for gaseous emissions from waste combustion

In 2000 the European Union issued the Directive 2000/76/EC [2] for the incineration of waste. It was largely based on a German guideline, the 17th Ordinance for the Implementation of the Federal Act on Immission Control of 1990 (17th BlmSchV) [3]. Since there were nonetheless deviations between both guidelines the German one had to be amended and this was completed in August 2003 such that in Germany the 17th BlmSchV of August 2003 [4] is governing now the emissions from waste combustion. Table 1 gives a comparison between the two regulations. The EU has given its member states the possibility to further tighten up the emission limits and the German government has in the past often made use of this opportunity. For example, we

see in Table 1 that the emission limit for Hg is 0.030 mg/m³ in Germany while the EU considers 0.050 mg/m³ to be sufficient. There are a lot more differences between the two guidelines but a detailed analysis is not within the scope of the present paper. In this context it should be noted, however, that for local authorities the numerical values of the emission limits listed in the 17th BlmSchV are only binding in the sense that they are upper limits. The local authorities when granting operating permissions to a waste incineration plant often impose limiting values for the emissions which are well below those listed in the 17th BlmSchV.

Both the EU directive and the new 17th BlmSchV consider not only the mono-combustion of wastes in especially designed incineration plants but also the co-combustion of waste in coal-fired power plants. As an example Table 2 shows the conditions

Table 1
Emission limits per day for waste combustion (after [5])

	EU-Directive 2000/76/EC	17th BImSchV of 19/08/2003
Reference O_2	11%	11%
Hg	0.05 mg/m³	0.03 mg/m³
CO	50 mg/m³	50 mg/m³
HCl	10 mg/m³	10 mg/m³
HF	1 mg/m³	1 mg/m³
NO_2 ($NO + NO_2$)	200 mg/m³ for > 6 t/h or new plants[*] 400 mg/m³ for < 6 t/h[*]	200 mg/m³
TOC	10 mg/m³	10 mg/m³
SO_2 ($SO_2 + SO_3$)	50 mg/m³	50 mg/m³
Sulphur separation efficiency	–	–
Cd + Tl	0.05 mg/m³ 0.1 mg/m³[**]	0.05 mg/m³
Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V	0.5 mg/m³ 1.0 mg/m³[**]	0.5 mg/m³ (incl. Sn)
As, Cd, Co, Cr, B(a)P	–	0.05 mg/m³
Dioxins + furans	0.1 ng/m³	0.1 ng/m³

[*] Until 1 January 2007 and without prejudice to relevant (Community) legislation the emission limit value for NO_x does apply to plants only incinerating hazardous waste.

[**] Until 1 January 2007 average values for existing plants for which the permit to operate has been granted before 31 December 1996 and which incinerate waste only.

Table 2
Emission limits per day for the co-combustion of wastes in coal fired fluidized-bed power plants with furnace capacities between 100 and 300 MW (the numerical values are daily average values; for application of the mixing rule W = waste (11% O_2) and P = process (6% O_2); ** means that these limits are related to 11% O_2)

	EU-Directive 2000/76/EC	17th BImSchV of 19/08/2003
Reference O_2	6%	6%
Hg	0.05 mg/m³	0.03 mg/m³
CO	No limit value	W = 50 mg/m³ P = 200 mg/m³ existing plants P = 250 mg/m³
HCl	No limit value	100 mg/m³ (CFB plants only)
HF	No limit value	1 mg/m³
NO_2 (NO + NO_2)	W = 200 mg/m³ P = 300 mg/m³ W = 350 mg/m³ existing plants	W = P = 200 mg/m³
TOC	No limit value	10 mg/m³
SO_2 (SO_2 + SO_3)	W = 50 mg/m³ P = 850–200 mg/m³ with linear decrease (P = 850–400 mg/m³ for existing plants)	W = 50 mg/m³ P = 200 mg/m³
Sulphur separation efficiency	Or >92%	And >85% or 300 mg/m³ + 92%
Cd + Tl**	0.05 mg/m³	0.05 mg/m³
Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, **	0.5 mg/m³	0.5 mg/m³ (incl. Sn)
As, Cd, Co, Cr, BaP**	–	0.05 mg/m³
Dioxins + furans**	0.1 ng/m³	0.1 ng/m³

which apply for co-combustion in coal-fired fluidized bed power plants of between 100 and 300 MW furnace capacity.

For co-combustion plants, the provisions define two categories of limit values:

- fixed limit values and
- limit values referring to the flue gas portion of the standard and waste fuels, respectively, i.e. so-called mixed emission limits (dust, SO_2, NO_x in the european guideline; CO, NO_x, and SO_2 in the German guideline).

The calculation of the mixed emission limit values is based on the following formula:

$$C = \frac{V_{waste} \times C_{waste} + V_{proc} \times C_{proc}}{V_{waste} + V_{proc}}$$

where C = mass concentration related to the reference oxygen content of 6% C_{waste} = emission limit of pollutant for waste incineration (originally based on 11% O_2, to be converted to 6% O_2 reference before inserting into formula if applied to co-combustion in a solid-fuel fired power plant) C_{proc} = emission limit of pollutant for combustion of standard fuel (based on 6% O_2 in the case of combustion in solid fuel fired power plant) V_{waste} = waste gas volume from waste incineration V_{proc} = waste gas volume of standard fuel combustion.

