1. Draft of a German Report with basic informations for a BREF-Document “Waste Incineration“

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1 GENERAL INFORMATION

1.1 Introductory Remarks

The incineration phenomenon has not always been interpreted correctly as an amalgamation of materials with oxygen. The German MD and chemist Georg Ernst Stahl (1660 – 1734), for example established the theory in 1697 that a gaseous “something“ escapes when burning material, which he called “phlogiston“. According to this theory (“phlogiston theory“) it was assumed that material would burn easier and more vigorous, the more phlogiston it would contain. According to this theory, sulfur, phosphor, carbon and hydrogen were considered material very reach in phlogiston. When Lavoisier showed in 1777 that oxygen which had been discovered independently by Carl Wilhelm Scheele (1742 – 1786) and Joseph Priestly (1933 – 1804) as an air part, was necessary for burning and that a weight increase and not a weight reduction could be discovered during the burning, the phlogiston theory was not discarded. There was an attempt to save it by additional hypotheses. It was assumed that oxygen was “dephloggisized“, meaning air liberated from phlogiston, which has the great desire to withdraw phlogiston from other materials. A “negative weight“ was attributed to phlogiston.

Today we might not completely understand this stubbornness used in the attempt to maintain the phlogiston hypothesis for a century. We must, however, keep in mind that this hypothesis contained a kernel of truth. What the phlogicists saw as escaping phlogiston could be seen today as escaping energy. As the phlogistron theory did not make a clear distinction between the energy and the material conversion, and as it considered phlogiston a material, the theory soon entangled itself in contradictions without any solutions.

1.2 Work Scope

The IVU-Guideline 96/61/EG describes the scope for this work as waste incineration plant with a throughput of > 3t/h which corresponds an annual throughput of 21,000 to 24,000 t considering the normal operational times in a plant. The following waste types fall within the scope of this document:

- Municipal waste
- Non-hazardous waste
- Hazardous waste
- Sewage sludge
- Hospital waste

The incineration of waste can be performed in specially built plants or within the framework of other thermal processes, which is then called co-incineration.

Emissions and technical general requirements for waste incineration and co-incinerations are regulated as minimum requirements in Guideline 2000/76/EG on “Waste incineration“ [16].

1.3 Purpose and Waste Incineration Processes

The essential targets for waste incineration the reduction of waste volume the upgrading and outward transfer of inorganic substances, which are created during the incineration, as well as the reduction of the degree of danger of treated waste and the energetic utilization. In the future, the importance of reducing waste gases which are harmful to climate, epsecially CO_2 and N_2o, will increase considerably in connection with the demand for an even more efficient utilization of energy in accordance with the IPPC guideline.

The chemical reaction to atmospheric oxygen with a combustible material is called incineration (oxidation). Waste is a heterogeneous fuel, consisting essentially of organic substances, minerals and water. During the incineration waste gases are created containing heat as main part of the fuel energy. Carbon, hydrogen, nitrogen and the better part of sulfur are latent in organic fuel substances.

The organic fuel substances burn as soon as they have reached the necessary ignition temperature and come in contact with oxygen. The actual incineration process takes place in fractions of seconds and releases simultaneously new energy to reach the ignition temperature leading to a thermal chain reaction with appropriately dosaged air supply.

The incineration process starts with drying and **degassing** and the expulsion of volatile ingredients (e.g. smoldering gases, hydrocarbons, and water) at temperatures in areas of 100 to 250°C. The drying and the degassing process doe not require any oxidation agent. It is only dependent on the supplied heat. The next process step is the **Gasification**. This is the conversion of solid organic matter to gaseous products. This process occurs mainly in a temperature range of 500 to 600^0 C. In addition to the temperature, water steam and oxygen support this reaction. Finally the actual **incineration** of combustible gases will take place which had been created in the previous processes via the fuel and the atmospheric oxygen. Depending on the selected incineration method. Adiabatic [1] waste gas temperatures of up to 1450^0 C are created.

A space and time separation of above described processes during waste incineration is only possible to a limited extent. The processes occur parallel in part and influence each other. Nevertheless the possibility of an influence on the incineration quality and a minimization of the toxic agents which are either formed during or remain after the incineration through furnace-technical measures , such as incineration air duct, furnace chamber design and control engineering.

Incineration creates mainly CO_2. In addition, excess gases such as water steam, nitrogen and oxygen are released which had been added with the fuel and the incineration air but which had not been converted during the incineration process. Small amounts of CO, HCl, NO_x, PCDD/PCDF, PCB and heavy metal compounds among others are formed or remain during the incineration which are also present in the waste gas as well as flying dust attached to the waste gas. As mineral residue flying dust and ash is created, whereby ash is reduced to approximately 10 percent volume and approximately 30 percent of the solid waste, not taking the waste gas cleaning products and the small pat s of flying dust.

A sufficient air supply is essential for the gaseous and material incineration quality. The so-called air ratio number "n" as quotient of the supplied incineration air amount to the

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[1] Without heat exchange

stochiometric incineration air amount lies between n = 1.5 to 3.0 depending on the different furnace systems.

The incineration should not be seen as an independent element in the thermal waste treatment. It should always be optimized in connection with the individual elements of total process engineering, in order to ensure the highest degree of environmental compatibility and economic efficiency (see Table 1).

Targets	**Responsibility of**
• Destruction of organic basic substance • Destruction of organic toxic agents • Production of exploitable slag • Volume minimization of residues	Furnace
• Upgrade of inorganic toxic agents in small residue amounts (filter dust, sludge from wastewater treatment) which are removed from the ecological system and safely deposited.	Gas cleaning
• Recovery of useable energy from organic basic substance	Heat de-coupling

Table 1: Incineration purpose

1.4 Overview of the Waste Incineration in the European Union and joining Countries

Approximately 200 million mg accumulate annually in the member states of the European Union where incineration could be considered as a method in waste treatment. Table 2 on the next page shows an estimate of the percentile share of the waste that could be combusted or deposited in addition of the actual available amounts in the member states for municipal waste, hazardous waste and sewage sludge. The column of deposited waste was included as a considerable part of those wastes could be shifted in the future to other waste treatment methods, including incineration.

Country	Total estimated MSW-production (in 10^6 Mg)	Year of data source	% landfilled	% incinerated	Total estimated HW-production (in 10^6 Mg)	Year of data source	Amount landfilled in (in 10^6 Mg)	amount incinerated (in 10^6 Mg)	Total estimated SS-production (in 10^6 Mg)	Year of data source
Austria	2,78	1996	32	16	0,76	1996		0,11		
Belgium	4,85	1997	42	35	2,03	1997	0,79	0,14	0,85	1997
Denmark	2,77	1996	15	56	0,27	1996	0,09	0,1	0,15	1997
Finland	0,98	1997	77	2	0,57	1997	0,28	0,1	0,14	1997
France	26,00	1997	60	30	5,9	1997	3	1,3[2]	0,82	1997
Germany	41,20	1999	34	28	9,17	1997	2,7	1,4	2,70	1999
Greece	3,20	1993	93	0		1993				
Ireland	1,80	1998	100	0	0,23	1995	0,03	0,03	0,39	1997
Italy	25,40	1995	85	8		1995				
Luxembourg	0,30	1995	24	48	0,14	1995				
Portugal	3,48	1999	65	25	0,9	1996			0,25	1998
Spain	14,30	1997	85	8		1997				
Sweden	3,80	1999[3]	24	38	0,5	1996		0,1	0,23	1997
Netherlands	7,95	1997	20	62[4]	1,27	1997	0,25	0,31		
United Kingdom	27,20	1999	85	6	2,37	1996	0,86	0,24	1,2	1999[5]
European Union	164,51		71	18	23,21		8	3,36	6,26	

Table 2**:** Amounts of municipal waste (MSW), hazardous waste (HW) and sewage sludge (SS) in Europe and their treatment[6]

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[2] The figure includes about 300 000 Mg of co-incineration in cimentkilns and includes plants for incineration of waste oils and plants for evapo-incineration (where only the organic fraction is incinerated).

[3] Swedish Waste Management 2000 (RVF)

[4]-The percentages for the Netherlands have been corrected compared with the statistica data provided by EU, as those where obviously wrong

[5] ENDS Report 312 January 2001 (figures include co-incineration (50%/50%)

[6]The difference to 100% for the treatment methodologies is e.g. due to recovery and recycling

According to a recent study, the following waste amounts are accumulated in the countries joining the European Union:

Country	Year	Municipal Waste in Mg/Year	Hazardous Waste in Mg/Year
Bulgaria	1998	3.199.000	548.000
Czech. Republic	1999	4.199.000	3.011.000
Estonia	1999	569.000	5.865.000
Hungary	1998	5.000.000	3.915.000
Latvia	1998	597.000	41.100
Lithuania	1999	1.211.000	244.900
Poland	1999	12.317.000	1.340.000
Romania	1999	7.631.000	2.323.000
Slovak. Republic	1999	3.721.000	1.737.600
Slovenia	1995	1.024.000	25.000

Table 3: Annual Accumulation of Municipal Waste and hazardous waste in joining Countries

A number of guidelines govern the waste treatment in the European Union. An essential guideline is 75/442/EWG [17], which includes the following hierarchy for the handling of waste:

- Avoidance
- Re-use as well as material and energetic utilization
- Removal

Within this hierarchy waste incineration is utilized for energetic utilization as well as for waste removal. The heat produced during the incineration is used in the majority of incineration plants. There are isolated cases of plants not utilizing the heat. Heat utilization is prescribed in Guideline 2000/76/EU that took effect on 12/28/2000.

1.5 Geographic Distribution of Waste Incineration Plants in Europe

Waste incineration has a very differentiated tradition in the individual member states of the European Union leading to a network of waste incineration plants with different density depending on the individual member states. As we have shown in the previous chapter, the share of incinerations in waste treatments ranges from zero to 69 percent in the member states.

The following Table 4 shows how many incineration plants exist in the member states for the different waste types and their total capacity. In addition, concrete planning exists for numerous other locations that have not been included here.

Country	Total number of MSW-incinerators	Capacity	Total number of HW-incinerators	Capacity	Total number of sewage sludge-incinerators	Capacity
Austria	3	0,5	1	0,1		
Belgium	18	2,5	1	0,1		
Denmark	34	3,82	1	0,1		
Finland	1	0,07	1	0,1		
France	258[7]	13,3	14?	1,0		
Germany	61	13,9	35[8]	1,5	14	
Greece	0		0			
Ireland	0		6?	0,03?		
Italy	32	1,71	6?	0,1?		
Luxembourg	1	0,15	0			
Portugal	3	0,9	0			
Spain	9	1,13	1	0,03		
Sweden	22	1,9	1	0,1		
Netherlands	11	5,7	1			
United Kingdom	17	2,71	3	0,12		
European Union	362	44,49	45	2,25	14	

Table 4: Geographical distribution of incineration plants for municipal – and hazardous waste and sewage sludge

According to a recent study [13] the following number of waste incinerator plants exist in the joining countries. Data on the total capacities apparently have not been determined.

Country	Total number of MS-incinerators	MS-incinerators (> 3t/h)	Total number of HW-incinerators	HW-incinerators (>10t/d)
Bulgaria	0	0	0	0
Czech Republic	3	3	72	14
Estonia	0	0	1	0
Hungary	1	1	7	?
Latvia	0	0	0	0
Lithuania	0	0	0	0
Poland	4	1	13	4
Romania	0	0	3	3
Slovak Republic	2	2	?	1
Slovenia	0	0	0	0

Table 5: Incinerator Plants for municipal Waste and hazardous Waste in joining Countries

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[7] Among those are 76 plants with a capacity >6t/h representing about 75% of the total capacity.

[8] figure includes sites of chemical industry.

1.6 Economic Situation of Waste Incineration

Municipal regional administrative bodies as well as private firms own incineration plants in Germany. In the last few years more often-mixed corporation forms can be found. Waste incineration plants can produce current, steam, heat and other products, such as HCl. The proceeds from current and heat production reduce the costs of heat production. The amount of this costs depends very much on the differing promotion of current and heat production in the individual member states. Competition and other disposal methods (landfills, fuel production, etc.) as well as investment cost and operational expenses have a decisive role on the acceptance fees to the waste disposal plants.

The **capital investment costs for incineration plants for municipal plants** in Germany (grate furnace) are dependent on the plant size and the expenditure in plants with grate furnaces for the waste gas cleaning and residue treatment in the following dimensions:

Type of Waste Gas Cleaning	Specific Investment Costs in [DM/Mg Waste]			
	100.000 [Mg/a]	200.000 [Mg/a]	300.000 [Mg/a]	600.000 [Mg/a]
Dry	1.340	1.064	883	694
Dry/wet	1.489	1.192	1001	787
Dry/wet with Residue Processing	1.804	1.402	1.173	914

Table 6: Specific Investment Costs depending on Annual Capacity and Type of Waste Gas Cleaning

The **incineration costs**, meaning the remuneration (fees, prices) for the acceptance of municipal wastes in incineration plants in Germany in 2000 were between DM 180.00 and DM 700.00. In the following Table 7 examples as of 1999 for municipal waste and hazardous waste incineration plants (always new plants) are shown as average values of the specific incineration costs. It becomes obvious that the specific costs for the incineration are determined essentially by the capital service and, therefore, by the investment costs and the plant capacity. Significant cost changes can occur and depend on the set-up such as depreciation period, interest costs, etc. Plant utilization can also have a significant influence on the incineration costs.

Cost Structure	Incineration Plant for	
	Municipal Waste with a Capacity of 250,000 Mg/a in [10^6 DM]	Hazardous Waste with a Capacity of 70,000 Mg/a in [10^6 DM]
• Planning/Approval	7	12
• Machine Part	140	65
• Component	56	55
• E-/MSR	35	40
• Infrastructure	28	25
• Construction Time	14	13
Total Investment Costs	280	210
Incineration Costs		
• Capital Cost	28	21
• Personal	8	11
• Maintenance	6	8
• Administration	1	1
• Operating Resources/Energy	6	5
• Waste Disposal	7	3
• Other	2	1
Total Incineration Costs	58	50
Specific Incineration Costs (without Proceeds)	ca. 230 DM/Mg	ca. 700 DM/Mg

Table 7: Compilation of individual Cost Elements for Waste Incineration Plants

In addition, there are significant differences among the member states due to various emission requirements, salary costs and depreciation periods, etc. These differences will be reduced significantly within the next few years, as the member states must adhere to Guideline 2000/76/EG within two years. The listed acceptance fees in the following tables 8 and 9 are only comparable to a limited extent for above named reasons.

Member State	Acceptance Fees in €/t incineration plants	
	Municipal Waste	Hazardous Waste
Belgium	90-130	100-1500
Denmark	40-70	100-1500
France	50-120	100-1500
Germany	100-350	50-1500
Italy	40-80	100-1000
Netherlands	90-180	50-5000
Sweden	20-50	
United Kingdom	20-40	N/A

Table 8: Acceptance Fees in European Waste Incineration Plants

1.7 Important Environmental Influences of Waste Incineration

Table 9 describes the typical composition of municipal waste, hazardous waste and sewage sludge. The following waste groups are included in municipal wastes:

→Municipal waste
→Bulky refuse
→Garden, market and parking space garbage
→Non-hazardous waste from commerce and industry
→Construction and demolition waste

All wastes classified as hazardous under Guideline 91/689/EWG [18] are hazardous wastes. The current directory can be found in Commission Decision 2001/118/EU [19] which serves for example as basis for the above mentioned Guideline. Sewage sludge includes sludge from wastewater treatment of communities and industries.

Parameter	Municipal Waste	Hazardous Waste	Sewage Sludge
Calorific Value (Hu) (kJ/kg)	8000-12000	1000-42000	1000-14000
Water (%)	25-40	0-100	3-80
Ash	20-35	0-100	25-60
Carbon (% TS)	18-35	5-99	20-35
Hydrogen (% TS)	4-5	1-20	2-5
Nitrogen (% TS)	1-2	0-15	1-4
Oxygen (% TS)			10-20
Sulfur (% TS)	~ 0,2		
Fluor (%TS)	0,1-0,25	0-50	0,1-1
Chlorine (% TS)	0,1-1	0-80	0,05-4
Bromine (%TS)		0-80	No Data
Iodine (%TS)		0-50	No Data.
Lead (mg/kg TS)	100-2000	0-200 000	4-1000
Cadmium (mg/kg TS)	1-150	0-10 000	0,1-50
Copper (mg/kg TS)	200-700		10-1800
Zinc (mg/kg TS)	400-1400		10-5700
Mercury (mg/kg TS)	1-50	0-40 000	0,05-10
Thallium (mg/kg TS)			0,1-5
Manganese (mg/kg TS)			300-1800
Vanadium (mg/kg TS)			10-150
Nickel (mg/kg TS)	~ 30		3-500
Cobalt (mg/kg TS)			8-35
Arsenic (mg/kg TS)	~ 5		1-35
Chrome (mg/kg TS)	≤ 200		1-800
Selenium (mg/kg TS)			0,1-8
PCB (mg/kgTS)	0,2 –0,4	Up to 60 %	0,01-0,13
PCDD/PCDF (ng I-TE/kg)[9]	50 –250	10-10000	8,5-73

Table 9: Typical Composition Ingredients of Waste in Germany[10]

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[9] I-TE: International Toxicity equivalent

[10] Table was compiled in the basis of numerous bibliographical data. It lists Typical ingredients for municipal waste and possible ingredients for hazardous waste.

1.7.1 Emissions into the Air

During waste incineration waste gases are created which depended on the process but contain in addition to CO_2 and H_20 also for example CO , SO_2, NOx, dust, HCl, heavy metals and PCDD/PCDF. The amount of these emissions which is extrinsic to air should be reduced as much as possible through appropriate measures. Applicable processes are described in detail in Chapter 4.

In Germany, specific emission requirements for waste combustion plants were first determined in the Technical Instructions for Air Pollution Abatement (TA air) of 1974 (replaced) and 1986 [24]. These include, in particular, requirements for the furnace (minimum temperature, minimum residence time, minimum oxygen content) and the determination of limit for numerous toxic agents relevant to the environment. For the operators of plants, these limits became binding with the granting of a licence. Both regulations contained transitional regulations for old plants valid for a limited period.

