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Overview of municipal waste incineration industry in west Europe (based on the German experience)

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Abstract

This paper presents an overview of the current status of the waste-to-energy activities in the west European countries, outlining the demand for municipal waste incineration and the development in the design of the combustion system as well as in the air pollution control system. Trend setter in the technical development over the last 10 years have been the emissions regulations for waste incinerators. As an example the Dutch, Austrian, Swiss, German and EC-legislation is compared with the current state-of-the-art flue gas treatment technology and its achievable emission values. The boost of new technologies was mainly created by the dramatic tightening of these emissions legislation.

The second part of the paper details the status of air pollution control technologies currently being used. Various four to five stage flue gas cleaning processes, including the recovery of marketable products from the residuals, are covered. Hence not only the minimization of stack emissions is politically pursued. The requirement of resource recovery from residuals has become more and more a major criteria for the design of flue gas treatment processes. This paper explores the process technologies used in achieving this goal as well as giving an outlook on novel concepts aiming for even higher rates of recovery and better quality products.

The paper concludes with a listing of the major technology vendors and with some economical/ecological aspects of waste incineration plants equipped with modern combustion and air pollution control technology.

Keywords: West-Europe/Germany; Municipal waste incineration; Flue gas cleaning

1. Introduction

The west European countries are characterized by being highly industrialized and by having a very dense population, with up to 350 inhabitants per square kilometer for example in the Netherlands and in Belgium. In the average the population

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produces about 300 to 400 kg of domestic waste per year and inhabitant. Due to the high density in population the countries are lacking in landfill possibilities on one side. On the other side, the population is very sensitive with respect to any environmental short-cuts and acceptance of waste incineration in the vicinity of populated areas is achieved only if applying the latest technological developments. The technical development thus has been heavily driven by the environmental legislative requirements.

2. Demand for municipal waste incineration

Since the turn of the century the combustion of municipal waste in Europe was pursued in order to eliminate the harmful effects of landfilling untreated waste. Mainly the contamination of drinking water, hygienic considerations and objectable odors from landfills caused the start of waste incineration. Today the inertization of waste by means of combustion and incineration is an ongoing important factor in environmental protection, because no other technology permits the treatment of municipal and hazardous wastes to such an extent. At the landfill the disposed wastes undergo uncontrolled chemical reactions for a long period of time. Namely the controlled inertization of the waste in an advanced waste incineration facility, combined with a 90% reduction in volume and the use of the released heat for steam and electricity production, have led to extensive use of waste incineration in western Europe [1]. Fig. 1 presents the percentage of municipal waste being disposed of by means of incineration for most west European countries [2].

In the past 10 years the overall strategy to eliminate the waste problems in the west European countries has been an approach following the priorities:
(1) avoiding of waste as far as possible,
(2) recycling of waste as far as possible,
(3) inertization of nonavoidable waste by MWI,
(4) separation, treatment and recycling of residuals during and after the MWI process.

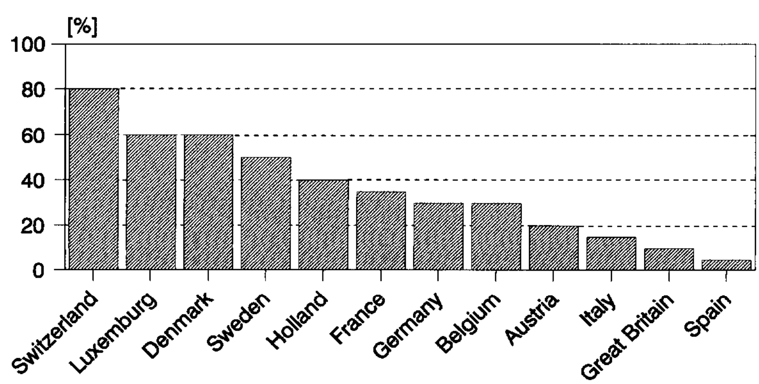

Fig. 1. The percentage of waste incineration in various European countries, source [1].