The flue gas portion of waste incineration is subject to the emission limits for waste incineration plants and the flue gas portion of the standard fuel is subject to the emission limits for large combustion plants, the so-called process emission limits. The flue gas portions are usually determined on the basis of average values for the respective fuels. This is based on the operational case with the highest admissible portion of waste input in the fuel mixture as per approval. As a rule, the waste gas volume portion is larger than the furnace capacity share. With account taken of the respective particular rules applying to the determination of the respective individual limit values, the so-called mixed emission limit values are established.

Here, the reference O_2 is also determined according to the rule of mixing. So the emission limits in the waste gas flow from the co-combustion of waste in power plants are subject to the same strict requirements as those applying to the combustion of such fuels in waste incineration plants.

The details of these regulations are very complicated. For further details the reader is referred to ref. [5].

3. Methods and technologies for keeping the emission limits

With the exception of CO and TOC which can only be influenced by primary measures inside the furnace (mixing, temperature, residence time) all pollutants can be treated with a wide variety of methods and technologies. For example, NO_x emission can be influenced inside the furnace (staged combustion), by selective non-catalytic reduction (SNCR) and by SCR, i.e. via selective catalytic reduction. HCl and HF can be treated in scrubbers or by chemisorption. SO_2 can in fluidized-bed combustors be captured by injection of limestone into the combustion chamber, but it can also be converted in wet, semi-dry or dry scrubbing processes. Equally, dioxins and furans may be destroyed under proper combustion conditions or if they are created by de-novo-synthesis in the flue gas path, adsorption or catalytic processes may help. Finally, Hg can be captured either in scrubbing or in adsorption processes. All these processes are well known and detailed descriptions can be found in books, e.g. [6,7].

A state-of-the-art incineration plant is shown in Fig. 2. It consists of a waste storage and feeding section followed by combustion, heat recovery and a complex flue gas treatment section. The flue gas cleaning technologies have been developed in the past following the successive requests by governmental regulations as typical "end-of-pipe" technologies.

The different harmful substances in the flue gas are each treated in a separate process and apparatus: we see scrubbers for HCl and SO_2 capture, catalyst beds for NO_x removal and special reactors for dioxin destruction. The development over
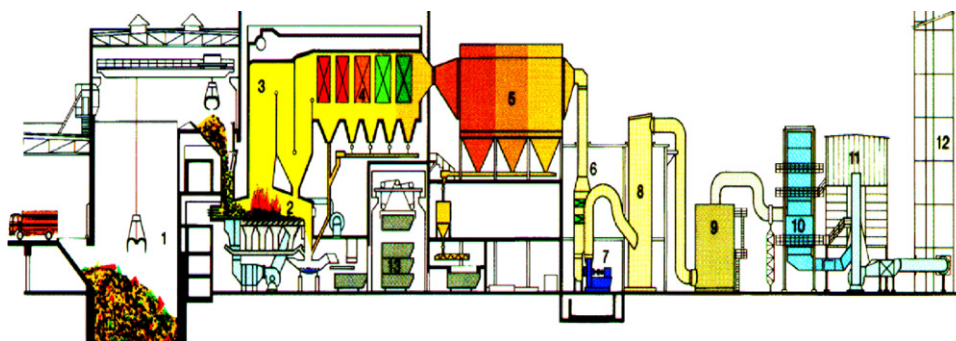
Fig. 2. Example of a state-of-the-art incineration plant (1, hopper; 2, furnace with grid; 3, after-burning chamber; 4, waste heat boiler; 5, electro static precipitator; 6, economizer; 7, blower; 8, scrubber; 9, wet electrostatic precipitator; 10, NO$_x$ removal; 11, dioxin removal, 12, stack; and 13 slag removal, from [8]).

the last decades has led to a structure of municipal waste incineration which functions well, works reliably but is complex and therefore expensive. Furthermore, due to the necessity of coping with large variations in the firing characteristics of municipal waste, the plant must be operated at fairly high levels of oxygen in the flue gas which lowers the energy efficiency. In summary, it can be stated that a modern waste incineration plant contains sophisticated technologies, fulfils the requirements set by governmental emission guidelines, can be operated reliably but is costly and significantly less energy-efficient than combustion in a power station.

Both aspects – cost and energy efficiency – are recently receiving increased attention. This has led to technology developments which will be reported in the present paper.

4. New developments in flue gas cleaning

### 4.1. Hg removal by injection of bromine salts

Different technologies are available for the removal of Hg from flue gases. If the mercury is in its oxidized form the adsorption in a scrubber solution with subsequent precipitation will be the method of choice. If it is in the elemental form adsorption or chemisorption with different sorbents will be necessary to capture it. Unfortunately, part of the mercury leaves the combustion process in the oxidized and part in the elemental form. If the mercury is to be removed in a scrubber an oxidation of the elemental Hg is necessary. In many technical processes chlorine is used for this purpose which is generated by addition of suitable oxidants. A detailed analysis of this process by Vosteen et al. [9] have shown, however, that part of the chlorine thus generated is consumed by reaction with the SO$_2$ present in the flue gas according to

$$SO_2 + Cl_2 + H_2O \rightarrow SO_3 + 2HCl$$

Vosteen et al. [10] found out that instead of chlorine bromine serves the same purpose without having the disadvantage of being consumed by SO$_2$. They injected in large-scale tests NaBr into the combustion chamber and were able to demonstrate a drastically improved Hg capture. The process was successfully tested in sewage sludge incinerators but also in large-scale coal-fired power stations. The system is now marketed by Alstom [11].