With the entry into force of the Ordinance on Combustion Plants for Waste and Similar Cumbustible Materials – 17. BImSchV [22] – in the year 1990, the requirements of the TA air of 1986 for waste combustion plants became generally legally binding as emission limits, certain requirements were formulated more precisely, and most emission limits were set in a clearly stricter way with view of the state of waste gas cleaning technology. for dioxins/furan, an emission limit of 0.1 I-TE/m^3 was determined. Old plants had to comply with the requirements of the ordinance by 1996 at the latest. Besides, in the 17. BImSchV, the co-combustion of waste in combustion plants other than those for waste was first regu-lated. With the ammendment of the 17. BImSchG as of 23/02/1999, the Council guideline of 16/12/1994 on hazardous waste combustion was implemented into German law. Furthermore, the continuous measuring of mercury emissions was required.

In the new European Directive 2000/76/EG for the incineration and co-incineration of waste limit requirements of emissions are described. The following table 10 offers an overview on the listed half hourly and daily average values. Stricter requirements are valid for mercury in Germany (daily average value 0.03 mg/m^3, half-hourly value 0.05 mg/m^3, and continuous measurements).

Parameter	Continuous Measurements (k) or Measurement twice a Year (d)	Half-hourly average value (mg/m^3)	Daily average value (mg/m^3)
Dust	k	20	10
HCl	k	60	10
HF	(k)	4	1
SO2	k	200	50
NOx	k	400	200
TOC	k	20	10
CO	k	100	50
PCDD/PCDF (ng I-TE/m^3)	d		0,1
Hg	d		0,05
Cd + Tl	d		0,05
Other heavy Metals	d		0,5

Table 10: Half-hourly and daily mean limits for Air Emission according to Guideline 2000/76/EG

Waste gas emissions of all waste incineration plants and their share of total emissions can be seen in the example of Germany on Table 11. With a share of 6 percent mercury still has the highest percentage, while the share of the much-discussed polychlorinated dioxins and furans lie below 1 percent. We assume that the ratios are similar in Austria and in France, as they have comparable low limits. The shares of dioxin and mercury could be significantly higher in other European countries especially in those with a higher share of older plants where such low limits are not valid yet. For all other emissions the share of waste incineration versus the total emissions is generally very low.

Parameter	Total emissions in Germany 1999 Mg/a	Total emissions from waste incineration 2000 Mg/a[11]	Share of Emissions from Waste incineration in %
Dust	259 000	375	0,145
NOx (as NO$_2$)	1 637 000	7 500	0,458
SO$_2$	831 000	1 875	0,225
CO	4 952 000	1 875	0,0038
TOC	1 651 000	375	00226
NH$_3$	624 000	375	0,06
Hg*	31	1,875	6
Cd*	11	0,024	0,22
Pb*	624	0,12	0,019
Cr*	115		
PCDD/PCDF	approx. 67 g I-TE	< 0,5 g I-TE	0,75

* 1995

Table 11: Emissions from Waste Incineration compared with all Emissions for Germany

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[11] Values were estimated using current incineration capacity (15 Mio t/year) and based on half of the permitted emission limit. As the actual emissions on average are much lower with the exception of NOx, ist the share of the waste incineration most likely significantly lower.

The following Table 12 shows as an example the development of emissions of a municipal waste incineration from 1989 to 2000.[12]

	89	90	91	92	93	94	95	96	97	98	99	00
SO2	65	61	46,4	34,4	25,4	36,9	5,0	4,5	6	<4	<2	<2
HCl	52	50	21,8	22,4	22,7	26,7	0,3	0,5	0,4	<0,2	0,1	0,1
Dust	44	44	40	25,7	27	20,6	1,3	0,9	0,9	<1,5	<1,3	<1,1
NH3	-	-	-	-	-	-	-	<0,32	<0,1	<0,1	<0,1	<0,1
HF	0,3	-	<0,2	<0,26	<0,28	<0,41	0,07	<0,04	<0,02	<0,03	<0,02	<0,02
NOx	-	-	186	209	246	335	56	71	73	<83	<80	<80
Cges	-	-	5,3	3,6	3,5	3,4	2,3	1,3	1,3	<1,8	<1,5	<1,4
CO	80	-	87,6	68,9	50,5	58,5	48	37	<23	<25	<23	<20
Hg	<0,1	-	-	-	-	-	0,007	<0,004	<0,005	<0,011	<0,003	<0,003
Cd+Tl	<0,18	-	-	-	-	-	0,003	<0,011	<0,0002	<0,0002	<0,0003	<0,0002
others	<0,9	-	-	-	-	-	0,24	<0,058	<0,0007	<0,0002	<0,0004	<0,0003
PCDD /PCDF	14,9	-	0,46–6,47	1,1 –8,0	2,3-2,8	5,65-14,5	0,006	<0,004	<0,0031	<0,0015	<0,00036	<0,0009

Units: mg/m^3 or. ng I-TE/m^3 (PCDD/PCDF)

Table 12: Development of Emissions (annual average values) of an Incineration Plant for municipal waste from 1989 to 2000

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[12] Emission Report of MKVA Krefeld for 2000. The emission limits were changed (reduced) each year for 1990, 1991, 1995 and 2000 (only Hg).

1.7.2 Emissions into the Water

In dependence of the applied waste gas cleaning technology (compare Chapter 4), the waste incineration plants also divert emissions via wastewater. Incineration plants for municipal waste in Germany almost exclusively operate without wastewater. Special emission limits are prescribed in Guideline 2000/76/EG for the drainage of wastewater from waste gas cleaning and are shown in the following Table 13.

Polluting Substances	Emission Limit expressed in Mass Concentration for unfiltered Samples	
1. Suspended solid matter total according to Guideline 91/271/EWG	95 % 30 mg/l	100 % 45 mg/l
2. Mercury and mercury compounds, measured as mercury (HG)	0,03 mg/l (0,05)[1]	
3. Cadmium and cadmium compounds, measured as cadmium (Cd)	0,05 mg/l (0,05) [1]	
4. Thallium and thallium compounds, measures as thallium (Tl)	0,05 mg/l	
5. Arsenic and arsenic compounds measured as arsenic (As)	0,15 mg/l	
6. Lead and lead compounds measured as lead (Pb)	0,2 mg/l (0,1) [1]	
7. Chrome and chrome compounds measured as chrome (Cr)	0,5 mg/l (0,5) [1]	
8. Copper and copper compounds measured as copper (Cu)	0,5 mg/l (0,5) [1]	
9. Nickel and nickel compounds measured as nickel (Ni)	0,5 mg/l (0,5) [1]	
10. Zinc and zinc compounds measured as zinc (Zn)	1,5 mg/l (1,0) [1]	
11. Sulfid	(0,2)[1]	
12. Dioxin and furan, defined as total of individual dioxin and furan calculated according to Appendix I	0,3 ng/l	

[1] Requirements according to Appendix 47, German Waste water Ordinance [26]

Table 13: Emission Limit for Drainage of Waste Water from Waste Gas Cleaning according to Appendix V of Guideline 2000/76/EG

1.7.3 Emissions into the Ground

Waste incineration plants are constructed on sealed floors and operated in such a way that the entry of toxic agents in the immediate vicinity can be excluded. Entries into the ground outside of this area via the air have been considered in the determination of air emission limits in Guideline 2000/76/EG to avoid the contamination of the ground or to prevent the relocation of the contamination.

1.7.4 Wastes and By-Products from the Waste Incineration

The following waste among others are produced during the incineration process:

- Ashes and slag
- Boiler ashes
- Filter dust
- Other residues from the waste gas cleaning
- Sludge from waste water treatment

The following by-products, besides others could accumulate:

- Plaster
- Hydrochloric acid
- Sodium carbonate

A detailed description of these wastes and by-products can be found in Chapter 3.6.

1.7.5 Noise Emission

Noise emissions during the waste incineration can come from the following areas:

- Turbines
- Suction drafts
- Boiler(cleaning)
- Air cooler
- Delivery Traffic
- Bunker

TA Noise Limits are valid in Germany depending on the location. The individual areas will be explained in detail in Chapter 3.8.

1.7.6 Heat Utilization

In principle, waste incineration plants are operated in Germany with energy-recovery features based on legal regulations, with the exception of certain plants in the industrial area. The released heat will normally be used for process steam or power generation, which aids in the conservation of resources. In contrast, Italy, France, and Great Britain operate plants without heat utilization.

The released energy from the waste incineration in the form of hot waste gasses should be used as much as possible for ecological and economic reasons. As a rule, the steam that is generated can be used for the following purposes:

→ Power generation
→ Utilization of available heat (process steam, thermal value)
→ Utilization of electricity and available heat (power and heat coupling)

Primary energy carriers, such as coal, oil and gas, are saved through the incineration of trash. Plant efficiency or the fuel utilization factor (in power and heat coupling) determines how much fossil fuel can be substituted for waste.

The plant efficiency factor or fuel utilization factor is the quotient of utilization to expenditure. The definitions of utilization and expenditure depend, however, on the observed system. As a rule, electrical power or the transferred heat are seen as utilization, while expenditure is seen as fuel energy power, meaning the product derived fuel mass power and heat value.

The utilization degree depends significantly on the process-technical and location-dependent options for energy release and utilization. Under favorable local conditions, a municipal waste incineration plant in Germany can achieve a base load operation in the generation of steam, power, and warm water, or in exclusive steam release, a gross utilization quotient of up to 76 percent (without a deduction for its own use). The gross utilization quotient in exclusive power generation lies in the range of 10 – 25 percent, at most. The reason for the lower energy exploitation in comparison to power plants or other industrial thermal processors can be seen in the lower steam parameters (pressure, temperature). The location selection for a thermal waste treatment plant therefore plays an important role in addition to regional planning or logistical considerations (proximity to the waste producer) and to the aspects of the highest possible energy utilization through the release of power, steam and/or heat to the client who is located close to the plant. The emissions released from those plants should play no role in the selection of their location, as they are now so low that no hazard exits for the population or environment.

Based on the composition of the waste as fuel, corrosions, such as chloride corrosion, can occur in the area of the steam generator, as the corrosion rates increase exponentially depending on rising pipe wall temperatures. The following hot steam parameters have proven practical under business economic considerations:

- Municipal waste incineration plants: 40 bar at 400° C
- Hazardous waste incineration plants: 32 bar at 320° C.

In addition to the substitution, the biomass share present in the waste should be considered a measurement of reducing CO_2. Climate-relevant carbon dioxide will be released into the atmosphere during incineration but, in its totality, this process is CO_2-neutral, as only as much CO_2 is released as has been used by the biomass. As municipal waste is a heterogeneous mixture of wastes, a differentiation is made in the incineration plants between carbon biogen and fossil origin in the source of CO_2. In the literature, a share of CO_2 that is attributed to fossil origin (i.e., plastics) and can be seen as climate-relevant, is given at 33 – 50 percent.

2 GENERAL PRINCIPLES OF WASTE (CO-INCINERATION) INCINERATION

2.1 History of Municipal Waste Incineration

To be exact, waste incineration is as old as time, when Mankind learned how to handle fire. Archeological findings can be traced back 750,000 years. It has been said that released heat has been used to keep warm. Waste incineration has been passed down from the beginning of recorded history.

In the Middle Ages, the first mobile incineration carts were wooden vehicles protected with a clay bed. They were pulled through the streets by horses and the citizens threw their trash into the moving “bonfire.“

The dearth of appropriate containers and disposal systems, as well as health and plague problems such as the ever-present cholera, led to considerations of hygiene and trash reduction at the end of the 19th century. Thus the age of “technical“ incineration began. It all started with a plant in Nottingham, which was also dubbed the “destructor. “ After gaining experience with the introduction of trash incineration in Manchester in 1876, discussions also started in Germany. After initial challenges, incineration proved itself leading to the construction of more than 210 plants in England at the beginning of the 20th century, of which 14 were operated in London alone. These plants had very few technical standards. They stank and caused inflammation of the eyes and lungs. This was accepted as a necessary evil.

At that time resistance already existed to the construction of waste incineration plants in Germany. Despite this, the first waste incineration plant in Germany was built and became operational in Hamburg in 1894/95, after the last large cholera epidemic. This plant was the first “large“ incineration plant on the European continent and was based on the applied technology of the British models. This British-model plant was operational until 1920.

These first plants were designed as so-called cell furnaces, and included a fixed slotted grade, slanted forward. The waste was shoveled manually into the oven through a door and at intervals the slag was removed through the same door. The furnace was significantly cooled during waste supply, stoking, and ash removal due to this discontinuous operational method,. The cell furnaces were combined to grate series with waste gas removal on the side as a result of this experience,. The cell series equipped with slotted grades were separated by edges from the neighboring grate. This arrangement facilitated improved utilization of the radiation heat and increased the out-put. Simultaneously, a more uniform incineration chamber temperature can be reached. At the turn of the century, this construction was used in practice and very soon the steam generators were complemented with an economizer.

The first mobile grate systems were developed during the 20s and 30s in this century, such as cascade grates and sloping grates. The use of these systems, whose conceptual design differs only slightly from today‘s grate systems, made it possible to remove the slag from closed furnaces. The slag was thrown from the end of the furnace grate to a lower slag grate or a waterbed.

Parallel to the grate technology, numerous vertical kiln types were developed and used. Starting with the “Dörr“ system that was used in 1902 in the Wiesbaden incineration plant, the vertical kiln principle was further developed. Firms, such as Uhde and Lurgi, developed a concept that was used in 1930 in Hamburg in the Borsigstraße plant. The decisive progress that was achieved in the development of vertical kilns facilitated a completely automated plant system with continuous supply and ash removal. Those were the basic preconditions for modern incineration plants.

As capacities at the end of the 20s were insufficient, the construction of a new waste incineration plant was decided upon in 1927. For this project, Hamburg stipulated requirements that are easily comparable to modern conditions.. A plant that is to function economically should have a high degree of automatization and should facilitate optimal energy utilization in the form of power and heat. In September 1931, the new waste incineration plant at Borsigstraße became operational. It consisted of three vertical kilns with a capacity of 120Mg/d, enabling an output of 360Mg/d. This plant was the first to have an underground hopper where the new motorized removal carts could empty the waste. An electric grapple that served to supply the plant reloaded it into the carts.

In response to complaints coming from the region, the plant operator was required to equip the plant with the current state-of-the-art technology for cleaning waste gasses. In the years 1932 – 1935, the plant was upgraded with an electrical filter. The Hamburger Elektrizitätswerke (HEW) was responsible for power generation; and beginning in 1937, was also responsible for processing steam.

Only a few German waste incineration plants were operational between 1940 and 1950. Increased composting between 1945 and 1949, as well as the low heat value of waste, led to lower utilization, and therefore, to operational interruptions. At the beginning of the 50s, the plants in Barmen and Aachen were closed. The plants in Hamburg-Altona and in the Borsigstraße were the only remaining operational plants in Germany. The increase in the amount of waste, and the increased heat value of the waste in the 50s, did nothing to change the fact that in the 60s, Hamburg remained the only city in Germany that operated waste incineration plants. In 1959, the Borsigstraße plant received a continuously operating incineration grate and became the model for later plants.

Table 14 (below) illustrates the development of thermal municipal waste treatment plants in Germany from 1965 to the present.

Year	Number of Plants	Waste Throughput z in 1000 Mg/a	Av. Throughput per Plant in 1000 Mg/a
1965	7	718	103
1970	24	2.829	118
1975	33	4.582	139
1980	42	6.343	151
1985	46	7.877	171
1990	48	9.200	191
1992	50	9.500	190
1993	49	9.420	192
1995	52	10.870	202
2000	60	13.900	230
2005*	75	17.600	234

*including scheduled plants and those in an advanced stage of planning

Table 14: Development of municipal thermal waste treatment plants in Germany

2.2 History of Hazardous Waste Incineration

The history of hazardous waste incineration is described using the example of a firm in the chemical industry. An increase in the amount of organic chemicals used in the production process led to a higher accumulation of hazardous organic wastes. These were at first discarded above ground, as were inorganic wastes.

Starting in 1950, some of the major firms were considering the incineration of those waste products. In 1956, BASF AG in Ludwigshafen erected a vertical kiln for the disposal of fluid and pasty residues. The operation continued until 1970. Parallel to that, the firm commenced the operation of a grate furnace plant utilizing heat for the disposal of industrial wastes. Starting in 1961, a part of Ludwigshafen‘s municipal waste was also burned there.

The heavy increase of fluid, pasty, and solid wastes with high heat values soon demonstrated the limitations of vertical kiln and grate furnace technology. This led to the development of drum-type kiln technology and after-burner chambers positioned in sequence, today‘s prevalent technology for hazardous waste incineration. By 1964, BASF AG commenced operation of the first drum-type kilns and constructed additional plants using this technology.

The first drum-type kiln for hazardous waste outside the chemical industry was constructed in Niederkassel-Ranzel in 1966, based on a drum-type kiln in a tar-mixer plant. At the beginning of the 70s, additional publicly-owned hazardous waste incineration plants followed. A series of incineration plants were built for old oil using incineration chambers.

Wastes containing high chloride and other hazardous materials were incinerated in incineration chambers on ships at sea between 1970 and 1990. The development of new technologies led to the end of such practices at sea in Germany in 1988, for which environmental associations such as Greenpeace had fought.

Year	Number of Plant Locations	Number of Incineration Units	Installed Incineration Capacity in 1000 Mg/a
1965	3	4	68
1970	10	15	222
1975	13	22	382
1980	21	34	620
1985	23	38	740
1990	30	51	1.010
1993	30	52	1.044
1995	32	55	1.120
2001	31	52	1.230

Table 15: Development of hazardous waste incineration plants in Germany

2.3 History of Sewage Sludge Incineration

Incineration of sewage sludge has a decades‘long tradition. In principle, the same technologies can be applied as in the incineration of municipal waste, whereby in practice incineration occurs in fluidized bed plants. The prohibition of dumping sewage sludge into the North Sea lead to an increase of sewage sludge incineration in Germany during the 70s after the first sewage sludge incineration plant was put into operation in 1962.

The thermal treatment of sewage sludge had begun by 1880 when the accumulated sewage sludge was incinerated in a purification plant in Salford, England in six incineration furnaces that were constructed in a fashion similar to that of line burners. These furnaces, which were also heated with coal, were in operation until 1883.

In 1951, mono-sewage sludge incineration occurred in Europe for the first time in an incineration plant that was operated in the vicinity of the Maple Lodge purification plant in England. The control of the plant facilitated an exclusive method of drying sewage sludge, as well as drying and incinerating sewage sludge, which could occur separately from each other.