A various number of different legislation have passed the parliaments, forcing the manufacturers of mass products to reduce the amount of waste generated when consuming those products (in Germany for example: preference of recyclable glass bottles instead of one-way plastic bottles, or requirements which force manufacturers to take back a product when it is worn out). Concerning recycling, the municipal waste disposal organizations have introduced the recycling of wastes, by organizing separate collection, which is being sorted by the consumers. However recent studies have shown that, from an environmental point of view, no clear advantage could be attributed to: (1) the re-use of products versus their recycling or, (2) to the recycling of products versus their incineration. As a result, in the latest draft of this European Directive [3] the 're-use/recycle/incinerate/landfill' hierarchy has been phased out and ranges of mandatory recycling rates are now present in the last draft of the directive (in addition to the existing minimum recycling rates, maximum recycling rates are required).

Nevertheless, despite of all the efforts in avoiding and recycling, the amount of municipal waste left is still a problem and therefore the number of municipal waste incineration plants in western Europe is increasing each year. A perfect example of this statement is the development of waste incineration in Germany, which is shown in Table 1. Twenty years after the end of World War II, when the German economy had just begun to emerge from the post-war depths the number of waste incineration plants was still small. In the following 20 years the number grew by a factor of almost seven, thus reflecting the economical growth [4]. Now, with stringent environmental laws in effect and after the reunification of Germany, the number is still expected to be at least double within the next 10–20 years. The activities in MWI projects and orders placed in 1993 and in the first half of 1994 confirm that this is going to happen.

Table 1
Development of municipal waste incineration in Germany

Year	Number of MWI facilities	Capacity in 1000 t/a	Number of thousand inhabitants whose waste is incinerated	Percentage of municipal waste to be disposed of by incineration	Average capacity per MWI-plant in 1000 t/a
1965	7	718	2450	4,1	103
1970	24	2829	8590	14,4	118
1975	33	4582	13 590	22,0	139
1980	42	6343	17 730	28,9	151
1985	46	7877	20 630	33,7	171
1990[a]	48	9200	21 600	27,4	191
1992[a]	50	9500	22 100	28,1	190
1995[a]	53	10 700	24 200	30,7	202

[a] After reunification of Germany.

3. Technological developments

For a long period of time mass burning of municipal waste was considered a cheap source of energy, combined with an ideal way of waste disposal. The common technology used was, and still is, a grid firing system, followed by a steam generator. With respect to combustion and inertization there are also other technologies available like rotary kiln furnaces, fluidized-bed combustion and pyrolyses.

Rotary kiln furnaces are commonly used for incineration of hazardous waste originating from chemical plants or industrial processes and most of the large chemical plants in Germany and in the other European countries own and operate their ow waste incineration facilities using this technology. The advantage of rotary kiln furnaces is that they can burn solid, fluid and pasty waste at the same time but with respect to mass burn of municipal waste they are limited in their specific capacity.

Fluidized-bed combustion is commonly used for sludge incineration, the sludge originating from industrial or municipal waste water treatment plants. There have been attempts in Germany to use fluidized-bed combustion also for incineration of pretreated municipal waste, but the projects have never developed further than the application in pilot plants, mainly because the pre-treatment of the municipal waste causes too many disadvantages in comparison to the untreated mass burn of waste.

After the oil crises in 1973 a lot of projects using pyrolyses for inertization of municipal waste have been started in Germany, but the majority of these projects have been cancelled because of disadvantages in comparison to mass burn [5]. Nowadays only two pyrolyses projects which could be considered serious are still being followed. These are the KWU process and the Thermoselect process, the later being installed in a demonstration plant in Italy. However, the two pyrolyses technologies do not show economical nor ecological advantages in comparison to a modern conventional grid firing system, when taking into consideration the overall conversion of waste to energy [6].

It was not until the early 1980s, when environmental awareness grew, that waste incinerators were recognized as potential sources of air pollution. At that time most waste incinerators were, if at all, equipped only with an ESP for flue gas treatment. The development of more and more sophisticated methods of sampling and analysis for toxic and harmful air pollutants led to the discovery of many of these pollutants in the flue gas from waste incinerators. Especially significant concentrations of toxic heavy metals such as mercury and cadmium as well as highly toxic chlorinated organics created public concern about waste incineration.