4.2. Desulphurization with less limestone consumption

In a fluidized bed combustor SO$_2$ can be captured in-situ by injection of limestone which according to

$$CaCO_3 \rightarrow CaO + CO_2$$
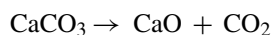
calcines to burnt lime which then reacts with SO$_2$ to form calcium sulphate,

$$CaO + SO_2 + (1/2)O_2 \rightarrow CaSO_4.$$
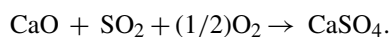
However, in practice only part of the burnt lime is used for the desulphurization. A significant part is entrained from the combustion chamber and simply increases the amount of solid waste collected in the flue gas path. As a consequence, in order to achieve a sufficient degree of desulphurization a high overdosing of limestone with Ca/S values of up to above 2 is required. Notter et al. [12] have recently suggested for cases when high-sulphur coals are to be burnt to use the surplus lime which is leaving the combustion chamber unreacted as a sorbent in the low temperature part of the flue gas path. They use for this purpose Alstom's NID process (see below under 4.3) where by the addition of water CaO hydrates to form Ca (OH)$_2$ which further reacts with SO$_2$ to form SO$_3$·1/2H$_2$O. A part of the sulphite further oxidizes to form gypsum, CaSO$_4$·2H$_2$O. Excellent separation efficiencies are reported for this two-stage desulphurization process.

4.3. Combined removal of pollutants in integrated processes

The integration of several cleaning steps into one apparatus is able to cut the investment costs of gas cleaning considerably. A good example is Alstom's NID (Novel Integrated Desulphurization) process which has been mentioned above already. Its flow sheet is shown in Fig. 3. NID is a dry flue gas desulphurization process based on the reaction between SO$_2$ and Ca(OH)$_2$ in humid conditions [12]

$$SO_2 + Ca(OH)_2 \rightarrow CaSO_3·(1/2)H_2O + (1/2)H_2O$$
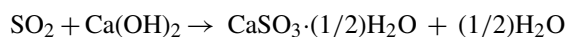
Similarly, HCl is reacted to calcium chloride,

$$2HCl + Ca(OH)_2 \rightarrow CaCl_2·2H_2O.$$
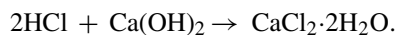
The most important parameter for the SO$_2$ reaction is humidity either as liquid water in drops to carry the reactant lime or as
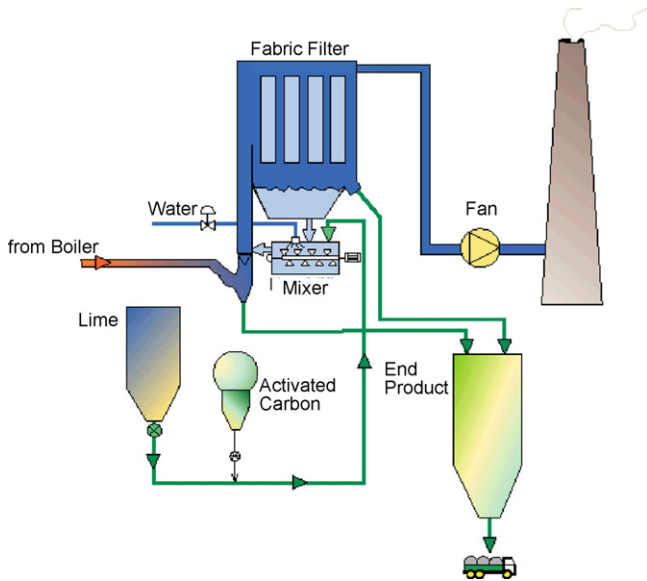
Fig. 3. The NID process for flue gas cleaning.

adsorbed humidity on the recirculated agent. Since humidity is sufficient the particles can be kept in a free-flowing state and the capture of SO_2 can be effected in an entrained flow reactor. Fresh lime and recirculated particles are thoroughly mixed in the mixer with an addition of water. The reaction mixture is then injected at the base of an upward directed duct where it is contacted with the flue gases. The entrained flow conditions together with the acceleration zone at the base of the duct provide the necessary contact time. The entrained and reacted solids are collected in the fabric filter and recirculated to the mixer or extracted for disposal.

In this way it is possible to capture the acid gases (SO_2, HCl, HF, HBr). However, since NID is a dry process it is quite easy to add additional adsorbents to capture other harmful components. For this purpose activated carbon is used which is able to capture heavy metals as well as dioxins/furans. The NID concept is thus able to capture the acid gases, heavy metals, dioxins

and the fine ash particles. If a circulating fluidized bed (CFB) is chosen as a combustion device one may take into account that the CFB is known for its temperature homogeneity and its generally low combustion temperature. This normally allows to keep not only CO but also NO_x below the legal limits. In this way the conventional sequence of different apparatus for capturing one harmful substance after the other is replaced here by a single-step process which reduces the investment costs drastically. It is admitted, however, that the resulting ash is mixed with spent sorbent which may lead to problems with its disposal. The NID process has already been successfully applied in coal-fired power stations as well as in biomass combustion and in waste combustion [13].

Somehow similar to Alstom's NID process is the Circoclean process developed by Lurgi Lentjes [14]. As is obvious from the flow sheet in Fig. 4 the main difference is the shape of the reactor: the flue gas enters through the bottom of the venturi shaped absorber which is operated as a circulating fluidized bed (CFB). The optimal reaction temperature which is 20–30 °C above the wet bulb temperature is achieved by water injection directly into the bottom of the fluidized bed. For operation in part load of the boiler clean gas can be recirculated to ascertain a stable operation of the CFB. The differences between Circoclean® and the Turbosorp® process which is marketed by AE&E and Von Roll Inova [15] are difficult to find. Fig. 5 shows an artist's picture of this latter process. Some differences are visible with regard to the solids inlet into the absorber.