Starting from 1968 Sheffield operated two multiple hearth furnaces where drying and incinerating of sewage sludge could take place. The sludge was distributed over nine floors and was moved from the top to the bottom. Furnace air and waste gases flowed in the opposite direction. The sewage sludge incineration was supported by the addition of heating oil. Additional British towns joined the development and constructed double-deck furnaces or rotary grate cyclone furnaces. The latter was a typical construction technology that was mainly unknown in the rest of Europe.

The first double-deck furnace was operated in 1934 in Dearborn, Michigan, and had the option to be operated as a rack dryer. Another representative of progressive sewage sludge incinerator plants was introduced in 1962 in Lynnwood, Washington, - a sewage sludge plant using the fluidized bed technology. It was called “Fluidized Bed Incineration“ in the U.S. This technology had been developed already in 1919 by Fritz Winkler, a chemist at BASF in Ludwigshaven and had been applied initially in the gassing of dietary fiber lignite (“ Winkler Generator“). The fluidized bed technology as an intensive mixing of particles and a fast and complete heat exchange takes place in a fluidized bed.

Parallel to the development of fluidized bed furnaces , wet oxidation was utilized starting from 1961, the first one in Wheeling, West Virginia (USA). The term “wet oxidation“ is the oxidation of mostly organic, sometimes biologically resistant substances in a fluid phase. In contrast to the high temperature incineration, this reaction occurs without any flames. The organic material is transformed with air, oxygen or other means of oxidation such as lead hydroxide to carbon dioxide and low molecular particles in temperatures up to 400 °C, in exceptions up to 600 °C, and pressures up to 250 bar.

Waste incineration plants played an important role already in 1876 and supplied pumps and purification plants with necessary steam. This development included the option of co-incineration of sewage sludge, practiced primarily from 1883 in a newly erected waste incineration plant in Ealing, near London. Sewage sludge and waste was mixed before the incineration in a ratio of 1 : 2 and pre-dryed. The drainage occurred with a filter press from 1902 on until the closing of the plant in 1935. Comparable processes were characteristic for the operation of other waste incineration plants, that were built around the turn of the century.

A characteristic in the area of co-incineration of waste and sewage sludge represents the plant in Altrincham, built in the 70‘s. Here, liquid sludge is injected into the incineration chamber and finely distributed so that the sludge water almost evaporates while the organic dry mass is combusted at the same time.. The utilization of the released excessive heat energy that can be used for the pre-drying process of the sludge and that limits the supply of natural not-again growing fuels could be seen as an advantage of the co-incineration of waste and sewage sludge.

Co-incineration in a double-deck furnace was implemented for the first time in the 60‘s. The crushing of the waste and the drainage of the sewage sludge via a centrifuge to water content of 75 percent were presupposed. Different material flows were supplied via different levels to the furnace. The process failed due to the problem of smell annoyance.

Increasingly the homogenization of waste and drained sewage sludge before the incineration through a mixing and crushing process or the fine dust injection of pre-dryed sewage sludge directly into the incineration chamber is a recognized process. Today the thermal treatment of sewage sludge is performed almost exclusively in mono-sewage sludge incineration plants. Considering the type of the heat transfer to the sewage sludge, the drying processes are divided into:

- Direct drying in convection dryer (vaporization dryer)
- Indirect drying in contact dryer (evaporation dryer)
- Radiation dryer (electromagnetic radiation or infrared radiation)

In Germany the preconditions for the sewage sludge incineration had been created by the progressive development in the area of wastewater purification. One experimented with the addition of chemicals and carbon powder to the wastewater with the target, to improve the cleansing performance. The result showed that the addition of ground lignite helped in the formation of flocks but also helped the following sludge treatment (“Carbon Mash Process according to Degener-Rothe). This technology was mainly applied in the Berlin area. The accumulated sludge was detained with the help of filter presses, air-dryed (60 percent water content) and then incinerated. As an example the town Köpenick provided its sludge for incineration in an electrical power plant starting in 1907.

The incineration of sewage sludge was practice into the 30‘s but was continued after WW II only in 1957. Incineration plants for communal sewage sludge in the form of double-deck furnaces (counterflow and directional flow) were widely used in the 60‘s but have been converted during the past years into fluidized bed furnaces.

The Federal Office of Statistics has calculated the sewage sludge accumulation (given in mass dry substance m_T) from a total of 10,337 purification plants that operated in Germany in 1998 as approximately $2{,}5x10^6$ Mg m_T /a. The largest share of approx. $1{,}5x10^6$ Mg m_T (60,3 %) was recycled material (agriculture, other agricultural recycling , composting), 270,000 Mg m_T (10 %) were transferred to other purification plants for further treatment, approx. 120,000 Mg m_T (4.7 %) were intermittently stored for later use, approx. 209,000 Mg m_T (8,3 %) were placed in landfills and the remaining 400,000 Mg m_T (15.9 %) underwent a thermal treatment.

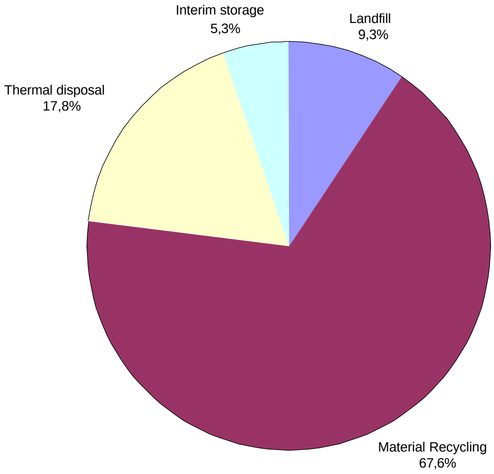


Figure 1: Shares of Sewage Sludge Disposal (minus the amount of sewage sludge transferred to other purification plants that is also recycled and registered after treatment) [2]

2.4 History of the Hospital Waste Incineration

As a consequence of the heightened requirements , especially in the area of keeping the air clean the number of hospital-owned waste incineration plants and furnace plants , where regularly wastes from hospitals and the health industry were incinerated, experienced a steady decline. In addition to TA Air 1974 and 1986 [24] the 17. BImSchV [22] in 1990 contributed to the significant decline of the numbers. This development – especially in the middle 80's - can be seen clearly from the data of the Federal Office for Statistics. The number of hospital-owned waste incineration plants and incineration plants in Germany, where wastes were co-incinerated on a regular basis declined from 554 plants in 1984 to 218 plants in 1987 and to 102 plants in 1990. According to the waste statistics of 1993 only approximately 370 Mg hospital-specific wastes were incinerated in four hospital-owned incineration plants. In 2001 no more hospital-owned incineration plants were operated. Instead, a special central hospital waste incineration plant is operated in Kiel (according to the so-called Hoval Technology). In Bielefeld and Augsburg special incineration lines for hospital waste are operated in connection with municipal waste incineration plants.

Important reasons for the plant closings are the high investment- and operational costs, resulting from the requirements to reduce emissions at incineration plants while there is a simultaneous reduction of extremely hazardous wastes making an economical plant operation impossible.

One of the very important changes in the waste disposal from hospitals occurred after the decline of the so-called own disposal in the hospitals through hospital-owned waste incineration plants or the utilization of present furnace plants for solid material. This development was accelerated by the fact that certain hospital wastes were pre-treated in the hospital (e.g. disinfected) and could, therefore, disposed of outside of the hospital, just like municipal waste. The waste amounts planned for incineration could be significantly reduced through an improved allocation of wastes from the health industry to certain waste groups and their associated disposal methods (municipal waste incineration plants, hazardous waste incineration plants, landfills).

The applied processes for the (pre) treatment of hospital wastes can be divided into different thermal disinfection processes with the appropriate incineration process or the ?? process. In the other disinfection processes a difference is made between the following two methodologies:

- Boiling with water and
- Steam disinfection

Steam disinfection is divided into

- Steam flow process and
- Fractionated vacuum process.

In addition to the already mentioned process principles for the disinfection of wastes there are other permitted special technologies, whose characteristics include limitations of the permitted wastes for treatment in addition to the operational parameter requirements. Those are mostly technologies using microwaves for heat generation and that are, therefore, dependent on a sufficiently high water/fluid content in the treated material for a safe disinfection.

In 1999 approximately 1400 Mg infectional wastes as well a organs and body parts were disposed of at the location in Augsburg. About the same amount was disposed of at the location in Bielefeld, while the plant in Kiel disposed of approximately 530 Mg.

2.5 History of Co-Incineration of Wastes and Sewage Sludge

With Regulation 17. BImSchV effective in 1990 in Germany and the Guideline 94/67/EU [20] effective in 1994 within the European Union, rules were introduced with the so-called “Ratio of Mixture Calculations“ for the co-incineration of wastes. Emission requirements for the mixed use of fuels were determined by a percentage calculation. For the share of the waste gases determined from the incineration of wastes that are related to the incinerator heat performance, the stricter requirements for the waste incineration must be applied.

The new Guideline 2000/76/EG on the incineration of wastes published in December 2000 develops this principle on a European level. According to this guideline the stricter requirements of clean waste incineration are valid in the future for a whole series of toxic airborne substances, meaning all of the waste gas flow and also for plants using co-incineration of wastes.

2.6 Incineration Technologies for Municipal Wastes

The figure (below) shows the structure of an incineration plant for municipal wastes schematically. The individual plant parts and their functions will be explained in detail below.

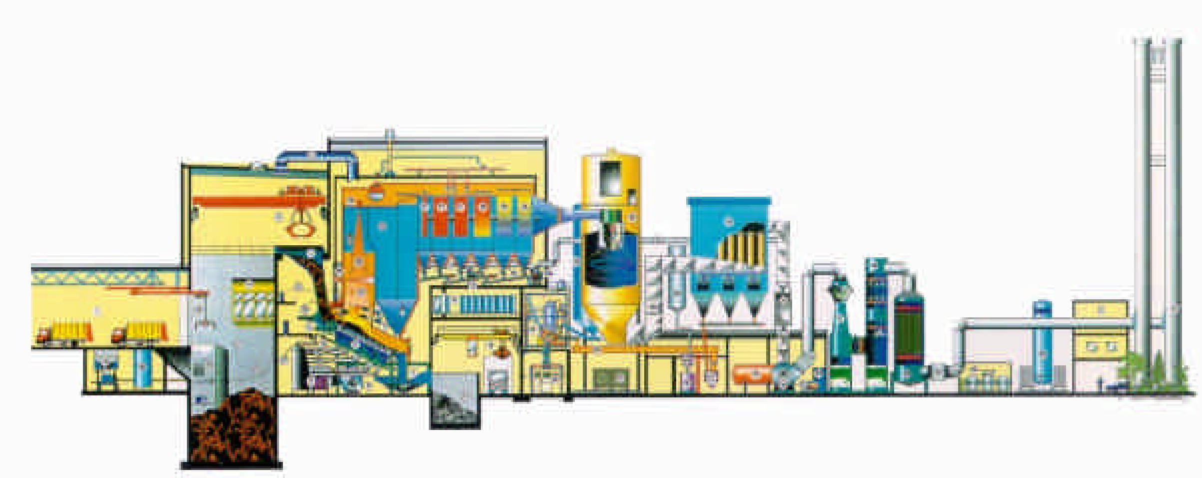


Figure 2: Principle Structure of an Incineration Plant for Municipal Wastes

2.6.1 Collection and Pretreatment outside the Incineration Plant

The portion selected for incineration is mainly that which is left over from the collection of municipal waste, as recyclable household waste is for the most part collected separately. According to the sort-yield in separate collections of those recyclable portions (glass, paper, packaging, and bio-waste), the materials described above may be contained in the remaining waste to varying degrees. In addition, there are non-recyclable sorting materials from processing plants, as well as other flammable non-hazardous waste. Hazardous waste, inert materials, and bulky waste can be initially sorted for incineration using additional organizational and technical measures.

2.6.2 Waste Pre-treatment within the Incineration Plant

In general, pre-treatment is limited to the shredding of pressed bales, bulky waste, etc. The following equipment is used for the pre-crushing of waste, which usually occurs in the bunker area (compare Chapter 2.6.3.2):

- Crocodile shears
- Shredder
- Mills
- Rotor shears.

For fire-safety reasons, the following arrangement of the individual components has proven successful:

- Separation of the dump from the storage in the bunker
- Separation of hydraulic plants (oil supply, pump- and supply equipment) from the cutting tools
- Collection devices for leaked oil
- Decompression release in the housings to reduce explosion damage.

It is always necessary to pre-treat (i.e., crush) bulky waste when its border length is greater than that of the feed equipment to the furnace. Crushing, or homogenizing, the waste facilitates more effective incineration. Additional waste pre-treatment is unusual for grate furnace plants; the waste must be crushed before incineration in a double-deck furnace (compare Chapter 2.6.4.1).

2.6.3 Waste Storage

2.6.3.1 Waste Delivery

The waste delivery area is the location where the delivery trucks arrive in order to dump the waste into the bunker. The dumping occurs through the appropriate openings between the delivery area and the bunker. This is facilitated through either direct or indirect tilting via sliding beds. These openings can be locked, and also serve as odor and seal locks, as well as crash-protecting devices.

2.6.3.2 Bunker

The bunker is usually a waterproof, concrete bed that is filled with waste. The waste is piled there with cranes equipped with grapples according to a balanced heat value, and is dumped into the filling hoppers. Very stringent requirements must be set for the bunker to comply with fire protection regulations.

The crane cabs are designed in such a way that the crane operator has a good overview of the entire bunker. The cab has its own ventilation system, independent from the bunker.

In order to avoid gas formation and excessive dust development from the fermenting processes, as well as the accumulation of odor and dust emissions in the waste bunker, the greater part of the incineration air for the furnace plants is forced out of the bunker. After any work interruption of the plant‘s incineration equipment, the bunker should be emptied.

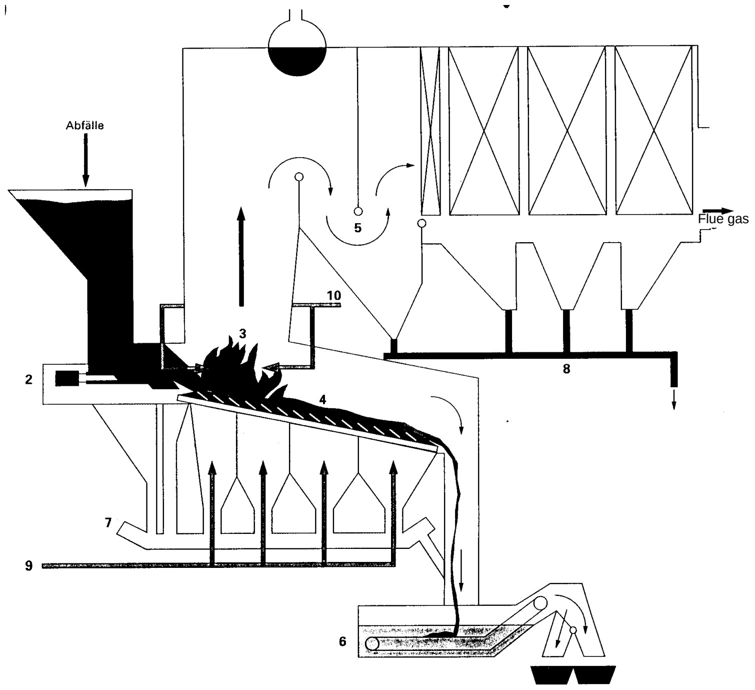
2.6.4 Furnace Systems

2.6.4.1 Grate Furnace

2.6.4.1.1 Structure

Grate furnaces essentially consist of the following components:

- Supply equipment
- Incineration grate
- Ash remover
- Incineration air duct system
- Incineration chamber
- Auxiliary burner



1 Trash delivery
2 Supply equipment
3 Incineration zone
4 Main incineration zone
5 Separator for large kernels
6 Slag purifier
7 Grate breakthrough
8 Boiler ash remover
9 Primary air supply
10 Secondary air supply

Figure 3: Grate Furnace and Heat Utilization of a Municipal Waste Incineration Plant

2.6.4.1.2 Supply systems

The filling hopper is used as a continuous waste supplier. It is filled in batches by a crane. As the filling hopper surface is exposed to great stress, materials with high friction resistance should be selected (boilerplates, wear-resistant casting iron). The material must survive occasional hopper fires unscathed.

If the delivered waste has not been crushed, it is very inhomogeneous and the kernel size varies greatly. The hopper must therefore be dimensioned in such a way that bulky materials fall through and bridge formations are avoided.

The compound aggregate between hopper and feeder (e.g., tappet or chain grate) is a supply shaft (chute). A bridge formation must be avoided in the chute, as well as in the filling hopper, as it could result in uneven feeding to the furnace due to loose waste in the chute. A backdraft could occur. The chute walls must therefore be protected from heat influences, e.g., through:

- Water-cooled double shell construction,
- Membrane wall construction,
- Water-cooled stop valves, fireproof brick lining

If the chute is empty, special stop valve equipment must be available to avoid flashbacks and for the prevention of air infiltration into the furnaces. A uniform amount of waste in the filling chute is recommended for uniform furnace management.

The junction between the lower end of the filling chute and the furnace consists of a dosing mechanism. The dosing mechanism could be driven either mechanically or hydraulically, and its feeding capacity must be completely adjustable. Different construction methods have been developed for the various types of feeder systems, such as:

- Chain grates/plate bands,
- Feed grates,
- Feed tapers.

2.6.4.1.3 Incineration Grate

The incineration grate accomplishes the following functions:

- Transport of materials to be incinerated through the furnace
- Stoking and loosening of the materials to be incinerated
- Positioning of the main incineration zone in the incineration chamber, possibly in combination with integration of the furnace performance control.

The target of incineration is distribution of the incineration air into the kiln run according to requirements. A primary air blower forces incineration air through small grate layer openings into the fuel layer.

In general, one can differentiate between continuous (roller grate, chain grate) and discontinuous feeder principles (push grates) (compare with Figure 4).