The result was a general revision of the emission standards in several steps starting from the late 1970s and proceeding till the early 1990s, as shown in the next Section.

These and a series of other laws and regulations added additional momentum in improving also the firing and heat recovery system, as well as to the development of the flue gas cleaning technologies. Especially in Germany the major requirements of the additional regulations are:

- the most effective use of energy recovery has to be applied, meaning all plants with a thermal output above 1 MW must be equipped with a steam boiler.

- the resource recovery from residuals of the combustion process and the flue gas treatment, meaning where ever technically possible, residues must be recycled regardless of the economics.
- the dynamic minimization of the emission values, meaning regardless of the standards, the best available control technology has to be applied.
- the effluent-free operation of waste incineration facilities, meaning no discharge of waste water is permissible.

The impact on the technological development was, that the firing system of waste incinerators was improved with respect to primary and secondary air control, gas flow, mixing, turbulence, temperature and residual time. One step in this direction is the trend to increase the firing temperature combined with a longer residence time of the flue gas in that zone. The legally required temperature of presently 850 °C, combined with a residence time greater than 2 s, may be extended to a temperature greater than 1000 °C, combined with a residence time greater than 2.5 s. Thus lower CO-, C_xH_y- and PCDD/F-levels (polychlorinated *p*-dibenzodioxins/*p*-dibenzofurans) at the outlet of the boiler can be obtained. The above measures will lead to a lower fly ash concentration, and the TOC content of the fly ash and of the bottom ash will be lowered also. A description of the modern, most commonly used grid firing systems in west Europe is shown in [7].

However, the most dramatic technological changes have been developed in the air pollution control equipment.

4. Requirements in air pollution control

Hand in hand with the possibilities to detect potential hazardous components in the emissions of MWI, revisions of the emission standards were set, like in Germany starting in 1974, which was documented in the Technical Guideline Air (Technische Anleitung Luft) 1986, TAL 86. The old 1974 standards were drastically tightened and additional new pollutants were regulated. Coarsely underestimating the dynamic of the public concern, the legislator decided to apply the TAL 86 immediately only to new waste incinerators and grant generous adaptation periods of up to six years for old sources. Thus the public opinion opposing waste incineration was fueled again. Several worldwide known incidents such as the Seveso accidents and the Love-Canal case provided additional ammunition against waste incineration. The pressure on the legislature grew and peaked in the late 1980s, forcing the establishment of a whole new line of laws regarding the treatment of waste.

In 1990 the TAL 86 was replaced by a new law, the 17th BImSchV. Thus, only four years after severe tightening of the emission standards, the next stringent reduction became effective. At that time most plants were still in operation under the exceptions of the six-year adaptation period of the TAL 86. For these plants the new law allowed an adaptation period of only a little over three years to comply with the new standards. For the plants in compliance with the TAL 86 an adaptation period of six years was granted. At that time many MWI's under construction were obsolete even before start-up and had to be retrofitted immediately.

Similar developments occurred in Holland, Sweden, Denmark, Austria and Switzerland around the same time. Table 2 shows the emission standards currently in effect in Germany, Austria, Holland, and Switzerland and compares them to the proposed EC and US legislation. Around 1989/1990 Austria, Germany, Holland and Sweden adopted a new standard for PCDD/F. This pollutant, to be regulated for the first time ever worldwide, was restricted to a standard of 0.1 ng TE/m^3 according to NATO-CCMS standards. The regulation of an organic pollutant required the relevant industry to develop complete new techniques for flue gas treatment, since the known techniques were only directed to the removal of inorganic pollutants such as HCl, SO_2 and heavy metals. Further more the commonly used dry and semi-dry flue gas treatment technologies became obsolete. Known technologies such as wet scrubbing had to be expanded on, and new technologies such as activated carbon filters had to be developed [8]. These new technologies were originally aimed to match the strict standards for PCDD/F as well as for heavy metals, namely mercury. This led to the side effect of extremely low levels for all the other pollutants. Hence, permitting agencies are already tightening the current emission standards in order to avoid further extensive public discussions. Fortunately, the new technologies are so effective in removing all toxic and harmful substances from the flue gas, that virtually all pollutants can be reduced to levels around the detection limit. Table 3 gives an overview of the development of the emission standards and compares them to the values currently achieved in the most modern state-of-the-art waste incineration facilities.