A more sophisticated process has been developed in the Forschungszentrum Karlsruhe [16] for the combined removal of mercury, dioxins and particulate fines and aerosols. Fig. 6 shows this multi-purpose apparatus. After passing a quench the flue gas is first entering a scrubber where it is contacted with a H_2O_2 saturated washing solution which oxidizes the elemental mercury according to the MercOx® process.

The scrubber contains an Adiox® packing which causes the dioxins to be absorbed in a plastic material and adsorbed at carbon particles embedded in the plastic. After the scrubber the flue gas is passing an ionizing section where fine particles
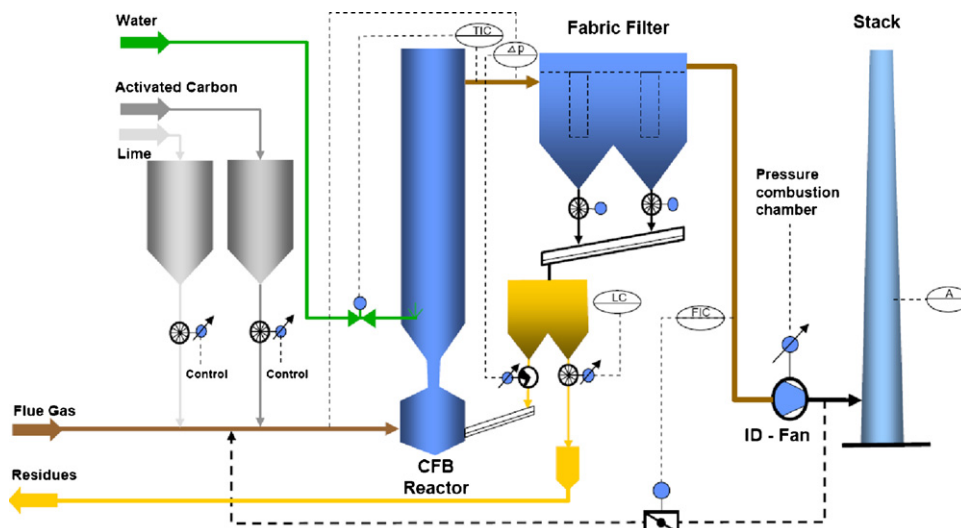

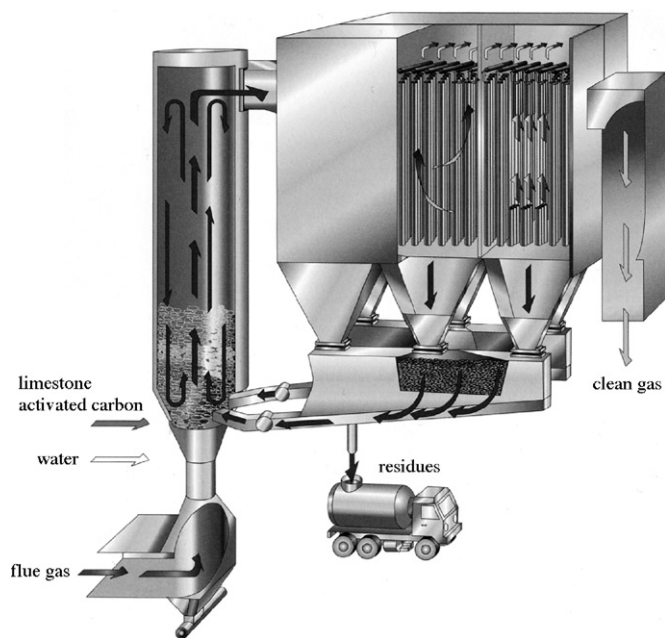Fig. 4. The Lentjes Circoclean process.

Fig. 5. AE&E's and Von Roll Inova's Turbosorp® process [15].

and aerosols are electrically charged (CAROLA® process) and subsequently precipitated on the surface of again an Adiox® packing. Excellent performance values are reported from measurements with a pilot plant which was operated in the bypass of the flue gas treatment of the industrial pilot waste incinerator THERESA. The combination of MercOx® and Adiox® has been installed in a waste incinerator plant in Sweden and is operating successfully.

5. New trends in waste combustion

The liberalization of the electricity market in Europe has brought utilities and waste incineration closer together. While the basic goal of utilities is to generate electricity at as low cost as possible the purpose of waste incineration is in the first place to transform the waste into an inert state. Both goals were merging
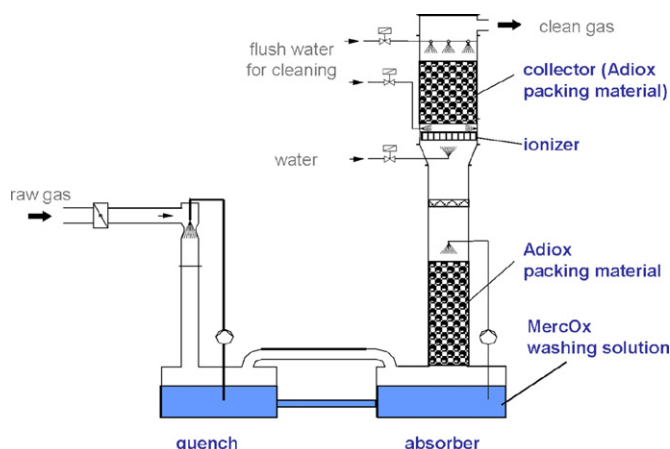
in recent years when utilities discovered waste as a cheap fuel for their boilers. As a consequence waste streams were diverted from the waste incineration plants and in order to remain competitive their operators had to think of increasing their process efficiency and to generate on their part more electricity in order to lower their incineration costs.