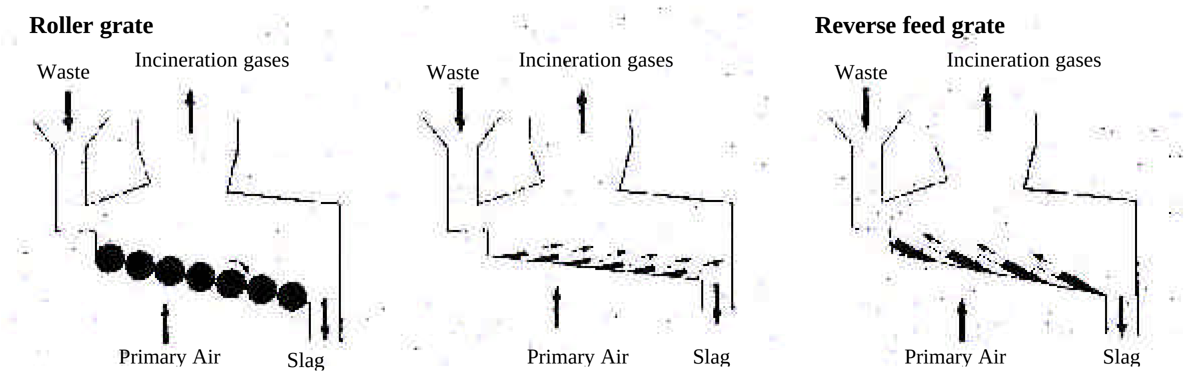


Figure 4: Different Grate Types

2.6.4.1.4 Ash Remover

The ash remover is used for removal and cooling of the accumulated solid residue at the incineration grate. It also serves as an air valve to the incineration grate and the furnace. Water-filled pressure pistons and drag constructions are primarily used. The aggregate should be used for the transport of fine kernel grate ashes, as well as for bulky objects. In addition, the air valve to the furnace must be capable of cooling and humidifying the grate ash thoroughly. The water used for cooling must be separated from the grate ash at the exit. The slack removal shaft is usually fireproof and is constructed in such a way that slag caking can be avoided.

Figure 5: Diagram of an Ash Remover

2.6.4.1.5 Incineration Chamber

The actual incineration process takes place in the incineration chamber (compare with Figure 6). The incineration chamber consists of a grate situated at the bottom, of cooled and non-cooled walls on the sides, and a ceiling or boiler surface heater is at the top. As the waste has a high volatile-ingredient content, only a small part of the incineration takes place on the grate or immediately above it.

The following requirements determine the design of the incineration chamber:

- Form and Size of the Incineration Grate → The size of the grate determines the size of the cross-section of the incineration chamber.

- Vortexing and homogeneity of waste gas flow → Complete mixing of the waste gasses is essential for good waste gas incineration.

- Sufficient residence time for the waste gasses in the hot furnace → Sufficient reaction time at high temperatures must be assured for complete incineration.
- Partial cooling of waste gasses→ In order to avoid fusion of the flying ash at the boiler, the waste gas temperature must not exceed an upper limit at the incineration chamber‘s exit.

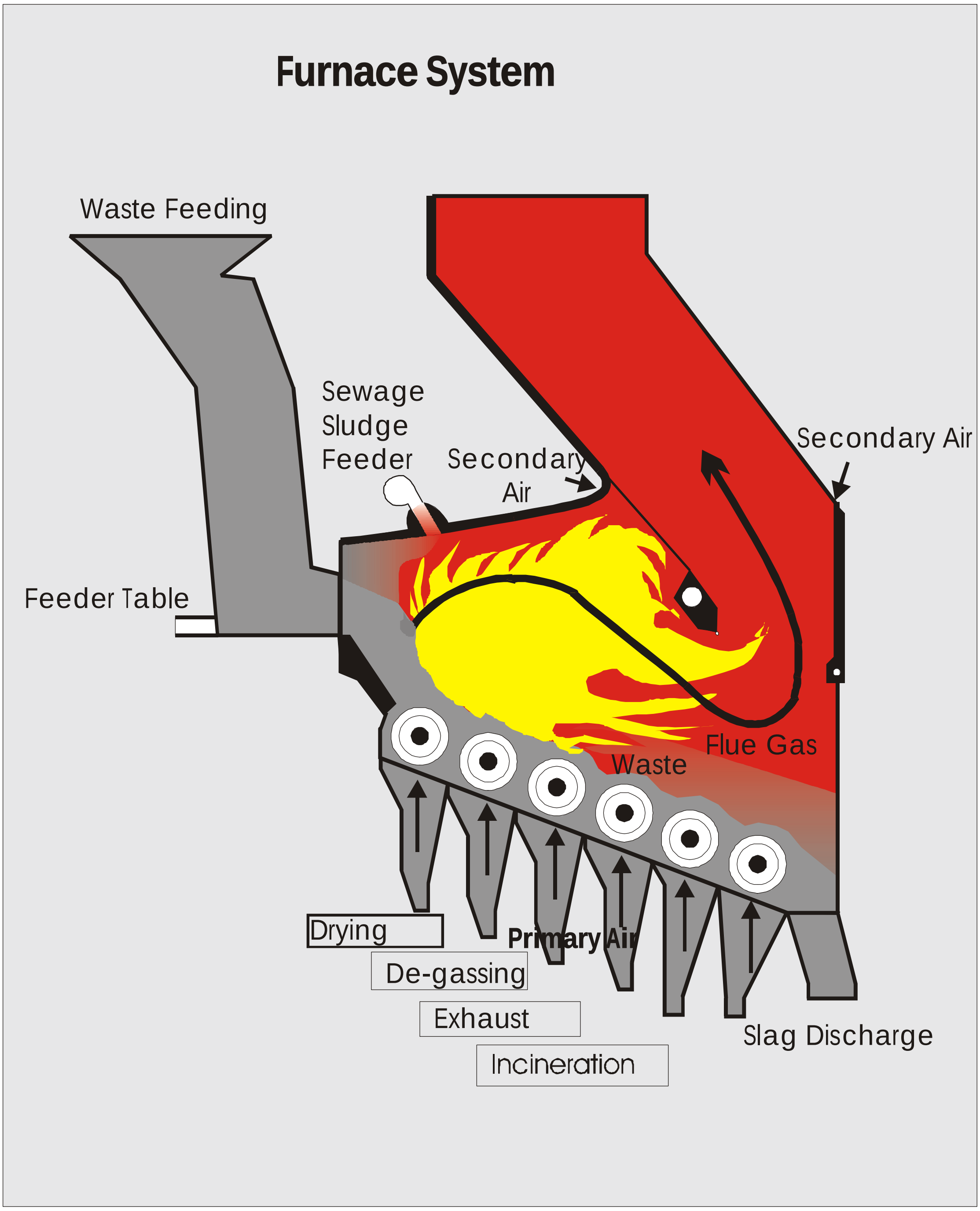
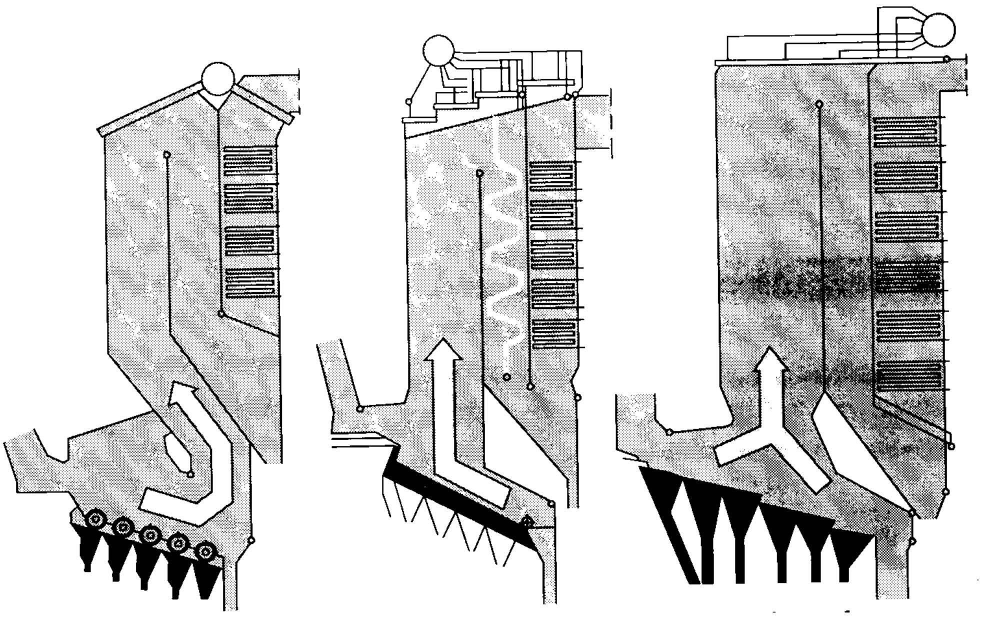


Figure 6: Diagram of a Incineration Chamber

The design of a incineration chamber demands compromises as the requirements change with the fuel characteristics. In principle, such differences are accommodated by uni-directional current, medium current, and counter-flow current (compare with Figure 7).

- The advantage of uni-directional current concepts is that the waste gas share has the longest residence time in the ignition area and that it must pass through the maximum temperature. To facilitate ignition, the primary air must be pre-warmed with very low heat values.
- Waste incineration with heat values is easily manageable using the counter-flow current concept because the hot waste gasses facilitate drying and ignition of the waste when the gasses are conducted over the ignition area in a counter-flow direction. Special attention must be paid that no strands with unburned shares reach the waste gas channel. As a rule, counter-flow current concepts require higher secondary or upper air shares.
- The medium current concept is a compromise for a wide feed value spectrum. A good mixture of all partial waste gas currents must be considered through mixture-promoting contours and/or secondary air injections.



Uni-directional Current Furnace **Counter-flow Current Furnace** **Medium Current Furnace**

Figure 7: Various Types of Incineration Air Feeding

2.6.4.1.6 Incineration Air Feeding

The incineration air must fulfill the following objectives:

- Provision of oxidation means
- Cooling
- Avoidance of slag formation
- Intensive mixing of waste gasses and avoidance of strand formation

Depending on the objectives, different air systems and air distribution (primary air, secondary air) result.

The primary air is removed from the waste bunker. This lowers the air pressure and eliminates most odor emissions. Primary air is conducted through a blower into the areas below the grate. If required, the air can be pre-heated if the value of the waste degenerates to the degree that it becomes necessary to pre-dry the waste. The primary air will be pressed through the grate layer into the fuel bed. It cools the grate bar and carries oxygen into the incineration bed.

Secondary air is blown into the incineration chamber at high speeds, for example, via lances. This should secure total incineration and is mechanically responsible for the intensive mixture of waste gasses, and prevents unburned gasses from forming strands.

2.6.4.1.7 Auxiliary Burner

In Guideline 2000/76/EU minimum temperatures are determined for waste incinerations that must be kept at all times during the operation when still unburned waste is present in the incineration chamber. They are:

- 850°C for non-hazardous waste and for hazardous waste with less then 1 weight percent of halogenated organic materials (counted as chloride)
- 1100°C for hazardous waste with more than 1 weight percent of halogenated organic materials (counted as chloride)

At the start-up of the plant the auxiliary burners are used to create a hot zone with the prescribed minimum temperature through which the waste gases are led from the furnace zone to the secondary incineration. This is the predominant operational condition for the burner design.

In order to assure a sufficient temperature under extreme fuel and load conditions, auxiliary burners are installed. They are always used when the temperature falls under the prescribed minimum temperature.

When the plant is shut down, the auxiliary burners are used when the temperature has fallen below the design limit of the furnace and the temperature sinks below the prescribed minimum temperature. They are only in operation until there is no waste in the incineration chamber.

2.6.4.1.8 Incineration Temperature, Residence Time , Minimum Oxygen Content

Based on the discussions on the emission of halogen-organic compounds from waste incineration plants in Germany the 17. BImSchV that became effective in 1990 determined a minimum temperature for incinerations of 850°C and a minimum residence time of the waste gases above this temperature of two seconds after the last incineration air supply.

Operational experiences in many German plants have shown, that the emission tolerance limit prescribed in the 17. BImSchV and the waste incineration could be performed with lower temperatures and shorter residence times. It could be shown with a series of comparative measurements that emissions and incinerations would not deteriorate by changing the operating parameters in a plant.

Using the same operational results it could be proven that the prescribed minimum oxygen content of 6 percent after the last incineration air supply could fall during the operation without lowering the quality of the gas incineration. The carbon monoxide content of the waste gas is the decisive nominal value for quality assurance (< 50 mg/m³ as daily average value).

2.6.5 Corrosion

With the introduction of minimum temperature residence time and oxygen content requirements, corrosion has significantly increased in steam generators at waste incineration plants.

Corrosion is caused by a chemical attack of waste gas and ash particles from the furnace. The incineration chamber, the radiation room, and the super heater are those boiler components that are most in danger of corrosion.
Erosion, which is the abrasion of surface material through vertical wear-and-tear, is caused primarily by the ash particles present in waste gas. Erosion appears mostly in the area of redirections, as the force of inertia concentrates as strands in the ash particles.
Pipe wear is caused by a combination of corrosion and abrasion. Corrosion appears on clean metallic surfaces. If the corrosion products deposit themselves as film on the pipe surface (oxide layer), they function as a protective layer and slow down corrosion. If this protective layer wears out through erosion, and if the metallic surface reappears, the entire process starts anew.

Coherent consideration of the corrosion processes is difficult, as physical, chemical, incineration-technical, metallurgical and crystallographic parameters interact. Various mechanisms can be detected in waste gas corrosions:

- Tinder process: O_2-High temperature corrosion when exceeding the tinder process temperature.
- Initial corrosion: Time-limited ferrous chloride formation before the first oxide layer formation at “blank“ steel during initialization. This reaction occurs continuously after the film removal through erosion (see above).
- Oxygen-deficiency corrosion through $FeCl_2$-formation under deoxygenated waste gas atmosphere, e.g., under films (such as oxides, contamination or fireproof material) and in the furnace area. $FeCl_2$ is sufficiently volatile in present temperatures and thereby mobile. The indicator for such a corrosion type includes, among others, the appearance of CO (this explains the often falsely used term CO corrosion). The microscopic situation at the border between material and film is, however, decisive. This corrosion is observed in individual cases with steam pressures above 30 bar, but normally above 40 bar. Corrosion speed increases with metal temperature. The corrosion products appear in flaky, pastry layers.

- Chloride-High temperature corrosion: Corrosion through chloride, which is released during sulphatizing of alkaline chlorides in the layers and that attacks iron or lead hydroxides. This corrosion mechanism is observed in waste incineration plants with waste gas temperatures > 700°C and at pipe wall temperatures from 400°C. The corrosion products can be recognized as a black firmly bonded cup that includes a hygroscopic red $FeCl_3$ layer in thicker films.
- Molten salt corrosion: If formations of eutectics are observable in the deposits, reactions corresponding to chemical melt decomposition appear. A characteristic of this corrosion type is pithng at the pipe surface. Drastic changes in temperature can cause the separation of salt mixtures and therefore the formation of eutectic melting. This melting formation can consist of chloridic as well as sulphatic salts.
- Electrochemical Corrosion: Is based on the electrical potential equalization of different metals. The conductor can be aqueous or it can be a solid that shows sufficient electrical conductivity at present temperatures. The conductivity can appear seamlessly from the water dew point to the sulfuric acid dew point to molten salt.
- Standstill corrosion: Based on its high chloride content (especially $CaCI_2$), the deposits are hygroscopic. The humidity in the air dissolves these compounds and causes chemical dissolution appearances in the material.
- Dew point corrosion: When the temperature falls beneath the acid dew point, wet chemical corrosions appear on cold surfaces. This damage can be avoided by raising the temperature or selecting the appropriate material.

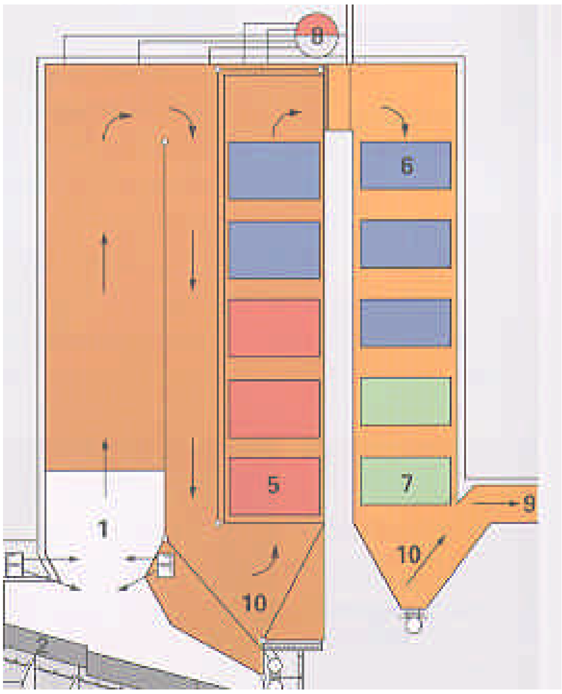
Corrosion is unavoidable from a thermodynamic perspective. Counter measures only help to reduce corrosion damage to an economically acceptable level. The causes of corrosion require constructive and operational counter-measures. It is debatable whether influencing via fuel quality is feasible or makes sense. Improvement possibilities can be found mainly in the steam generator. Low steam parameters, long reaction times before entry into the heat surfaces, lowering of waste gas speed, and leveling of the speed profile could be successful. The heat surfaces can be safeguarded by protective shells, tooling, stamping, and deflectors.

A compromise must be found in determining cleaning intensity between the best possible heat transfer (metallic pipe surface) and optimal corrosion protection (protective layer consisting of corrosion- and deposit products).

2.6.6 Steam Generation

Tubular water boilers are generally used for steam and hot water generation in waste incineration from the energy potential of hot waste gasses, meaning that steam or hot water is produced in waste gas pipes flowing back and forth, in contrast to large water boilers. The pipes form the envelopment walls of the incineration chamber and parts of the post-connected waste gas pipes, and are arranged in so-called bundled heating surfaces or bulkhead heating surfaces.

In steam generation, one usually differentiates among three heat surface areas, shown in Figure 8:



5 Feedwater preheating (Economizer): In this area, the feedwater is heated by waste gasses to a temperature close to the boiling point (designed as a bundled heating surface and/or part of the waste gas pipe).

6 Evaporation: In this area, the water coming from the economizer is heated until it reaches the saturated steam temperature (designed as a bundled heating surface, envelopment wall of the incineration chamber, and/or waste gas pipes).

7 Superheating: In this area, the saturated steam coming from the evaporator is superheated to the end temperature (as a rule, bundled heating surfaces or bulkhead heating surfaces).