5. State-of-the-art air pollution control equipment and trends

The requirements in resource recovery from waste incineration at any costs, combined with the strict new emission regulations lead to the extinction of the dry and semi-dry flue gas cleaning techniques. Where as these systems possibly could be upgraded to barely meet the new emission standards, there is no chance to meet the requirements of recyclable residues. The mix of fly ash, various salts, metals, and unreacted lime, as created from the old techniques, is considered hazardous waste by law and, at least in Germany, must be disposed of in underground salt caverns. Therefore nowadays all new MWI's currently under construction or in the phase of planning and/or permitting are equipped with wet flue gas cleaning systems, at least one out of four or five flue gas treatment stages being a wet scrubber [9].

In order to fulfill the requirement of recyclable residues from waste incinerators, modern flue gas treatment systems are designed to separate the pollutants as much as possible. This is commonly done by a four to five stage process. In the first stage fly ash is removed. Commonly used were ESP's, but since research indicated that a possible formation of PCDD/F occurs in ESP's, they are more and more replaced by baghouses. The use of a bag-house also permits the possibility of adding activated carbon to the flue gas prior to the baghouse. The activated carbon greatly enhances the removal of PCDD/F as well as vaporized heavy metals such as

Table 2
Comparison of various current emission regulations in central Europe and the proposed EC- and US-standards for new MWI's

Pollutant		Germany (in effect)	Austria (in effect)	Switzerland (in effect)	Holland (in effect)	EC (proposed)	US (proposed)
Particulate matter	(mg/m^3)	10	20	50	5	5	25
HCl	(mg/m^3)	10	15	30	10	5	27
SO_2	(mg/m^3)	50	100	500	40	25	55
HF	(mg/m^3)	1	0.7	5	1	1	—
NO_x	($mg\,m^3$)	200	200	500	70	—	240
C_xH_y	($mg\,m^3$)	10	20	20	10	5	—
CO	($mg\,m^3$)	50	50	—	50	50	80/120[a]
Cd	(mg/m^3)	0.05	0.05	0.1	0.05	0.05	0.015
Hg	(mg/m^3)	0.05	0.05	0.1	0.05	0.05	0.071
Sum other heavy metals	(mg/m^3)	0.5	—	—	1	0.5	0.115[b]
PCDD/F (according to NATO-CCMS Standards)	($ng\ TE/m^3$)	0.1	0.1	—	0.1	0.1	30(0.3)[c]

[a] For RDF-buring facilities.
[b] Pb only, other heavy metals are not regulated.
[c] Estimated TE-value based on a total mass emission of 30 ng/m^3.
(All values converted to dry flue gas conditions of actual (if $\leqslant 11\%$) O_2 @ STP.

Table 3
Development of the emission standards for MWI's over the last ten years in Germany

Pollutant		TAL 74 (1974)	TAL 86 (1986)	17th BImSchV (1990)	Current standards required by permitting agencies	Achievable values using state-of-the-art flue gas treatment technology
Particulate matter	(mg/m^3)	100	30	10	5	<1
HCl	(mg/m^3)	100	50	10	5	<1
SO_2	(mg/m^3)	—	100	50	25	<1
HF	(mg/m^3)	5	2	1	0.5	<0.1
NO_x	($mg\ m^3$)	—	500	200	70	<50
C_xH_y	($mg\ m^3$)	—	—	10	10	<2
CO	($mg\ m^3$)	1000	500	50	50	<25
Cd	(mg/m^3)	10	0.1	0.05	0.025	<0.005
Hg	(mg/m^3)	10	0.1	0.05	0.025	<0.005
Sum other heavy metals	(mg/m^3)	125	6	0.5	0.1	<0.01
PCDD/F (according to NATO-CCMS Standards)	($ng\ TE/m^3$)	Not regulated	Not regulated	0.1	0.05	<0.01

(All values based on dry flue gas conditions of actual (if $\leqslant 11\%$) O_2 @ STP.

mercury. In this case a quench cooler is commonly applied prior to the baghouse to support adsorption.