On both sides the goals – waste fuels for co-combustion in coal-fired power stations and increasing the process efficiency in the mono-combustion of wastes – can only be achieved if the waste is selected for uniformity or–if the waste is nonuniform as is the case for municipal waste – if the waste is preprocessed in such a way that a more homogeneous fuel is generated. Both routes will be highlighted in the following.

5.1. Methods of waste conditioning

Waste conditioning may be effected by either chemical or physical processes. A suitable chemical process is the pyrolysis which is applied in Technip's ConTherm® process. This process was for the first time implemented on the industrial scale by RWE Power [17]. The process flowsheet and its integration into the power station is shown in Fig. 7. After comminution the waste is pyrolyzed in an externally heated rotating drum. After a residence time of roughly one hour with maximum temperatures of 450–550 °C the solid products are subjected to a separation where metals are taken out. The remaining pyrolysis coke is fed into the coal mills from where it is conveyed directly to the burners in the combustion chamber. The pyrolysis gas is directly conducted into the lower part of the combustion chamber. No extra investments were in the present case necessary with regard to the flue gas treatment in order to fulfill the legal emission limits.

The big advantage of this type of thermal waste treatment is that it makes use of the infrastructure of the power station for combustion of the pyrolysis products, for heat recovery, and for flue gas cleaning. This means low investment costs and therefore a cost advantage compared to conventional plants for mono-combustion of waste.

The present plant is designed with its two pyrolysis drums for an annual throughput of 100,000 t of waste. It is not designed for the direct intake of unsorted municipal waste but rather for the high-calorific fraction from the mechanical–biological processing of municipal waste and for waste plastics. After smaller

Fig. 6. The combined scrubbing process developed by Forschungszentrum Karlsruhe [16].
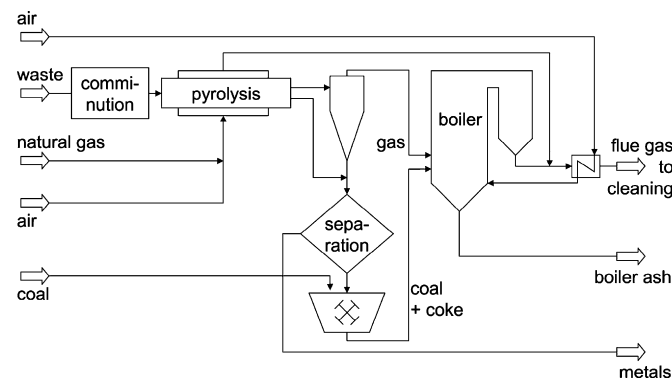

Fig. 7. The ConTherm® process and its integration into a coal-fired power station (after [17]).
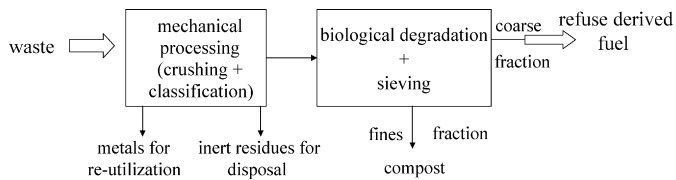
Fig. 8. Mechanical–biological processing of municipal waste.

modifications and optimization the system is reported to work well.

Instead of the pyrolysis drum a CFB gasifier may serve the same purpose. A respective process has been suggested by the Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik UMSICHT [18].

The basic concept of the mechanical-biological processing of municipal waste is schematically shown in Fig. 8. It starts with a mechanical processing step which consists of a comminution with subsequent classification and sorting. The latter step allows to separate metals for re-utilization and the inert residues for disposal. The remaining fraction is then subjected to biological degradation which converts part of the biomass to compost. In the following sieving step the fines fraction is taken out as compost for re-use in agriculture. The coarse fraction has a fairly high calorific value. This latter fraction may therefore be used as a refuse-derived fuel (RDF) for the substitution of fossil fuels in existing coal-fired power plants or for combustion

in new boilers which have been especially designed for this kind of fuel.

The author is presently involved in such a project. The Stadtwerke Neumünster GmbH (SWN) is a regional utility that supplies also heat for district heating to the city of Neumünster which is located northeast of Hamburg. In a first step a mechanical-biological processing plant was erected which has a capacity of 210,000 t/a municipal waste. This plant generates 103,000 t/a RDF with a heating value of 14.5 MJ/kg which is significantly larger than the 9 MJ/kg of the original waste [19].

The RDF is then used as a fuel in a newly constructed circulating fluidized bed (CFB) boiler which has replaced two old coal-fired boilers. The CFB boiler was built by Austrian Energy and Environment (AE&E). Its flowsheet is shown in Fig. 9 [20]. The heart of the plant is the CFB furnace with its large cyclone for recirculating the bed material. The combustor is followed by a heat recovery section and a flue gas treatment according the NID process. The plant is presently in the commissioning phase. The author's group is involved in measurement campaigns and modeling work which aim at the prediction and control of the particle size distribution in the circulation system.