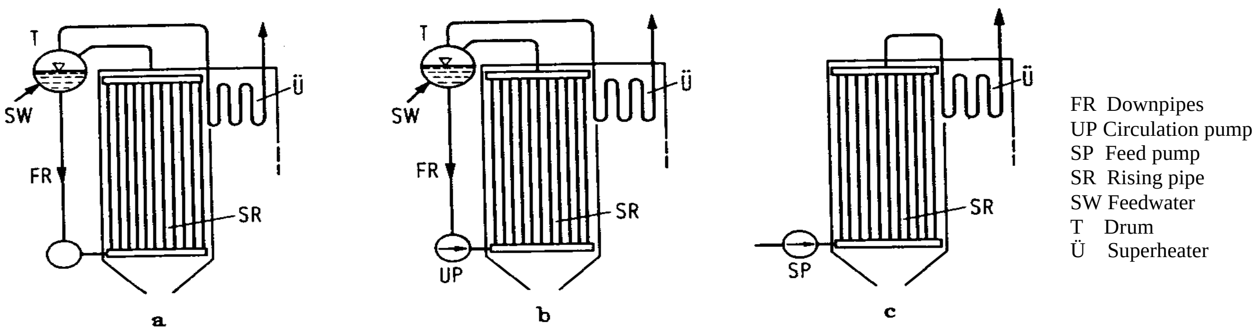
Figure 8: Illustration of individual heat surface areas in a steam generator

The following traditional evaporation systems can be differentiated (compare with Figure 9):

- Natural circulation: The water/steam mass flow in the evaporator is maintained due to the different density of the medium in heated and unheated pipes. The water/steam mixture flows into a drum. Here, steam and water are separated. The saturated steam then reaches the post-connected superheater.
- Forced circulation: This principle corresponds with the natural circulation, but is expanded by a circulation pump supporting the circulation in the evaporator.
- Forced continuous flow: In this system, the feed water is pressed in a continuous flow through the economizer, the evaporator, and the superheater.

Spray coolers and surface coolers are used in circulation boilers in order to keep the exact required steam temperature.. It is their function to balance the fluctuations of the steam temperature, these fluctuations being the consequences of load fluctuations, changes in the waste quality, the surplus air, as well as contamination of the heat surfaces.

Waste incineration plants require a compromise in determining steam parameters, as the selection of high temperatures and pressures better utilize the energy contained in the waste but high steam temperatures lead to significant corrosion problems, especially at the superheater surfaces, leading to the fact that usually 40 bar and 400° C are used. Based on these rather low steam parameters, almost exclusive natural circulation steam boilers are selected.



a Natural circulation b Forced circulation c Forced continuous flow

Figure 9: Basic flow systems

A peculiarity in waste incineration is the high dust load in waste gasses. In addition to the post-connected dust filter, other constructive measures are considered that support dust separation, such as a sufficiently low waste gas speed to support the gravity separation of flying ash or the redirection at the transitions of individual waste gas pipes.

The high proportion of ash in waste gas causes the danger of a correspondingly high contamination of the heat surfaces. This leads to a decline in heat transfer and therefore a performance loss. Thus, heat surface cleaning plays an important role. This cleaning can be accomplished manually or automatically with lances (compressed air or water jet), with agitators, with soot blowers using steam, with a hail of pellets, or with sound and shock waves.

Different boiler concepts can be used in waste incineration plants. They are (compare with Figure 10):

- Vertical boilers
- Horizontal boilers
- Combination of vertical- and horizontal boilers.

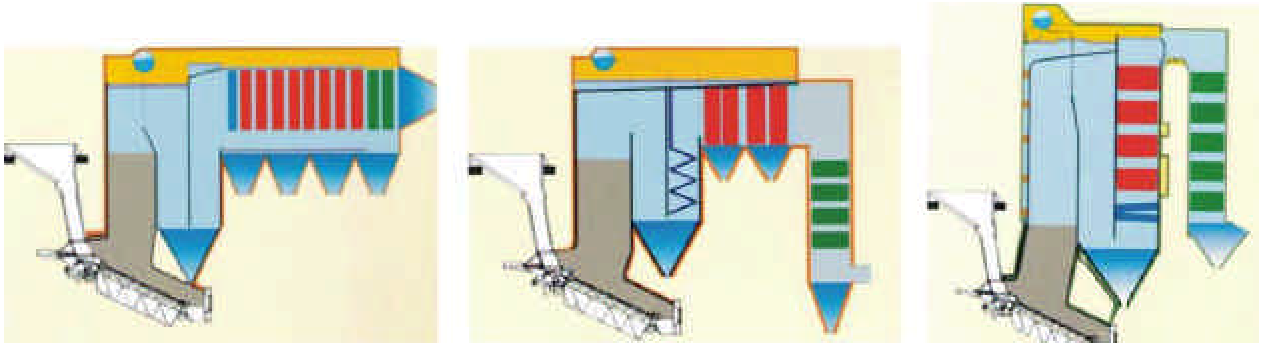


Figure 10: Overview of various Boiler Systems

In horizontal and vertical systems, so-called idle grooves are connected in a series of convection heat surfaces consisting of grooves with evaporation walls. The selection of the system to be deployed depends on the given building concept, the selected steam parameters, and the customer specifications.

2.6.7 Fluidized Bed Furnace

Fluidized bed incineration has been used for decades, until now mainly for incineration of homogeneous fuels. Among these are fabric coal, raw lignite, sewage sludge, and biomass (e.g., wood).

The technological principle upon which the fluidized bed furnace is based consists of the pouring of kernels and inert material, e.g., sand or ash, together with the waste into a reactor with nozzle plates and gas streaming against gravity, to keep this mixture in a fluidized state. Turbulent movement of the solid particles and intensive mixing of the bed mass with the solid, fluid or gaseous fuels is characteristic of the fluidized bed furnace. Using this method, favorable material and heat transfers are achieved.

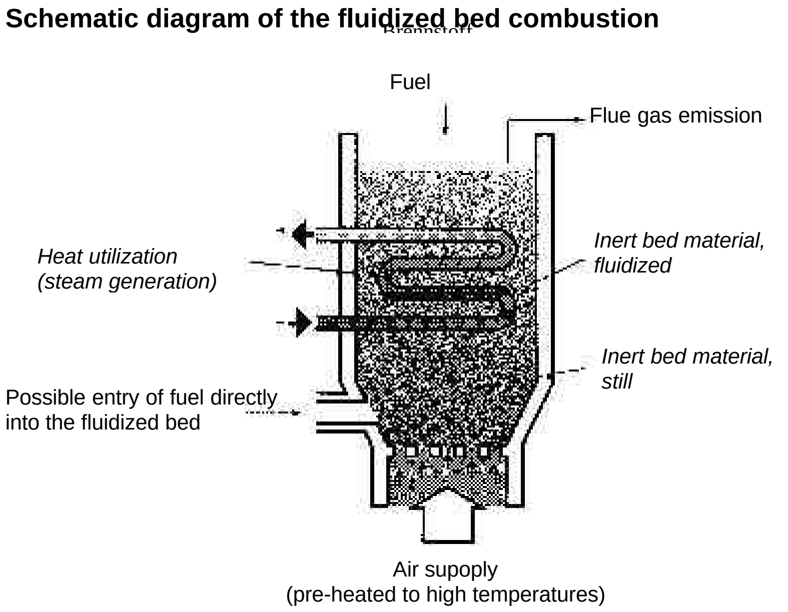


Figure 11: Principle of the Fluidized Bed Furnace

The prevalent, primarily homogeneous temperature distribution in the fluidized bed is one of the advantages of this technology. The fuel is fed either directly into the fluidized bed or from above it. During the incineration operation, the fluidized bed consists of the ash produced and the unburned fuel particles. An ash surplus or coarse kernel accumulation that influence the fluidized bed negatively are removed at the its lower area.

In order to begin the incineration process, the fluidized bed must be heated to the minimum ignition temperature of the added fuel. This is accomplished by preheating the air with oil or gas burners that remain operative until incineration occurs independently. The waste falls into the fluidized bed, where it is crushed through abrasion and incineration. After incineration is completed, the ash remains in the fluidized bed. It is removed regularly and transported with the waste gas flow through the heat exchanger into a filter where it is separated.

Due to the low reaction temperature, no thermal NOx is formed. The conversion of fuel nitrogen into NOx is also very low. Lack of air can lead to the formation of laughing gas (N_2O). Acidic waste gas components, such as SO_2 and HCl, can, in principle, be kept in check with the addition of appropriate sorbients (e.g., lime) whereby the formation of chlorides must be taken into consideration because of the danger of corrosion.

The following following fluidized bed furnace technologies can be differentiated in reference to the gas speeds and design of the nozzle plate, (for a detailed explanation, see Chapter 2.6):

- Stationary Fluidized Bed (atmospheric and pressurized): The inert material moves very little.
- Circulating Fluidized Bed: The higher gas speeds are responsible for partial removal of the fuel and bed material, which is fed back into the incineration chamber.
- Rotating Fluidized Bed: Here, the fluidized bed is rotated in the incineration chamber. This results in longer residence time in the incineration chamber and lower wear on the heat transferor.

Fluidized bed technology for municipal waste incineration has not caught on as yet in Germany because the kernel spectrum of the fuel has not been determined. This means that appropriate pre-treatment must precede incineration. This pre-treatment consists of sorting out and crushing larger inert particles. The only operating fluidized bed plant in Germany is a pilot program where municipal waste is incinerated and follows the principle of a rotating fluidized bed that was designed for an output of 8 Mg/h.

The main plant components of conventional grate incineration technology are used in fluidized bed plants, as the usual separation technology cannot be dispensed with, in order to fulfill the legal requirements of emission limits, in spite of the separation of acidic gas components and poor NO_x incineration. No principle cost advantage is achieved using fluidized bed technology versus conventional grate incineration technology for municipal waste incineration.

2.6.7.1 Heat Utilization

Steam generation for grate furnace plants is described in Chapter 2.6.6, as the utilization options are the same in principle.

2.6.8 Pyrolyse Technology

Strictly speaking, “Pyrolyse“ is the degassing of wastes without oxygen in which pyrolyse gas and solid pyrolyse coke are formed. The heat value of pyrolyse gas lies between 5 and 15 MJ/m^3. In a broader sense, “pyrolyse“ is a generic term including a number of different technology combinations that constitute, in general, the following technology steps:

- Smoldering Process: Formation of smoldering gas from volatile waste particles at temperatures between 400 and 600 °C.
- Pyrolyse: Thermal decomposition of the waste between 500 and 800 °C with gas formation.

- Gasification: Conversion of the carbon share remaining in the pyrolyse coke at 800 to 1000 °C with the help of a Gasification substance (e.g., air or steam) in a process gas (CO, H_2).
- Incineration: Depending on the technology combination, the smoldering gas and pyrolyse coke are incinerated in a incineration chamber.

Two pyrolyse plants for municipal waste treatment are operational in Germany. As this technology has either not proven itself in practice or is still in development, the essential technology steps will be described in Chapter 6.

2.7 Technologies in the Incineration of Hazardous Waste

2.7.1 Waste Acceptance

In contrast to municipal waste incineration for which there are no required admission controls, the handling of hazardous waste requires special precautionary measures. For each type of hazardous waste, a so-called declaration of the waste producer must be submitted and the waste manager can decide whether the treatment of each specific type of waste is possible. Such a declaration (called Waste Disposal Proof in Germany) includes, among others:

- Data on the waste producer and responsible persons
- Data on the waste code and other designations for the waste
- Data on the origin of the waste
- Analytical data on particular toxic materials
- Legally-binding signature
- Additional data upon request of the accepting plant.

Various types of waste require additional measures. While production-specific waste can easily be described in general based on its rather homogeneous composition and is therefore sufficient for acceptance with the above-described data, further preparatory measures might be required, including investigation of each individual waste container, especially with waste of unknown composition (predominantly from refuse dumps and collection of hazardous household waste).

When the waste composition cannot be described in detail (e.g., small amounts of pesticides or lab chemicals), the waste management company agrees with the waste producer on specific packaging regulations, making sure that the waste will react critically during transport or when it is accepted for incineration. This prevents substances from reacting with one another in a container, for example:

- Waster with phosphates,
- Waster with isocyanates,
- Waster with alkaline metals (e.g., or other reactive metals) or
- Cyanide with acids,

to name a few.

Delivered waste will be submitted to specific admission controls whereby the previously received declaration by the waste producer will be the guiding principle After comparison by visual and analytical investigation with the data contained in the declaration, the waste is either accepted, allocated to the appropriate storage area, or rejected in the case of significant deviations.

2.7.2 Waste Pre-treatment

The composition of hazardous waste can cover a wide spectrum, as well as chemical and physical characteristics. Pre-treatment might be necessary before the actual incineration process that would take place either in appropriate pre-treatment plants at the waste producer‘s or at the incineration plant. Necessary pre-treatment measures could include:

- Neutralization (for waste acceptance, pH-values from 4-12 are normal)
- Sludge drainage
- Solidification of sludge with binding agents
- Crushing of coarse waste or barrels
- Creation of the desired physical characteristics in order to improve the feed into the incineration process (e.g., suspension of viscosity).

2.7.3 Waste Storage

The details are described in the Horizontal-BREF “Emissions from Storage.“ Only specific storage conditions are described below.

2.7.3.1 Storage for Solid Hazardous Waste

Solid and unpumpable pasty hazardous waste that has not been de-gassed and does not smell, is stored temporarily in bunkers. Storage and mixing areas can be separated in the bunker. This can be achieved through several design segments. Cranes feed both solid and pasty waste products. The bunker must be designed in such a way that ground emissions can be prevented.

The bunker and container storage must be enclosed unless work-safety reasons (danger of explosion and fire) exist. The air in the bunker is usually removed and used as incineration air. In anticipating fires, monitors such as heat-detecting cameras, are used, in addition to constant monitoring by personnel (control room, crane operator).

2.7.3.2 Storage of Pumpable Hazardous Waste

Larger amounts of fluid and pumpable pasty wastes are temporarily stored in tanks that must be available in sufficient numbers and sizes to accommodate reacting liquids separately (danger of explosion, hardening).

Tanks, pipelines, valves, and seals must be adapted to the waste characteristics in construction, material selection, and design. They must be enough corrosion-proof, and offer the option of cleaning and sampling. Tanks are equipped with dosing mechanisms when acidic/alkaline wastes are neutralized. Flat bed tanks will only be deployed for large deposits.

It might become necessary to homogenize the tank contents with mechanical or hydraulic agitators. Depending on the waste characteristics, the tanks must be heated indirectly and insulated. Tanks are set in catch basins that must definitively designed depending upon the stored medium. The catch basins volume must be chosen so that it can hold the liquid waste occurring until the elimination of the leakage.

2.7.3.3 Storage for Containers and Tank Containers

Hazardous waste must be deposited in approved containers for safety reasons and to protect employees. The containers must then be delivered to the incineration plants. Especially dangerous wastes (poisonous, highly flammable) must be delivered in barrels to ensure employee safety. It is also permissible to deliver containers designed for large quantities of liquids. The contents are delivered via a separate pipeline directly into the furnace (if necessary, the system can be heated). This option can also be utilized to accept waste products that are only liquid at higher temperatures. In this case, the container must be heatable and the accepting plant must also have a pipeline system that can be heated. Storage areas for containers and tank containers are usually located outside, with or without roofs.

2.7.3.4 Storage for Hospital Waste

Hospital waste is also incinerated in hazardous waste incineration plants. If the incineration does not take place immediately, waste products must be temporarily stored.

Hospital waste stored for longer than 48 hours in the waste incineration plant must be deposited in cooled storage rooms (room temperature +10 ^{0}C at most). Work and storage areas must be designed to facilitate disinfection. Approved substances and processes are determined on the disinfection list of the Robert-Koch-Institute.

Appropriate cleaning and disinfection equipment must be made available for deployment of exchangeable containers to transport non-returnable containers. The wastes from disinfection must be collected and discarded.

2.7.4 Furnace Systems

2.7.4.1 Drum-type Kiln with After-burner Chamber

For incineration of hazardous waste, a combination of drum-type kilns and after-burner chambers has proven successful. As this combination can treat solid, pasty, liquid, and gaseous wastes uniformly (compare with Figure 12).

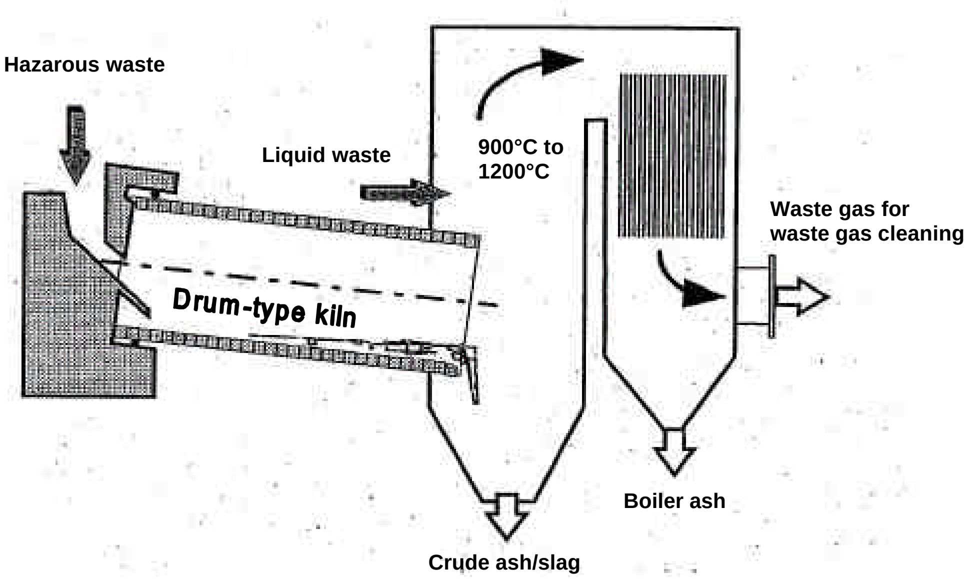


Figure 12: Drum-type Kiln with After-burner Chamber

Drum-type kilns between 10 and 15 meters in length, and having an inner diameter between three and five meters, are usually deployed for hazardous waste incineration. Table 16 provides an overview of the development of drum-type kilns in Germany.