The removed fly ash will usually be treated by extraction or vitrification. In the latter case the fly ash may be added to the bottom ash and vitrified in an electric arc furnace or a glass smelter, heated by burning natural gas with oxygen instead of air. The molten slag can be converted to mineral wool or other marketable products.

When the fly ash will be extracted with acid and compacted with clay or cement, it will be added to the waste feed again and ends as bottom ash. The bottom ash is either vitrified as described earlier or classified and recovered as construction material.

The second stage of the flue gas treatment system consists of an acid wet scrubber. It is operated at a pH-value below 1 in order to absorb only HCl and HF, but virtually no SO_2. The scrubbing liquid is pure water, no neutralizing agent is applied. The scrubber is designed in such a way that a 10–12% hydrochloric acid is recovered. This acid then undergoes further treatment, is purified and concentrated to over 30%. The final product is a marketable hydrochloric acid, suitable for a wide variety of applications in various industries. Alternatively, the acid can be neutralized with sodium hydroxide and evaporated to recover pure sodium chloride. It is usually recycled in the chlorine industry.

In the third stage the remaining SO_2 is removed from the flue gas by means of alkaline scrubbing. Commonly, lime milk acts as a neutralizing agent to convert the SO_2 to gypsum. The gypsum is washed, dewatered and marketed in the gypsum industry.

The fourth stage is designed to polish the flue gas and remove all residual pollutants. The most effective device for flue gas polishing is an activated carbon filter. By means of adsorption virtually all remaining pollutants are removed through the activated carbon to levels around the detection limit. In the case that the local political situation and the permitting agency do not require emission value significantly below the 17th BIm-SchV and a baghouse with activated carbon addition is employed as a fourth stage, the activated carbon filter might be left out.

If not considering the activated carbon reactor the fourth stage is a SCR-DeNO$_x$ plant operated at a temperature above 300 °C. It is equipped with TiO_2/V_2O_5 ceramic catalysts to reduce NO_x in the presence of NH_3 to N_2 and H_2O. Additional layers of catalyst are then employed to oxidize the remaining PCDD/F's below the required value of 0.1 ng TE/m^3.

If an activated carbon filter is installed as a fourth stage, the following SCR system can be greatly simplified. Due to the extreme purity of the flue gas leaving the activated carbon filter the temperature in the SCR unit can be lowered to 160–180 °C, thus making reheating less costly. The removal of all compounds possibly poisonous to the catalyst guarantees a lifetime of the catalysts in excess of ten years.

Fig. 2 presents a typical five-stage flue gas treatment system designed to achieve extremely low emission values. Fig. 3 shows a 'cheaper' four-stage system. Both systems provide complete resource recovery from the residuals. Table 4 gives an overview of the ways of recycling major pollutants and residues, respectively.

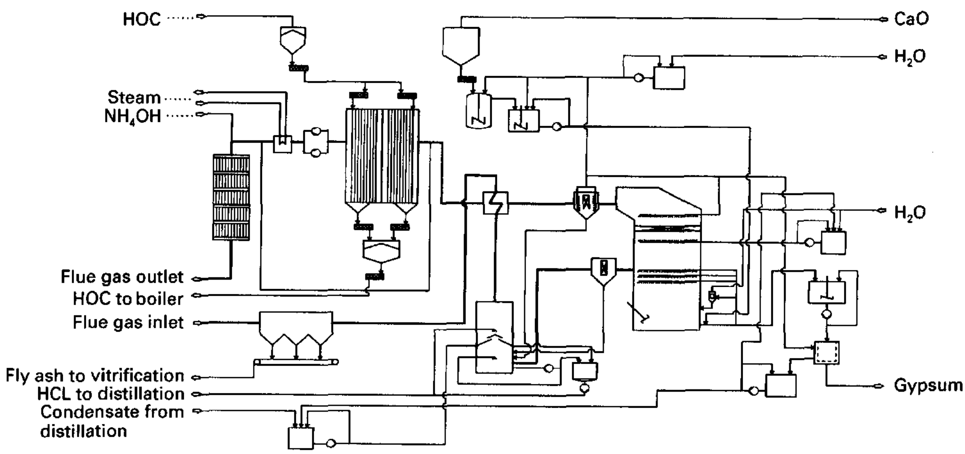

Fig. 2. Process flow diagram of a five-stage flue gas treatment system.