5.2. Co-combustion of wastes in coal-fired power stations

The EU Directive 2000/76/EC and the corresponding national regulations provide a legislative framework also for the co-
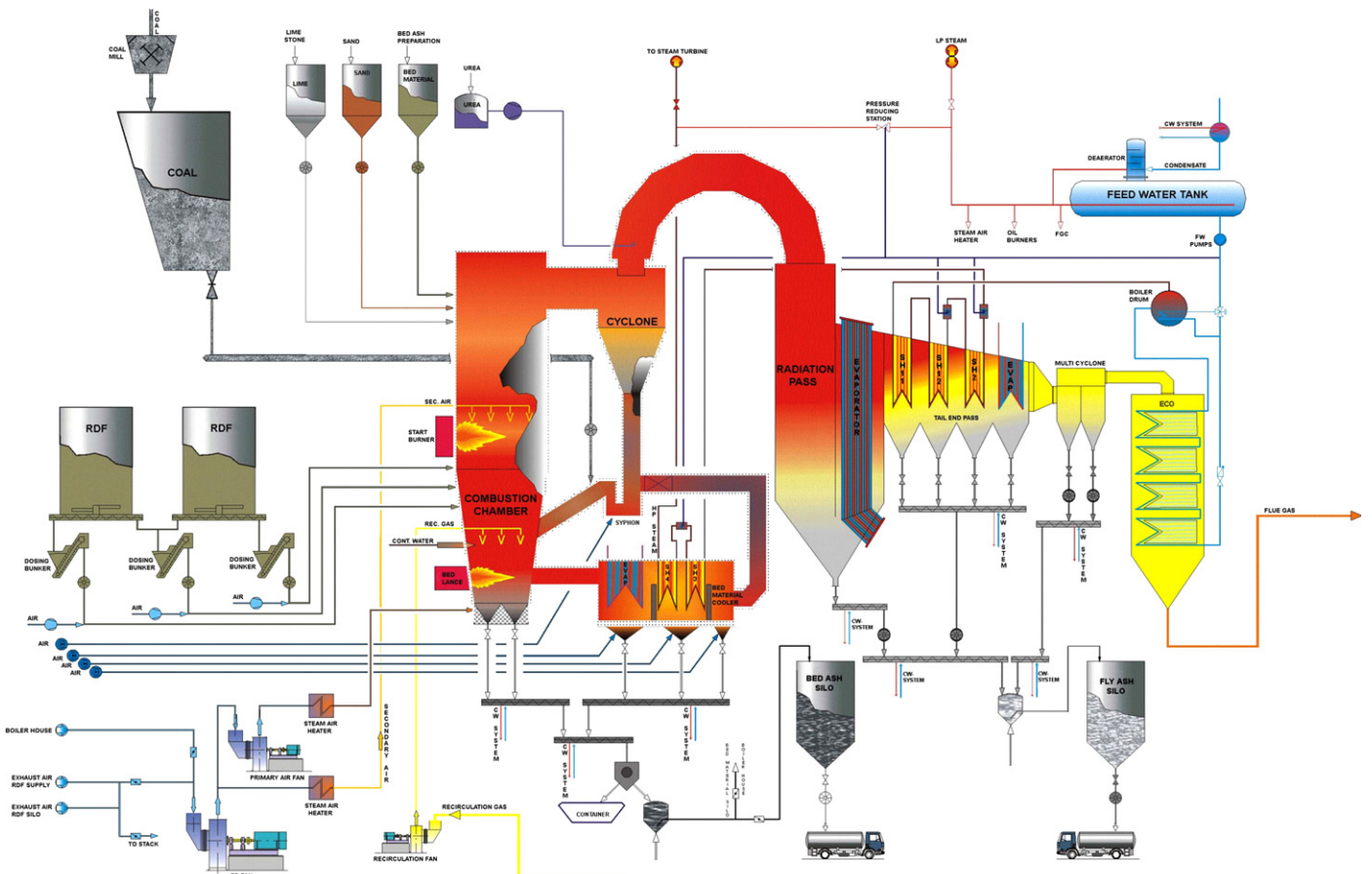

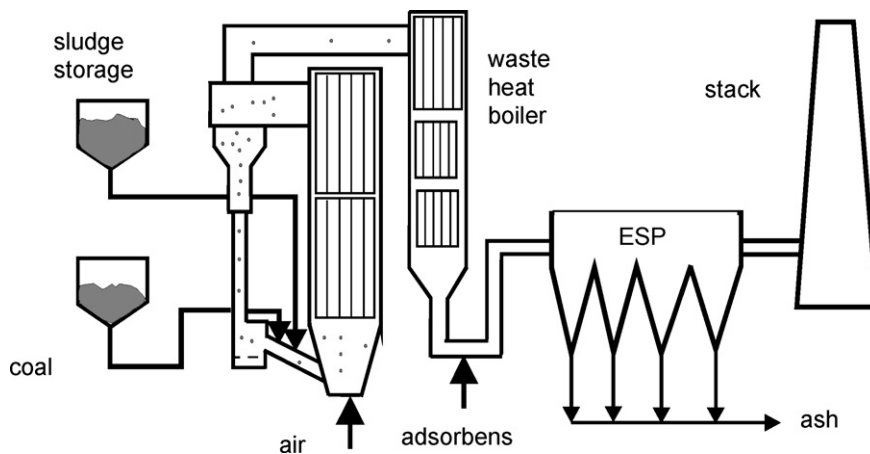Fig. 9. The Neumünster boiler for preconditioned municipal waste [20].

Fig. 10. Co-combustion of sewage sludge in the power station Berrenrath.

combustion of wastes. In 2001 43 power stations were co-firing waste [21] and this number has strongly increased since then.

Co-combustion is fairly easy for homogeneous wastes, e.g. for sewage sludge. Another point is that the production of sewage sludge in Germany of roughly 2.7×10^6 t dry matter per year is small compared to the consumption of fossil fuels (46×10^6 t/a hard coal and 151×10^6 t/a brown coal). The numbers are valid for 1996.