Drum-type Kiln	Start-up	Dimensions Drum-type Kiln in meters		Output in Mg/a	Steam generation in Mg/h	Thermal output in GJ/h	Power generation in MW
		Diameter	Length				
1	1964	2,5	10	10 000	8,5	35[1]	
2	1964	2,5	10	10 000	8,5	35[1]	
3	1970	3,1	10	16 000	14,5	50[1]	
4	1971	3,1	10	16 000	14,5	50[1]	
5	1974	3,1	10	16 000	14,5	50[1]	
6	1978	3,8	10	35 000	36,0	125[1]	
7	1989	3,8	10	35 000	33,0	125[2]	2,6
8	1991	3,8	10	35 000	33,0	125[2]	2,6

[1] 18 bar at 270°C, [2] 42 bar at 350°C

Table 16: Development of Drum-type Kiln Plants at an Industrial Location

New drum-type kilns have outputs of up to 50 000 Mg/a each. In correlation to the average heat value of the waste, the steam generation increases correspondingly.

In reference to the deployment of various waste types, drum-type kiln plants are highly flexible. The following range is usual in the composition of the waste menu:

- Solid wastes	10 – 70 %
- Liquid wastes	25 – 70 %
- Pasty wastes	5 – 30 %
- Barrels	up to 15 %.

To protect the drum-type kilns from the slag incineration process having temperatures of up to 1200°C, the drum-type kiln is equipped with refractory bricks. Bricks with high shares of Al_2O_3 and SiO_2 are considered appropriate, in principle. The decision regarding the selection of bricks appropriate for each application must always be seen as a function of the waste composition. The fireproof mass of the bricks can be attacked by alkaline metal compounds (formation of low melting eutectic alloys), as well as by HF. (formation of SiF_4). To protect from these chemical attacks and from the mechanical impact of the falling barrels, slag laps (e.g., made from glass) are usually produced and maintained in the drum-type kiln. There were also tests with other surfacing systems but neither injected nor stamped refractory masses have proven successful. The surfacing of the drum-type kiln with special alloyed steels was only successful in some interesting applications. The durability of the fireproof surfacing remains dependent upon the waste to be put in. Service life of between 4000 and 16000 hours is normal. Cooling the drum-type kilns is seen as a possible way of lengthening their service life. Several positive experiences have been noted at various plants.

The drum-type kilns are slanted towards the after-burner chamber. This slanting, along with the slowly turning drum-type kiln (approx. 20 – 40 rotations per hour) facilitates the transport of solid hazardous wastes that are fed from the front side, as well as the ash and slag produced during incineration, in the direction of the after-burner chamber. These are then removed together with the ash and slag from the after-burner chamber via a wet slag remover. The residence time for solid wastes generally amounts to more than 30 minutes.

The after-burner chamber, where the last injection of incineration air must be retained for a minimum of two seconds, serves as a guarantee for the incineration of the waste gasses produced during incineration, as well as the incineration of additional liquid and gaseous wastes.

A drum-type kiln incineration plant with an incineration capacity of 45 000 Mg/a is shown in Figure 13. The plant is divided into three areas from a process-technological perspective:

- Drum-type kiln with after-burner chamber
- Waste heat boiler for steam generation
- Multi-step waste gas cleaning.

There is, in addition, the infrastructure of storage, feed system, and disposal for the waste and wastewaters produced during incineration.

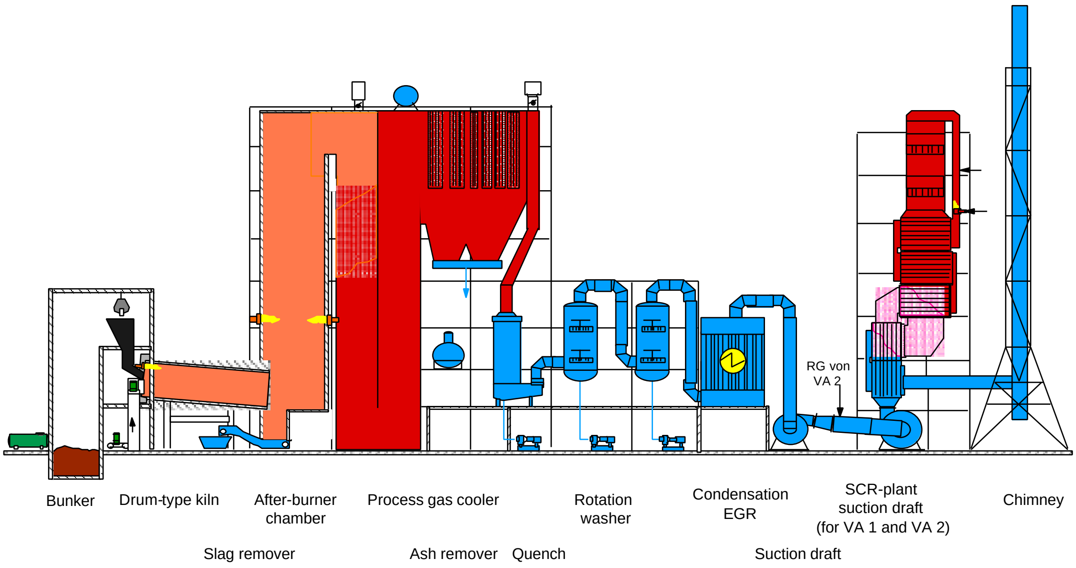


Figure 13: Example of a drum-type kiln plant for hazardous waste incineration

2.7.4.2 Incineration Chamber

Incineration chambers are only designed for the incineration of liquid and gaseous wastes, as well as solids disbursed in liquids. The principle structure and functional methods of a incineration chamber are shown in Figure 14.

All after-burner chambers in hazardous waste incineration plants are essentially incineration chambers and are used as such, as all wastes that have a high heat value, as well as liquid wastes having a low heat value, are incinerated there. In one plant (Ravenna, Italy) the after-burner chamber is so large that the total thermal performance can occur there.

The main application of incineration chambers in the chemical industry is the incineration of chloride-containing wastes with the target of recovering HCl. HCl is either recovered as such and utilized, or will be recycled into production via oxychloridation. Approximately 15 plants of this type are operated in Europe, each using specific plant designs. The total capacity of those plants amounts to 300.000 Mg per year.

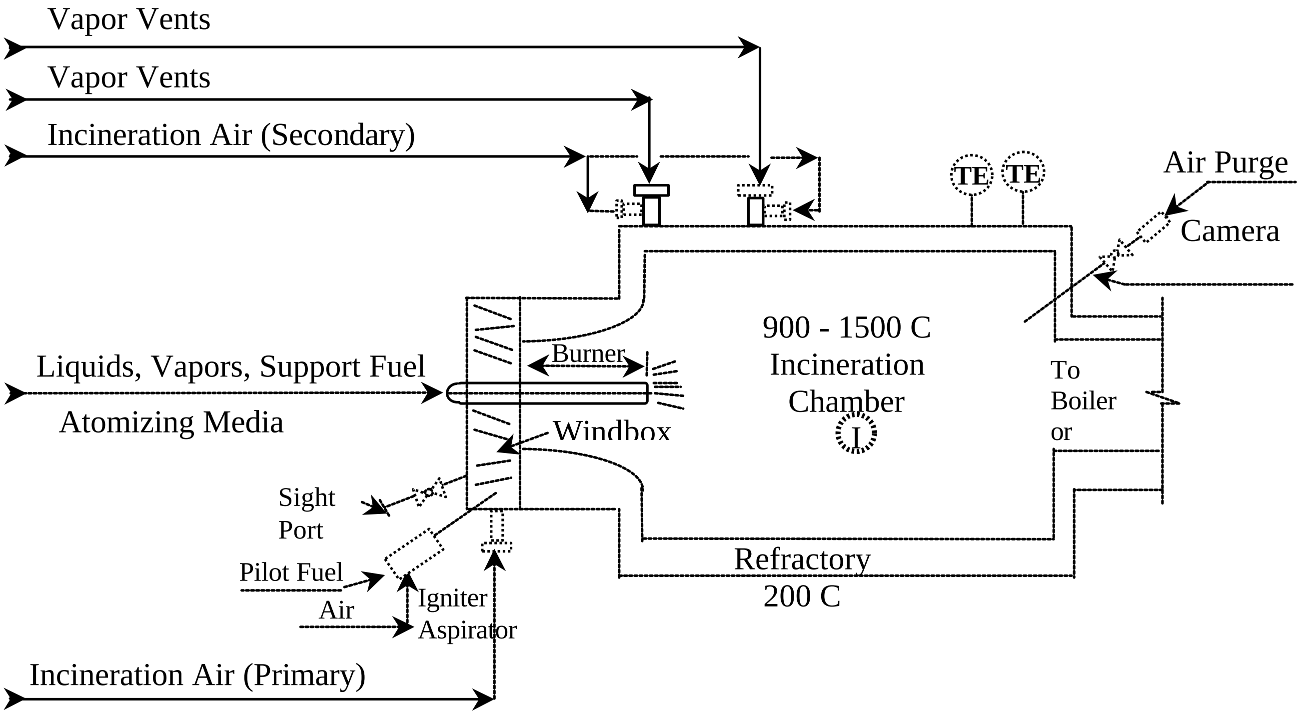


Figure 14: Principle of a incineration chamber

2.7.4.3 Description of a practical example – Plant for HCl recovery of residual gasses and liquid hologenated wastes

2.7.4.3.1 Introduction

The process technological parts include the incineration chamber with post-connected steam generator, as well as a waste gas cleaner combined with hydrochloric acid recovery and the waste gas chimney (compare with Figure 15). The plant utilizes liquid and gaseous chlorinated residual substances through the use of waste heat and the production of hydrochloric acid.

Heat is converted into steam in the steam generator (212°C, 20 bar) and transferred, for example, to the internal grid system. Waste gasses produced during incineration are freed from toxic particles and produce the highest possible concentration of hydrochloric acid in the waste gas cleaning plant. The removal and utilization of hydrochloric acid normally occurs within the plant.

2.7.4.3.2 Process Technological Description

Gaseous residual substances (waste gasses) will be lead to the recovery plant via transfer pipelines. Each waste gas flow is conducted through a separate deposit container before incineration. Liquid particles are separated from the waste gas flow in this deposit container. The feedlines are equipped with the appropriate flashback safety guards, according to the classification of the waste gasses. The number depends on the control mechanisms. The volume flow is collected via flow measurements that are pressure- and temperature-compensated. The waste gasses are fed into the incineration chamber via a pressure regulator having a quantity control with an upper limit. In addition, all waste gas lines to the incineration chamber are equipped with automatic emergency shutdown valves.

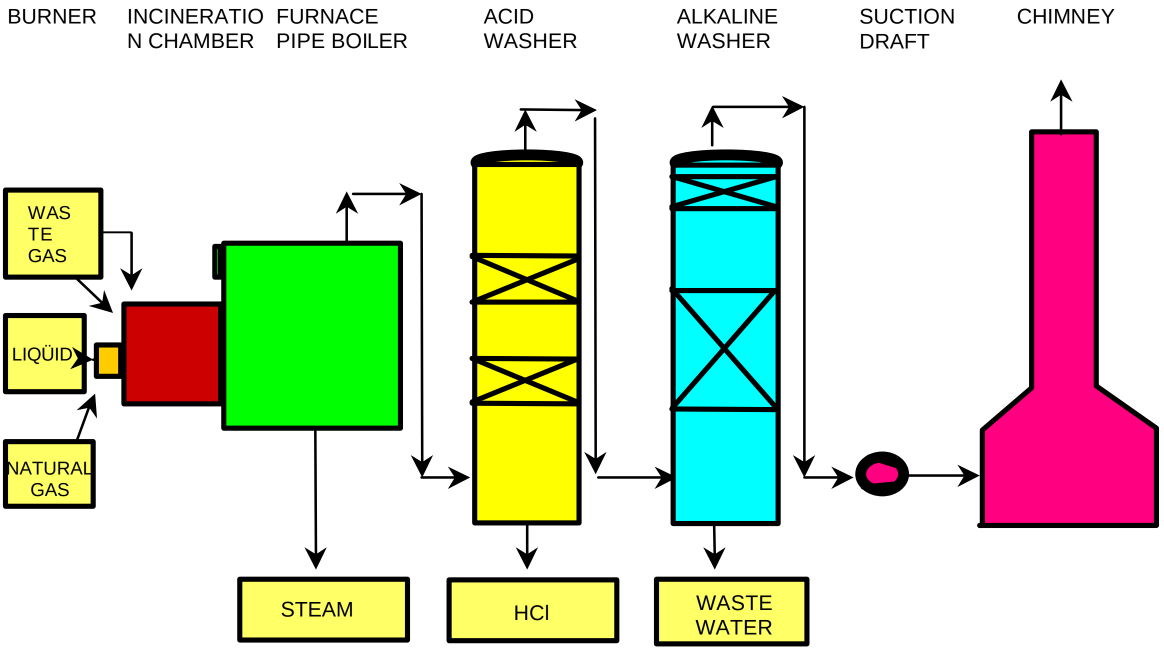


Figure 15: Diagram of a plant for HCl-extraction from residual gasses and liquid halogenized wastes

Liquid wastes are conducted to the plant via transfer pipelines that are also equipped with automatic emergency shutdown valves. All liquid wastes are conducted to a multi—material burner that is situated at the front side of the incineration chamber. Vaporization of these liquids occurs via pressured air and/or steam that have been fed into the burner by way of a separate gas quantity control. In addition, various waste gas flows are fed into the multi-material burner through waste gas lances. Each of these waste gas lances consists of concentrical pipes. Several waste gas flows can thus be fed separately into the incineration chamber. For cooling and avoidance of corrosion, the waste gas lances are continuously sprayed with air through the outer circular gap.

Deployment of primary energy (natural gas) is required for the plant start-up and for maintenance of the desired temperature in the incineration chamber. It is also fed to the multi-material burner by way of a separate blast connection. The flow of natural gas is regulated via a quantity control and is fed into the burner using a pressure regulator depending on the temperature in the incineration chamber. Natural gas is also required for the ignition flame that ignites the multi-material burner. Two automatic emergency shutdown valves with automatic gap releases can be found in the natural gas line to the multi-material burner and to the ignition flame.

Two independent flame-failure alarms (UV and IR) are installed to monitor the burner flame. In addition, the burner flame can be observed through inspection windows and with the help of a television camera that is installed on the back wall of the waste heat boiler. The amount of air is recorded with the appropriate gauges, as well as with pressure produced from a blower.

The cylindrical incineration chamber is designed in such a way that wastes have sufficient residence time to guarantee flawless incineration in relation to an operational temperature higher than 1100° during normal operation. The incineration chamber has been designed for a temperature of 1600 °C. The operational temperature is monitored continuously by thermal elements. Based on this high temperature, the whole incineration chamber, up to the entrance to the steam boiler plant, is lined exclusively with refraction bricks. The incineration chamber shell consists of boiler plate. The wet cleaning of the waste gasses occurs in two wash towers with a simultaneous recovery of technically reusable hydrochloric acid with the highest concentration. The deployment of chlorinated wastes facilitates the recovery of approximately 5–20 %-hydrochloric acid.

2.7.4.4 Waste Water Incineration

2.7.4.4.1 Introduction

When biological, chemical, and physical cleaning processes fail, wastewater can be cleaned through incineration of the organic content materials. This is a special technology for treatment of industrial wastewaters where organic and sometimes inorganic wastewater content material is chemically oxidized with the help of atmospheric oxygen through the evaporation of the water share at high temperatures. The term gas phase oxidation is used to differentiate this type of incineration from other technologies, such as wet oxidation. The process of gas phase oxidation is used if the organic substances in the water cannot be reused or if their recovery is not economical.

Wastewater incineration is an exothermic process. Independent incineration can only take place if the organic load suffices to evaporate the water share independently and to perform superheating. Therefore, wastewater incineration plants must be operated using secondary fires with small organic loads. Reduction of the requirement for additional energy can be achieved by reducing water content. This can be achieved through deployment of a preconnected, or multi-step, condensation plant. In addition, a heat recovery part (boiler) can be installed to recover steam for condensation from the furnace heat that is produced.

Depending on the individual organic and inorganic content of the wastewaters and the various local conditions, very different plant designs are customized as a rule for specific cases.

2.7.4.4.2 Plant Design

If wastewater should be discarded thermally, its heat value must first be determined since fuel consumption and operational costs depend decisively on this value. If the heat value of waste water is 0, for example, approximately 250 kg of light heating oil must be used for evaporation and super-heating for one ton of waste water with a incineration chamber temperature of 1000 °C and 40-% air surplus at 6 % remaining-O_2 and 5 % radiation loss. If the air is pre-heated from 20 °C to 300 °C, this value can be lowered to almost 200 kg of heating oil. In heat recycling through steam generation, (waste gas temperature 300 °C) the required heating oil can be reduced to approximately 91-100 kg per ton of water.

In slightly concentrated wastewaters, the specific steam consumption of 1 kg steam/kg water can be lowered to approximately 0.2 kg steam/kg water in a five step condensation process. In order to avoid narrowing the flexibility of incineration through pre-condensation to too great a degree, a sufficiently large intermittent tank should be placed between the two plant sections. If the contents of the material can be easily incinerated, complete incineration can be achieved at lower temperatures and a smaller degree of excessive air or the remaining -O_2. The advantage is a “smaller“ plant size, in addition to energy savings and lower NO_X-formation.

The deployment of multiple flood burners (e.g., light heating oil, natural gas, or waste solvents and waste water separated by a flame condensation burner) is recommended in waste waters with low heat values. In order to destroy organic material content quantitatively, optimal distribution must be guaranteed in the furnace. This is achieved by the deployment of vaporizer media, such as steam or compressed air (2-15 bar). Here the viscosity of the waste water, as well as particle size and distribution, must be taken into consideration.

2.7.4.4.3 Waste Water Supply

Waste water and fuel are injected via burners or lances at several locations within the incineration chamber. Atmospheric oxygen is also supplied at several locations with strands (primary air = atmospheric oxygen combined with fuel, secondary air = mixed air, e.g., circular channel). Temperatures within the individual zones can be regulated with fuel or air supplies. In sufficiently dimensioned incineration chambers, two step incineration (e.g., first step, wastewater; second step, waste gas) can occur with different residence times and temperatures. The incineration chamber must be dimensioned in such a way that the residence time for the waste gasses is sufficient for complete incineration. A sufficient air surplus must be provided. The incineration chamber shell is usually made of steel and often lined with fire-proof material.