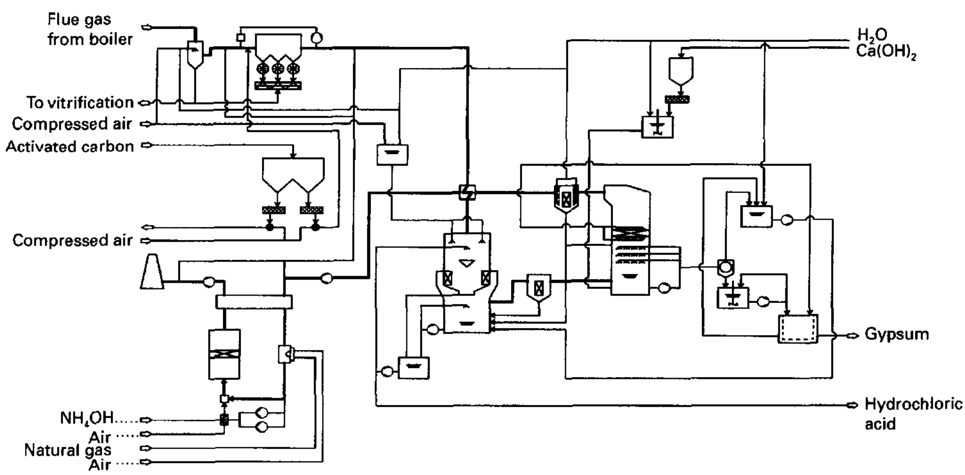

Fig. 3. Process flow diagram of a four-stage flue gas treatment system.

6. Vendors

Table 5 gives a listing of the vendors which split up about 90% of the European market of waste-to-energy facilities. The outlook for the industry is fair to optimistic, since the amount of waste generated increases continuously. As natural resources become precious and landfilling must be ruled out, waste minimization and direct recycling must be encouraged. The remaining waste must be disposed of by means of the least environmental impact, which is state-of-the-art waste incineration.

Table 4
The ways of recycling of major pollutants

Pollutant	Possible recycling product	Marketability	Public acceptance	Relative cost	Means of disposal or marketing
Hydrogen chloride	Hydrochloric acid	++	+	+	Chemical Industry
	Sodium chloride	+	+	0	Chemical Industry
	Calcium chloride	–	0	0	Chemical Industry
Sulfur dioxide	Gypsum	++	++	++	Construction Industry
	Sulfuric acid	0	0	–	Chemical Industry
	Sulfur	0	0	– –	Chemical Industry
Fly ash	Vitrified products (i.e. mineral wool)	++	+	–	Construction Industry
	Concrete additive	–	– –	+	Concrete Industry
Heavy metals	Recovery as alloy	++	+	–	Steel Industry
	Inclusion in vitrified products	0	0	–	Construction Industry
Organics	None	–	–	–	Thermal destruction
Nitrogen oxides	None	–	–	–	Catalytic reduction
Hydrogen fluoride	None	–	–	–	Salt cavern disposal

++ very good, + good, 0 fair, – poor, – – bad.