As an example Fig. 10 shows the co-combustion of sludge in RWE Power's Berrenrath power station [22]. The dewatered sludge is simply pumped to the boiler and is fed together with the coal into the solids recycle line which carries the recirculated solids back into the CFB combustion chamber. Since initially the limits for Hg emission were exceeded a modification of the gas cleaning had to be made such that adsorbents (activated coke) were blown into the duct which connects the boiler with the ESP. However, this was a minor modification.

No modification at all was necessary when the Heilbronn power station started co-combustion of sludge ([23], Fig. 11). The boiler no. 7 of EnBW Kraftwerke AG's power station in Heilbronn is a 750 MWe pulverized coal firing combustor which consumes 1.2×10^6 t/a bituminous coal. The power station has obtained permission to co-combust 20,000 t/a dry and 60,000 t/a
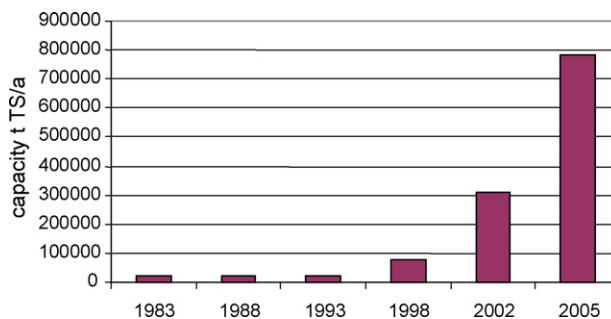

Fig. 12. Development of co-combustion capacities for sewage sludge in German power stations [24] (TS = dry matter).

mechanically dewatered sewage sludge which is simply co-fed with the coal into the mills.

The relative ease of the co-combustion makes it very attractive and this has prompted a strong increase of this practice. Fig. 12 shows the development of co-combustion capacities for sewage sludge in German power stations over of the last years. By 2005 the co-combustion capacity was expected to exceed already the capacity of the existing mono-combustion plants for sewage sludge by a factor of 2 [24].
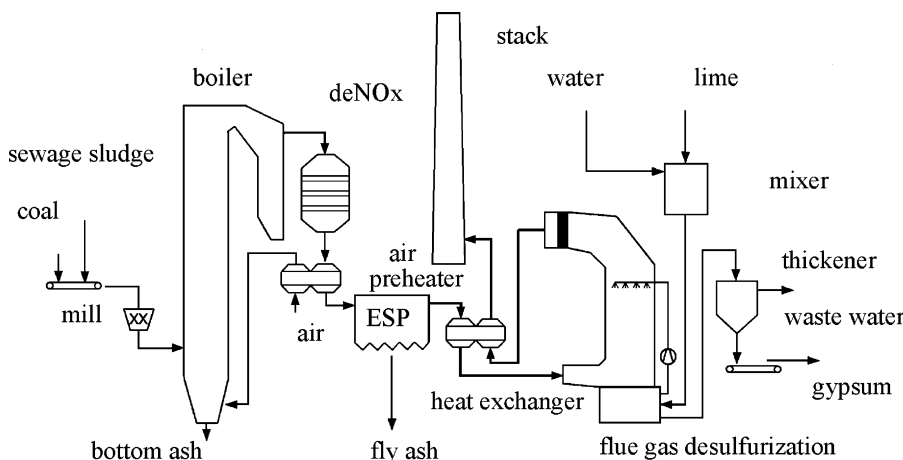

Fig. 11. Co-combustion of sewage sludge in the Heilbronn power station [23].
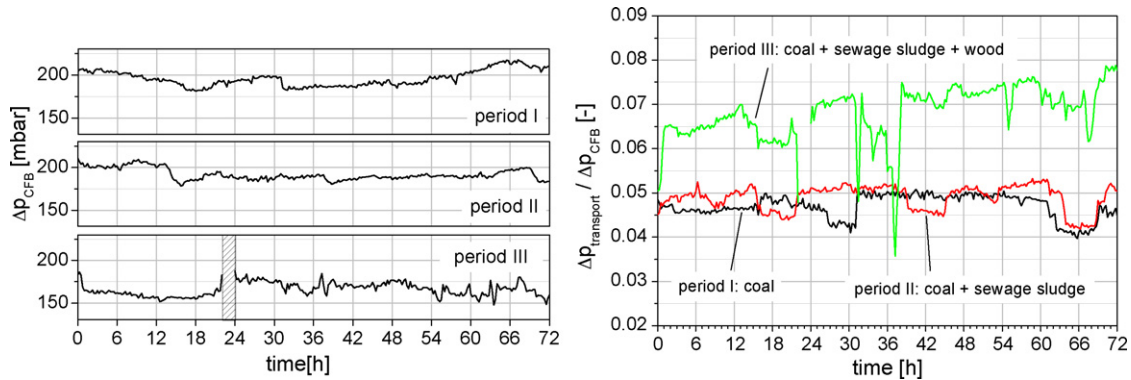
Fig. 13. Co-firing of waste with coal in the Duisburg boiler (Δp_{CFB} = pressure drop in combustion chamber, $\Delta p_{transport}$ = pressure drop in upper part of combustion chamber [26]).

Co-combustion of wastes in coal-fired power plants is not necessarily a low cost alternative for the thermal treatment of wastes only. There is also the chance that components in the waste may interact with the combustion of the main fuel in such a way that either the operating behavior of the boiler is improved or the emissions are reduced. A multi-national research project which is financed by the European Union within the 6th Framework Program currently aims at finding such synergies [25]. The author's group is participating in these activities. Within this project large-scale tests have been made in the 265 MWth CFB boiler of Stadtwerke Duisburg AG in Germany. Co-firing of sewage sludge with coal and of sewage sludge and wood pellets with coal was compared with pure coal combustion.