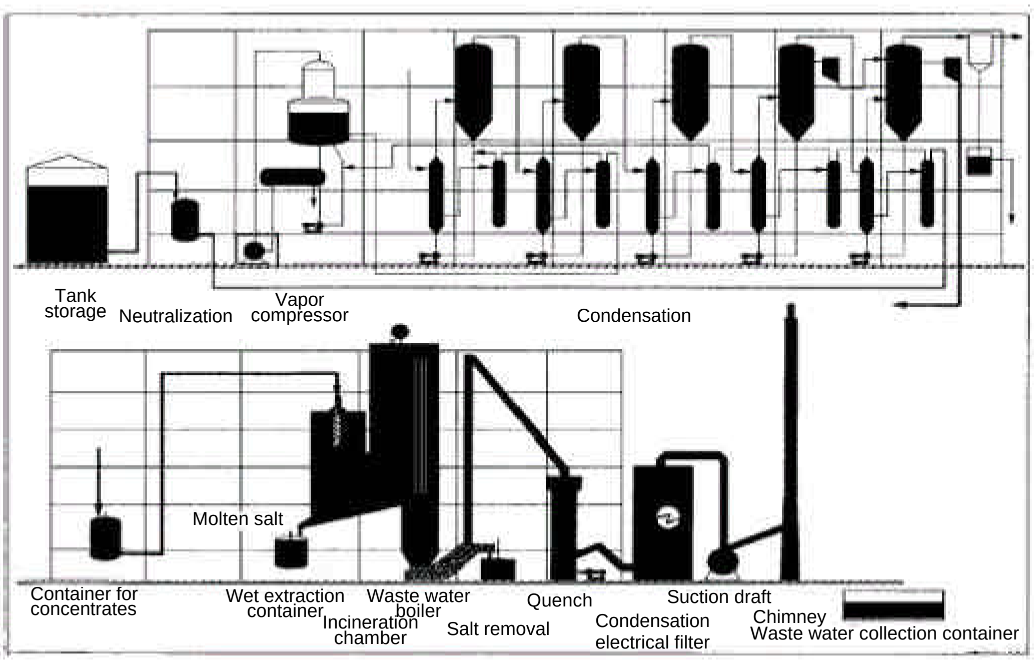


Figure 16: Example of a Waste Water Condensation Plant

2.8 Technologies in the Incineration of Sewage Sludge

2.8.1 Pre-treatment

2.8.1.1 Drainage

Mechanical drainage as a sewage sludge treatment step before incineration serves as volume reduction of the sludge mixture through the reduction of the water content. An increase in the heat value is associated with this process. This allows independent and economical incineration. The success of the mechanical drainage depends on the selected machines, a possible conditioning, as well as the type and composition of the sludge.

Through mechanical drying of the sewage sludge in decanters, centrifuges, belt filter presses, chamber filter presses a dry residue (m_T) between 20 and 45 % is achieved. Often the sludge is conditioned before the mechanical drainage to improve the drainage with the help of additives with flocking substances and material aiding the flocking formation). One must differentiate between inorganic flocking substances (iron and aluminum salts, lime, coal, etc.) and organic flocking substances (organic polymers). Inorganic substances are not only flocking substances but are also builders. They increase, however, the inorganic share substantially meaning the unburned share of the drained sludge (ash). Therefore, mostly organic conditioning substances are used in the treatment of sewage sludge.

2.8.1.2 Drying

Often a substance that has been dryed with mechanical drainage is insufficient for an independent incineration. A thermal drying plant for additional evaporation of the inner water and the absorption water can be used before the incineration furnace is utilized. The sewage sludge is further reduced through the removal of water and the hear value is increased again.

The drying of sewage sludge in separate drying plants, either in connection with a purification plant or independently (also in mobile plants). The following dryer plants are utilized:

- Disk dryer
- Drum dryer
- Fluidized bed dryer
- Belt dryer
- Thin film dryer/Disk dryer
- Cold air dryer
- Thin film dryer
- Centridry-Dryer
- Solar dryer

Drying processes can be divided in principal into two groups:

- Partial drying up to approximately. 80 Mass-% m_T
- Complete drying up to approximately 95 Masse-% m_T

For an independent incineration process in mono sewage sludge incineration plants drainage of raw sewage drainage up to a dry substance content of 35 percent would be sufficient. In co-incinerations of sewage sludge in municipal waste incineration plants (mixture ratio of drained sewage sludge and municipal waste 1:3) a drying process might have to follow the drainage. For the co-incineration in bituminous coal power plants drying to a dry substance content of 90 – 95 % is required. The deployment of sewage sludge in cement factories requires a complete drying process beyond the drainage.

The heat required for the drying process is usually extracted in the incineration process. In some drying processes, the sewage sludge to be dried comes into direct contact with the thermal carrier, the so-called convection dryers or direct dryers (e.g., belt, double-deck, fluidized bed dryers). During the drying process, vapor is produced that is a mixture of steam, air, and released gasses from the sludge; and hot gasses are produced in the direct drying process. The vapor and gas mixture must be cleaned.

In indirect drying systems, (e.g., worm, disk, thin film dryers) also called contact dryers, the heat is injected via steam generators or thermal oil plants. Heat transfer occurs between wall and sludge. Contact dryers generally achieve a R. m_T-content from 65 – 80 %. The evaporated water produced through the drying process is only contaminated with leaking air and small amounts of volatile gasses. The steam can be condensed almost totally from the vapor and the remaining inert gasses can be de-odorized in the boiler furnace.

2.8.2 Mono-Sewage Sludge Incineration Plants

The annual output of dried substances in the 23 existing plants for incineration of communal (16 plants) and industrial (seven plants) sewage sludge amounts to approximately 610.000 Mg. Combined with another planned plant, Germany can count on treating 630.000 Mg m_T of sewage sludge of in mono-incineration plants. This corresponds to a share of approximately 20 % of the accumulated sewage sludge in Germany.

In addition to the sewage sludge, swim scum, screenings, and fat extractors are incinerated in small amounts in three of the communal plants.

The sludge is incinerated independently in only half of the mono-sewage sludge plants in Germany. This means that no additional fuels, such as heating oil and natural gas, are used in incineration maintenance during the operation, but only for the start up and shut down of the furnaces. Only raw sludge is used for incineration in those plants where at least partial independent sewage sludge incineration occurs. New furnaces in Wuppertal, Hamburg and Munich are operated with partially-dried digested sludge, which facilitates independent incineration of the sludge. A temperature of 850°C at 2 seconds residence time must be maintained.

The heat values at independent incinerations lie between 4.8 and 6.5 MJ/kg sludge and at non-independent incinerations between 2.2 MJ/kg and 4.8 MJ/kg sludge, whereby exclusively raw sewage is contained in the incineration plants. As a rule of thumb, approximately 5 MJ/kg sludge must be considered the limit for independent incinerations.

Heating oil constitutes the main share in deployed additional fuels in mono-sewage sludge incinerations. Natural gasses and foul air are used in equal parts (heating oil, 68%, natural gas, 18%, and foul gas, 14%). Foul gas is preferred in the incineration of digested sludge,. The primary influencing factors on the requirement for additional energy are air pre-heating and degree of drainage. The influence of conditioning agents is relatively low. For start-up and supporting incineration, the heating oil requirement lies between heating oil/Mg m_T.

Mono-sewage sludge incineration serves exclusively for discarding sewage sludge in plants that are especially designed for this purpose. They are operated at temperatures between 850 and 950°C. Temperatures below 850°C can result in odor emissions, while temperatures above 950°C result in ash fusions. The temperature level during incineration depends on the energy content and the amount of sewage sludge to be incinerated and on the atmospheric oxygen level. According to Guideline 17. BimSchV, an oxygen content of at least 6 Vol.-%, a secondary incineration of at least 850°C, and sufficient residence time of the waste gas in the after-burner chamber of at least 2 s is required.

2.8.2.1 Furnace Systems

Four different furnace systems are differentiated in mono-sewage sludge incinerations, which are described in detail below:

- Fluidized bed furnace, with or without pre-dryer
- Double-deck furnace
- Double-deck fluid bed furnace
- Cycloid furnace

2.8.2.1.1 Stationary Fluidized Bed Incineration

The stationary fluidized bed (SWS, compare with Figure 17) consists of a cylindrical or rectangular lined incineration chamber, a nozzle bed, and a start-up burner located below. The pre-heated atmospheric oxygen flows from below through the jet grate and keeps a sand bed floating. According to the application, various bed materials (silica sand, basalt, etc.) and kernels (0.5 - 3 mm) can be used.

The sewage sludge can be supplied via the head, on the sides with belt-charging machines, or directly into the fluidized bed. There, the sludge is crushed and mixed with hot bed material, dried and partially incinerated. The remaining parts (volatile and fine particles) are incinerated above the fluidized bed. The remaining ash is removed with the flue gas at the head of the furnace.

In modern incineration plants, the drainage and drying aggregates are usually designed in such a way that the sludge burns independently. At start-up, or when sludge quality is low, (e.g., old sludge or a high share of secondary sludge) additional fuel (oil, gas, and/or waste fuel) can be used to reach the prescribed furnace temperature of 850 °C. Water can be injected into the furnace head to limit the temperature.

The fluidized bed furnace must be pre-heated to 850 °C in order to incinerate the sewage sludge in the fluidized bed. A start-up incineration chamber for this purpose is located below the nozzle bed. This has the advantage over an over-head burner, as the heat is introduced directly into the fluidizied bed. The furnace is pre-heated to 600 °C – 700 °C (according to the ignition temperature of the additional fuel) via the start-up incineration chamber. Additional pre-heating occurs by way of fuel lances that protrude over the nozzle bed into the sand bed. The sewage sludge is supplied when the furnace temperature reaches 850 °C.

The size of the furnace is essentially determined by the required evaporation (furnace cross-section), heat turnover in the furnace (furnace volume) and the required amount of air.

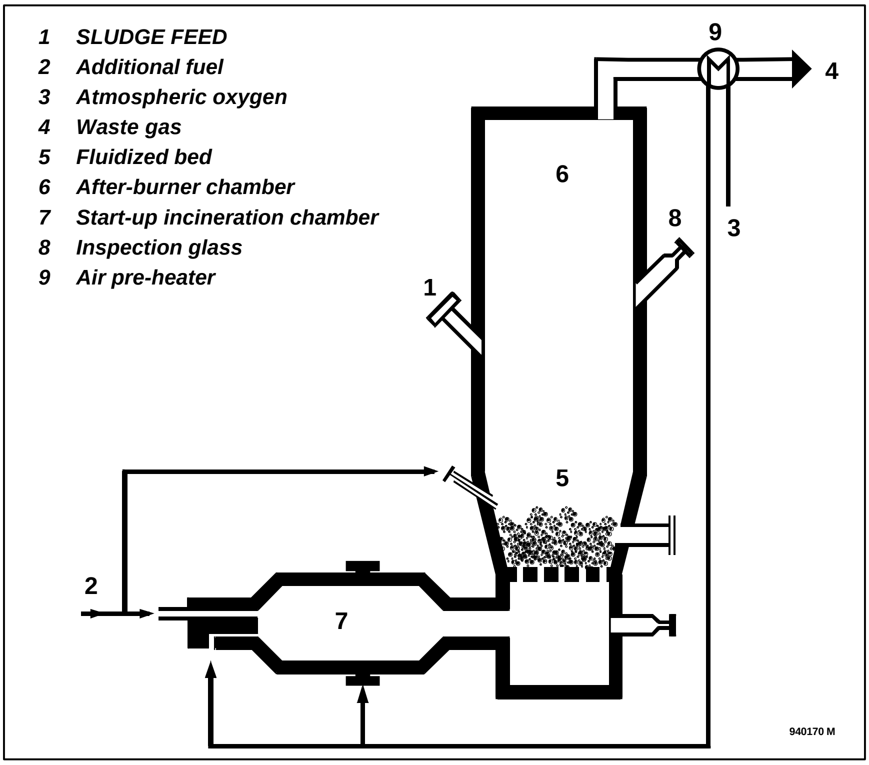


Figure 17: Functional Principle of a Stationary Fluidized Bed

The relevant operational parameters are shown in the following Table 17. The pre-heating of air can be eliminated completely with high caloric fuels (e.g., dried sewage sludge, wood, animal byproducts, colza) and the heat can be removed through membrane walls and/or immersed heating surfaces, depending on the independent incineration temperature, making it possible to maintain the incineration temperature of 850 °C over two seconds. A change in heat removal is not possible.

Steam load	kg/m^{2}h	300 – 600
Feed air amount	Nm^3/m^{2}h	1000 - 1600
Heat turnover	GJ/m^{3}h	3 – 5
Final incineration temperature	°C	850 – 950
Residence time, open space and afterburner zone	sec.	min. 2
Pre-heating of atmospheric oxygen	°C	400 - 600

Table 17: Essential Operational Criteria for Stationary Fluidized Beds

2.8.2.1.2 Circulating Fluidized Bed

The circulating fluidized bed (ZWS, compare with Figure 18) is especially appropriate for the incineration of dried sewage sludge with a high heat value. It works with fine bed material and at high gas speeds removing the greater part of the solid material particles out of the fluidized bed chamber with the flue gas. They are separated in a post-connected cycle and returned to the incineration chamber. This circuit gives its name to the process: Circulating Fludized Bed.

The advantage of this process is that high heat turnovers can be reached with low reaction volume. The fuel is injected at the side into the incineration chamber and is incinerated at 850– 950 °C . The surplus heat is removed through finned walls and via fluid bed condensers. The fluid bed condenser is placed between recycling cyclones and ZWS, and cools the returned ash. Using this method, the removed heat can be controlled.

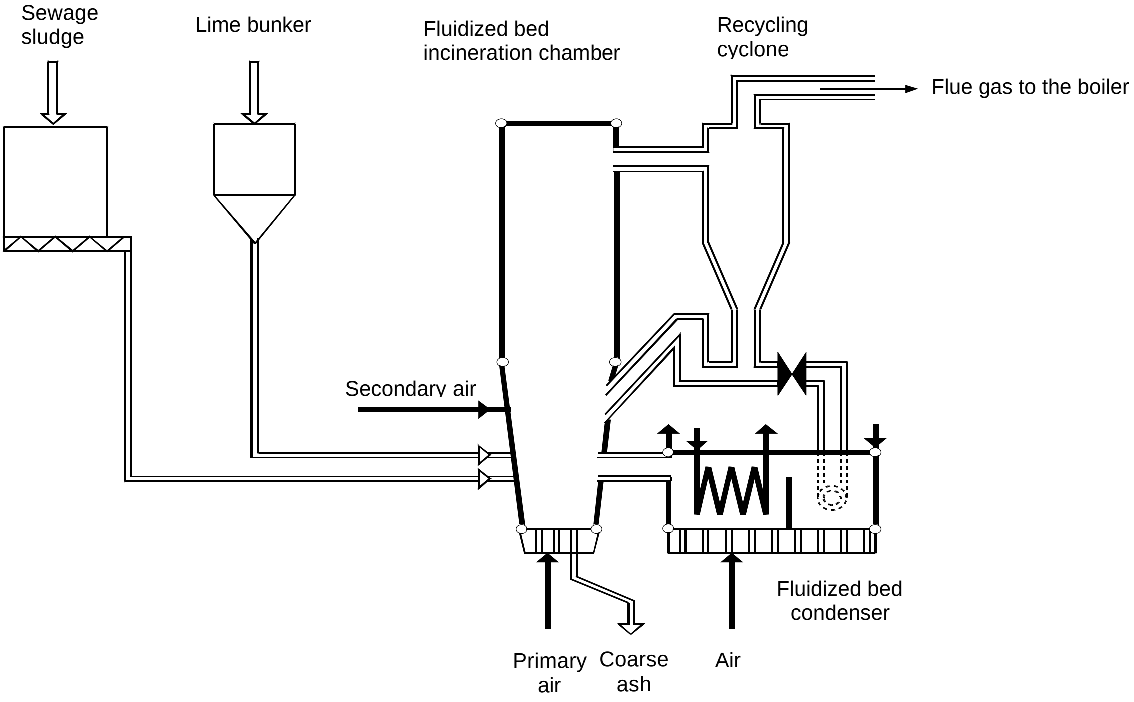


Figure 18**:** Principle Function of a Circulating Fluidized Bed

2.8.2.1.3 Multiple hearth Furnace

The multiple hearth furnace (compare with Figure 19) consists of a cylindrical lined steel jacket, horizontal layers, and a rotating sleeve shaft with attached agitating arms. The furnace is lined with refractory bricks. The number of days for drying, incineration, and cooling is determined based on the residual material characteristics. The multiple hearth furnace is also equipped with a start-up burner, sludge-dosing mechanism, circulation-, sleeve shaft- and fresh air-blowers.

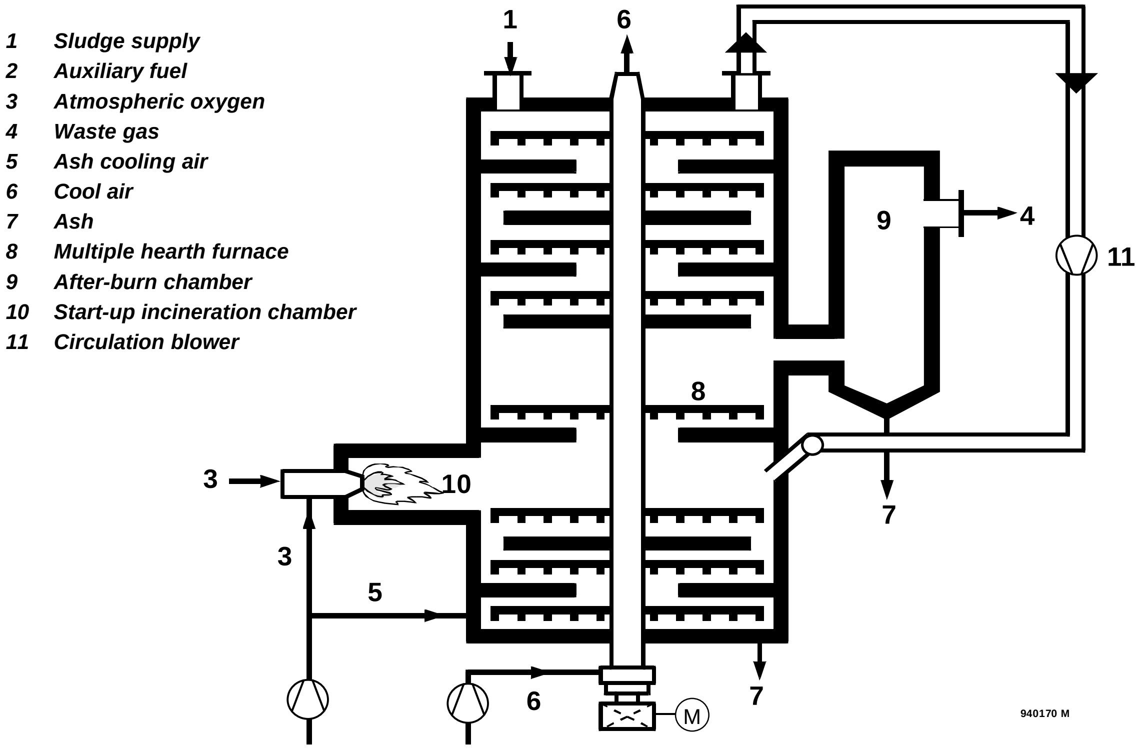


Figure 19: Principle Function of a Multiple hearth Furnace

The material to be incinerated is supplied at the highest furnace layer. It is captured by agitator sprockets, divided, and forced through the furnace layers through constant rotation. In a counter-direction to the sludge, hot flue gas is conducted from the highest incineration layer via the drying layers. The sludge is dried by the flue gas and heated to ignition temperature. The circulating air is augmented with steam and volatile particles during the drying process. It is lead toward the lowest incineration layer. The conversion of organic sludge particles into CO_2 and H_2O takes place at temperatures between 850 to 950 °C. If the desired incineration temperature cannot be reached independently, the start-up burner for support incineration is used. As an alternative, a solid auxiliary fuel can be added to the sludge.