Table 5
Major vendors of MWI-technology in Europe

Vendor	Country of origin	Firing system	Boiler	Flue gas cleaning
Deutsche Babcock Anlagen GmbH	D	X	X	X
L & C Steinmüller GmbH	D	X	X	X
Von Roll GmbH	CH	X	—	X
ABB Fläkt GmbH ABB W+E GmbH	S/CH	X	—	X
Martin GmbH	D	X	—	—
KRC Umwelttechnik GmbH/K+K Ofenbau GmbH	D/CH	X	X	X
ML (Lentjes/Lurgi) GmbH	D	X	X	X
EVT GmbH	D	X	X	—
AEE GmbH	A	X	X	X
LAB S.A.	F	—	—	X
Siemens AG (KWU)	D	X	X	—

Country Code: A = Austria; CH = Switzerland; D = Germany; F = France; S = Sweden.

7. Ecological/economical conclusion

The waste-to-energy technology has improved dramatically in the last 20 years and it is considered to be the best way of disposal for non recycable municipal waste, since it is the only way to eliminate potential harmful compositions once forever, without delaying the final solution to future generations.

Of course the additional efforts into the environmental protection of MWI's result in higher investment and O & M costs. Nowadays the investment into the flue gas cleaning and residual handling system make up to about half of the total investment costs of a full equipped MWI plant.

The total expenses of a MWI plant are covered by the tipping fee for the waste and by the revenues from heat and electricity sales. In earlier days the revenues from heat and electricity sales covered about 50% and more of the total cost. Nowadays, since the price of heat and electricity has not changed dramatically, this portion covers only 25% or less. Therefore, in order to cover the increased total costs, the tipping fees in western Europe have been raised quite a lot and still undergo changes. Nevertheless, the burden for an average household is still low compared to other monthly expenses like rental fee, heat, electricity and water. Besides ensuring proper and environmental safe disposal of nonavoidable waste, the increased tipping fees have alerted the population to reduce waste production and to save resources, which helps both the economy and the environment.

References

[1] H.-U. Hartenstein and B. Söhndel, The status of the waste-to-energy technology in Central Europe, Presented at the 3rd Internat. Conf. on Municipal Waste Combustion, Williamsburg, VA, USA 1993.

[2] P.K. Kneisel and H. Humer, Planung der AVA-Wels, Oberösterreich (Planing of MWI-Wels, Upper Austria), Presented at the VGB-Conf. "Thermische Abfallverwertung 1992", Essen, Germany, 1992.

[3] European Directive on packing and packing wastes.

[4] J.D. Schmitt-Tegge, Die Situation der Haus- und Sondermüllverbrennung 1992 in der Bundesrepublik Deutschland (The situation of municipal and hazardous waste incineration in Germany 1992), Presented at the VGB-Conf. "Thermische Abfallverwertung 1992", Essen, Germany, 1992.

[5] J. Heil, Entwicklungsstand der Pyrolysetechnology zur Entsorgung von Hausmüll (Stage of development of pyrolyses technology for disposal of municipal waste), Published in K.J. Thome-Kozmiensky (Hrsg): "Müllverbrennung und Umwelt 2" (Waste Incineration and Environment 2), Berlin, EF-Verlag, 1987, pp. 705–713.

[6] J. Becker and W. Schumacher, Moderne thermische Abfallver-wertung (Modern thermal disposal of Waste), Seminar held by the Bavarian State Office for Environmental Affairs in Wackersdorf, Germany on February 8, 1994.

[7] J. Becker, W. Schäfers, A. Rolf, A. Christmann and J. Martin, Rostfeuerungsanlagen für Abfallverbrennungsanlagen (Grid firing systems for waste incineration plants), Special edition of 'Jahrbuch der Dampferzeugertechnik', 7th ed., 1992, Vulkan-Verlag, Essen (Haus der Technik).

[8] H.-U. Hartenstein, Activated carbon filters for flue gas polishing of MWI's, Presented at the 3rd Internat. Conf. on Municipal Waste Combustion, Williamsburg, VA, USA, 1993.

[9] H.-U. Hartenstein, U. Mohn and B. Söhndel, Das Steinmüller-Konzept zur vollständigen Rauchgasreinigung mit weitestgehender Reststoffverwertung am Beispiel des Restmüllheizkraftwerkes (RMHKW) Böblingen (The Steinmüller concept for complete flue gas cleaning with integrated recovery of residuals as per the example for MWI Böblingen), Vulkan-Verlag, Essen, Germany, 1992.