As an example Fig. 13 shows the time-dependence of the pressure drop in the combustion chamber which is indicative of the solids holdup. We see that the addition of waste under conditions of unchanged load leads to a decrease of the pressure drop which means that the power requirement for keeping the bed in suspension is significantly reduced. At the same time we see in Fig. 13 that in the case of the coal-sludge-wood mixture the ratio of the pressure drop in the transport zone (i.e. in the upper part of the combustion chamber) to the total pressure drop is significantly increased. Both findings are indicative of a change in the fluid dynamics of the gas-solid flow in the combustion chamber which will also influence the gaseous emissions. If should be noted here that CFB boilers in general rely on the in-furnace control of gaseous emissions i.e. they normally have a dedusting device only (ESP or filter) in the flue gas path.

Fig. 14 shows the NO$_x$ emissions during the three test periods. Obviously, the addition of the sewage sludge decreases the NO$_x$ emissions although the N-in-fuel massflow was increased due to the high N-contents of the sludge. With an addition of wood to the coal and sewage sludge the level of NO$_x$ is increasing again. This is another synergy effect. The negative impact of the wood towards the NO$_x$ emissions is compensated for by the positive effect of the sewage sludge. The overall emissions remain at a level which does not exceed that of pure coal firing.

Finally, Fig. 15 reveals another synergy with regard to the sulphur capture. In order to keep the SO$_2$ emissions limit limestone is added to the coal feed. Unfortunately, the CaCO$_3$ dosage can only be estimated by the percentage of the control of the limestone feeding device. However, the message of Fig. 15 is clear: The addition of the waste reduces the limestone consumption. The reason is the relatively high Ca content in the sewage sludge which is obviously able to replace part of the limestone. Addition of the waste means in this case a saving of about 20% on the limestone. Further details about the tests may be found in [26].
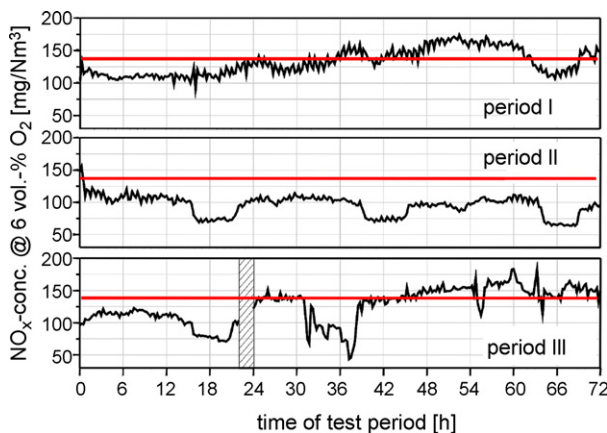

Fig. 14. NO$_x$ – emissions during co-firing tests in the Duisburg combustor [26].
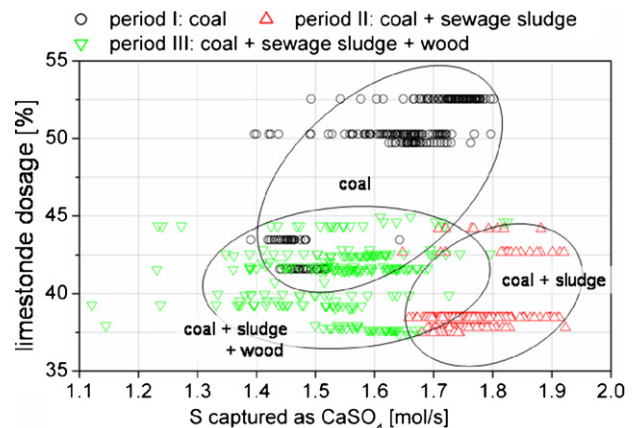

Fig. 15. Sulphur capture during the co-firing tests in the Duisburg combustor [26].

6. Conclusions

European and national legislation have established a network of regulations for gaseous emissions from waste combustion which are not only valid for mono-waste combustion plants but which include also co-combustion of wastes in other plants and preferably in coal-fired power stations.

A lot of different well-known and proven technologies are available for keeping the emission limits for the various pollutants. However, since these technologies were developed separately over the past 30 years as a result of increasing public awareness, flue gas cleaning in state-of-the-art waste combustors is effected by a multitude of specialized apparatus which make the flue gas cleaning not only complex but also expensive.

As a result of increasing incineration costs on the one side and decreasing profits due to the appearance of power stations with co-firing in the market there is a need for cost reduction in waste incineration. The present work highlights some new developments which can be summarized under the common goal of reducing the costs of flue gas treatment by applying systems which combine the treatment of several noxious substances in one reactor or by taking new, simpler routes instead of the previously used complicated ones or – in the case of flue gas desulphurisation – by reducing the amount of limestone consumption.

Cost reduction is also the driving force for new processes of conditioning of nonhomogeneous waste before combustion. Pyrolysis or gasification is used for chemical conditioning whereas physical conditioning means comminution, classification and sorting processes. Conditioning yields a fuel which can be used in power plants either as a co-fuel or as a mono-fuel and which will burn there under much better controlled conditions and therefore with less emissions in the raw flue gas than the nonhomogeneous waste in a conventional waste incinerator. Also for cost reasons, co-combustion of waste in coal-fired power stations is strongly pressing into the market. Recent investigations reveal that in special cases the addition of waste can also have beneficial effects on the operating behavior of the boiler and on the gaseous emissions.

Acknowledgments

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