The conversion of organic sludge particles into CO_2 and H_2O occurs at temperatures between 850 to 950 °C. If the desired incineration temperature cannot be reached independently, a start-up burner is used for support incineration. As an alternative, solid auxiliary fuel can be added to the sludge. The ash is cooled to approximately 150 °C at the lower layers of the furnace with counter-flowing cool air and the ash is removed via the ash system. The flue gas that is produced is fed through a post-reaction chamber with a guaranteed residence time of two seconds. Carbon compounds that have not been converted are oxidized here.

The multiple hearth furnace is deployed with sludge whose ash forms such low eutectics with the fluidized bed material that it x would cause operational problems in the fluidized bed furnace. Multiple hearth furnaces can be operated using the “traditional operating parameters,“ whereby the flue gasses are removed at the highest drying level and are fed to an after-burner (e.g., in a incineration chamber). This is advantageous at such locations where boiler plants are already available, facilitating the feeding of waste gasses into those plants. The after-burning process and the flue gas cleaning occur at those plants. The essential operational parameters are shown in the following Table 18.

Evaporation capacity	kg/m^2h	25 - 45
Heat conversion in incineration layers	GJ/m^2h	0,4 – 0,6
Incineration end temperature	°C	850 – 950
Residence time, free space, and after-burn zone	sec.	min. 2
Atmospheric oxygen pre-heating	°C	max. 600 °C

Table 18: Essential Operational Criteria for a Stationary Fluidized Bed

The following Figure 20 shows a practical example of a sewage sludge incineration plant with a capacity of 80,000 Mg/a.

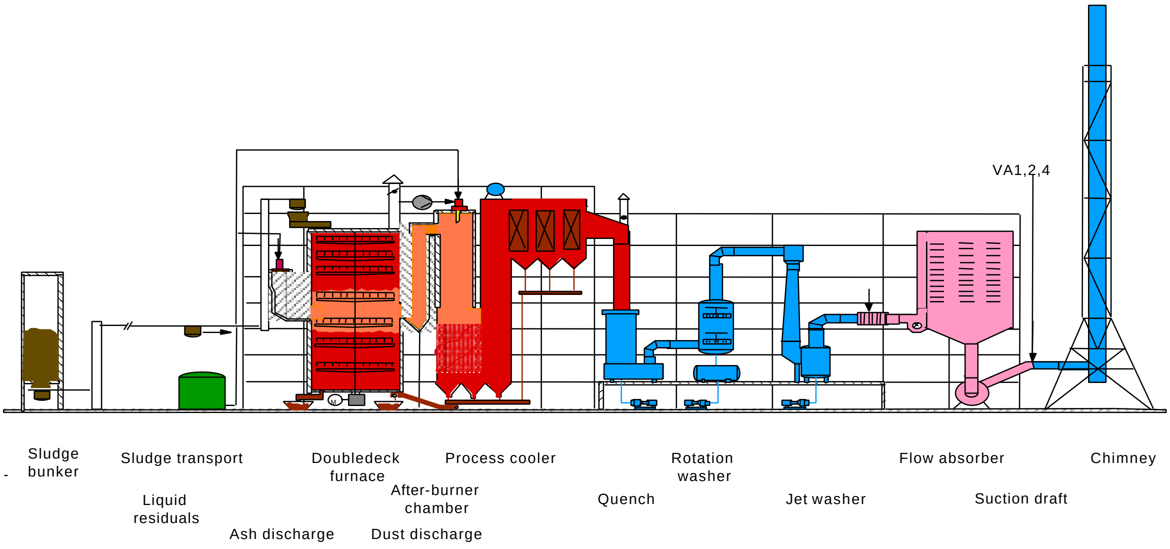


Figure 20: Example of a Sewage Sludge Incineration Plant with a Multiple hearth Furnace

The plant can be divided into the following areas:

The shown plant essentially consists of the following parts:

- Multiple hearth furnace
- After-burner chamber
- Waste water boiler for cooler utilization
- Multiple step waste gas cleaning

The accumulated sewage sludge is conditioned, meaning that it is converted into a form for filtering using additives or other measures. The sludge is drained as much as possible in chamber filter presses and then temporarily stored in a bunker. From there, the dependable press cake is deposited in buckets via a bucket loader. These buckets have a capacity of approximately 1.5 tons each. The sludge is loaded from the buckets into a filler container at the highest layer of the incineration plant and continuously fed into the furnace. Up to 12 Mg of sewage sludge can be processed per hour. This represents the contents of eight buckets.

2.8.2.1.4 Multiple hearth Fluidized Bed Furnace

Several layers are installed into the freeboard of a stationary fluidized bed, enabling the sludge to be pre-dried with flue gas. Using this pre-drying process, only a small amount of water must be evaporated in the actual fluidized bed, meaning that the grate surface and entire furnace can be minimized. Uniform incineration can occur in the multiple hearth fluidized bed furnace through optimal coordination of the fluidized bed air supply, sand kerneling, evaporation at the layers and in the fluidized bed. Higher temperatures (temperature differences between the furnace head and foot) can be avoided leading to a lower formation of NO_X.

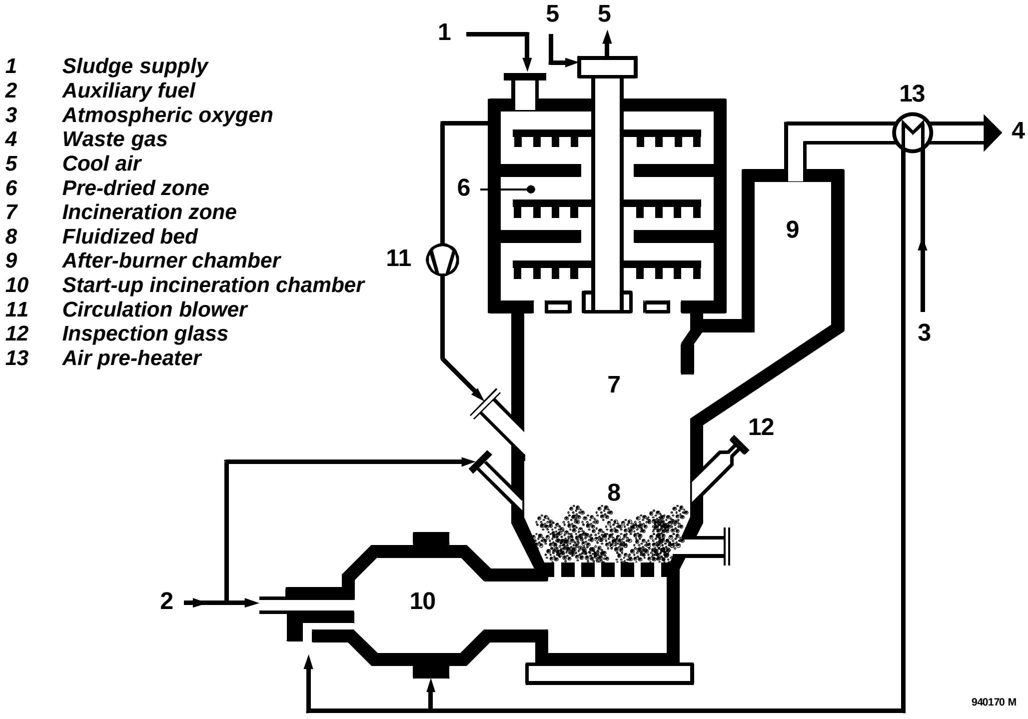


Figure 21: Principle Function of a Multiple hearth Fluidized Bed Furnace

2.8.2.1.5 Cycloid Furnace

The cycloid incineration chamber was originally developed for incinerating old coke derived from waste-cleaning at waste incineration plants and is now used for thermal disposal of sewage sludge. The optimal particle size for fuel ignition lies between 1 and 5 mm. Dust particles up to a size of 10 – 20 Gew.-% can be co-incinerated. Therefore, only dried sewage sludge granules can be used.

The fuel granules are supplied gravimetrically via a radial chute into the lower part of the incineration chamber, which is designed as a metallic air-cooled hopper. Atmospheric oxygen is blown into the incineration chamber at various air levels: The primary air enters the furnace at an angle through the lower part of the hopper, and the secondary air is injected on different levels through tangentially placed jets above the fuel feed. The distribution of primary and secondary air varies according to the specific fuel characteristics.

Incineration of sewage sludge requires even temperature distribution between 900 and 1.000 °C throughout the entire incineration chamber. Using this method, the temperature of the ash is maintained under its softening point. Flying dust is removed along with waste gas from the incineration chamber. The coarse kernels circulate in the tangential flow field until they are incinerated to the point that they can be removed as fine kernels. Crude ash, remaining coke, or metallic parts will be removed in a downward direction via a lock system.

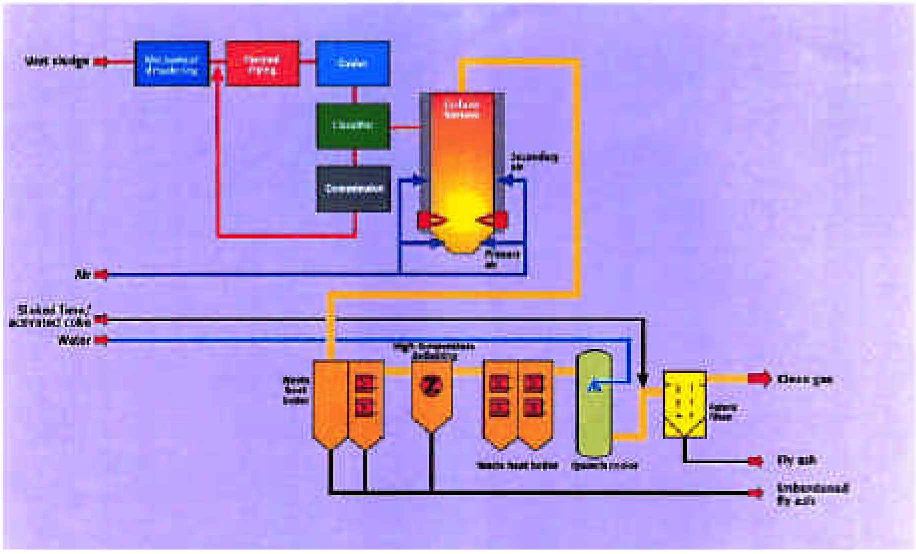


Figure 22: Illustration of a Cycloid Furnace

2.8.2.2 Comparison of Furnace Systems

The described furnace systems function according to different process technologies. The furnace structure, design, and operational technology of the incineration plant, the resulting post-connected cleaning equipment, as well as the transport of different material flows, have a significant influence on the resulting emissions. The characteristics of the various furnaces are shown in the following Table 19:

	Fluidized Bed Furnace	Multiple hearth Furnace	Multiple hearth Fluidized Bed Furnace	Cycloid Furnace
Features	No mechanically moveable parts and low wear	no separate pre-drying is necessary, extensive furnace structure with moveable parts, cooled hollow shaft	No separate pre-drying is necessary, moveable hollow shaft, low fluidized bed volume	No mechanically moveable parts and low wear, no fluidized bed material
Operational conduct	Fast start-up and shut-down through short heating- and cooling times, intermittent operation possible	Long heating time, continuous operation necessary	Medium heating- and cooling time	Comparable to the fluidized bed, deployable for a wide range of fuels
Incineration	Low air surplus required, complete incineration only above the fluidized bed	Incineration difficult to control, immune to fluctuations in loads and coarse material	Low air surplus required, good incineration control, incineration completed within the fluidized bed, greater immunity to quality fluctuations in the sludge than fluidized bed furnaces	Solid material shares, long and gaseous shares, short residence times, variable primary and secondary air supply on several levels
Ash content in waste gas	high	low	high	high
Ash removal	Via waste gas flow and sand removal	Directly from the lowest level	Via waste gas flow and sand removal	Via waste gas flow, crude ash at the bottom
Residues	Ash, fluidized bed material	Ash	Ash, Fluidized bed material	Ash, possibly coarse ash

Table 19: Comparison of Furnace Systems for Sewage Sludge Incineration

2.8.3 Sewage Sludge Incineration in Incineration Plants for Municipal Waste

Communal sewage sludge can be co-incinerated in some municipal waste incineration plants and in a pyrolyse plant. In additional plants, the co-incineration is in a test phase or planned after completion of the building phase leading to an additional future treatment capacity.

The incinerated sewage sludge accumulation in those 10 to 13 plants amounts to 120,000 to 140,000 Mg m_T/a. With 2.94 Million Mg m_T/a of sewage sludge, this only represents approximately 5 % of the total sewage sludge accumulation in Germany. Sewage sludge co-incineration is often included in the planning of municipal waste incineration plants, which, however, means additional investment

A more important investment area is that of the sludge supply. The following three supply technologies are used for combined sludge and waste incineration:

- Dried sewage sludge is blown as dust into the furnace
- Drained sewage sludge is supplied separately through sprinklers into the incineration chamber and distributed on a grate. The sludge is integrated into the bed material by overturning the waste on the grates. Operational experiences show up to 20 mass-% sludge (25 % m_T).
- Drained or dried sewage sludge is mixed with the remaining waste or fed together into the incineration chamber. This can occur in the form of a homogenization in an extra aggregate, in the waste bunker through targeted doses by the crane operator, or controlled in a feeding hopper.

2.8.4 Additional Technologies in Thermal Sewage Sludge Treatment

There are deployment possibilities for sewage sludge in the cement industry in brick production and in iron pyrite roasting (sulfuric acid production). Sewage sludge has been used for years in fixed bed pressure gassifiers in a secondary raw material utilization center (SVZ) in Schwarze Pumpe (Saxony). Here, the sewage sludge is first pelletized in a processing plant to achieve the necessary kernel size for the pressurized gasifier. The produced synthesized gas serves as an intermittent product for the production of methanol and/or for the generation of energy in its own GUD Power Station.

With the newly developed combination technology for thermal treatment of municipal wastes, such as the Thermoselect Process (see Chapter 6.4), the deployment of sewage sludge is planned. This process has not proven itself in practice on a large scale. With this methodology, the only appreciable contribution could lie in the combined gassing of sewage sludge and lignite in fixed bed gassing plants at the SVZ Schwarze Pumpe.

Co-incineration of sewage sludge in coal-powered plants is described in Chapter 2.12.2.1.

2.9 Technologies in the Incineration of Hospital Waste

Separate treatment of hospital-specific wastes is essentially concentrated on the disinfection/sterilization of infectious wastes (EAK 18 01 03, 18 02 02) and camouflaging organ and body parts (EAK 18 01 02-waste). This part of the hospital-specific wastes includes an annual waste amount of approximately 12,000 Mg in Germany, using the survey year 1993. The technologies used in the treatment of these wastes can be divided into various thermal disinfection processes to which the incineration or smoldering processes can be allocated. Incineration is allowed by the Robert Koch-Institute in the list of approved and recognized disinfection agents and processes for the complete microbiological A-D spectrum of activity whereby no additional process specific requirements are listed to the incineration processes.

There are two essential process principles in the other disinfection technologies:

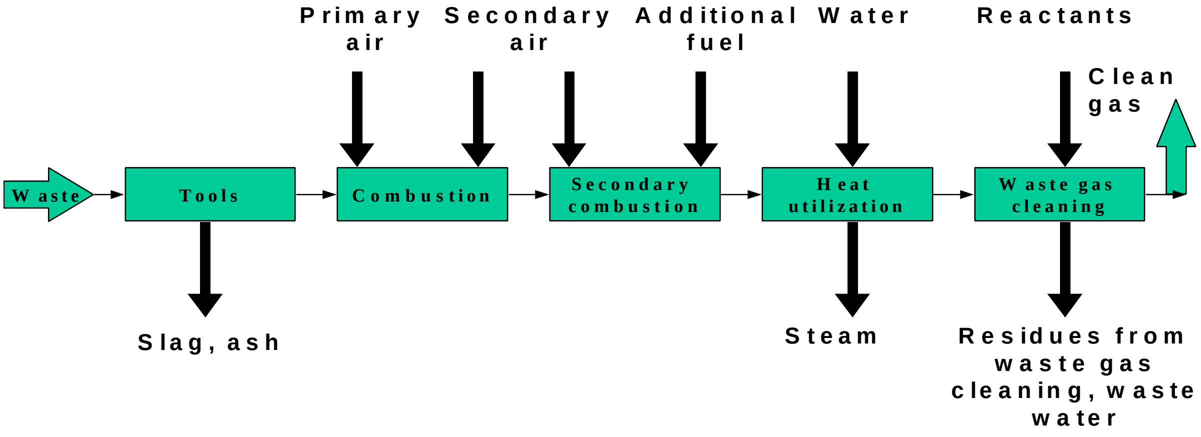
- Boiling with water and
- Steam disinfection.

These processes facilitate incineration of municipal waste in incineration plants.

Incineration processes without such pretreatment-specific furnaces (special grate construction or incineration chambers) and smoldering chambers or **smoldering processes** are deployed next to drum-type kilns at hazardous waste incinerators.

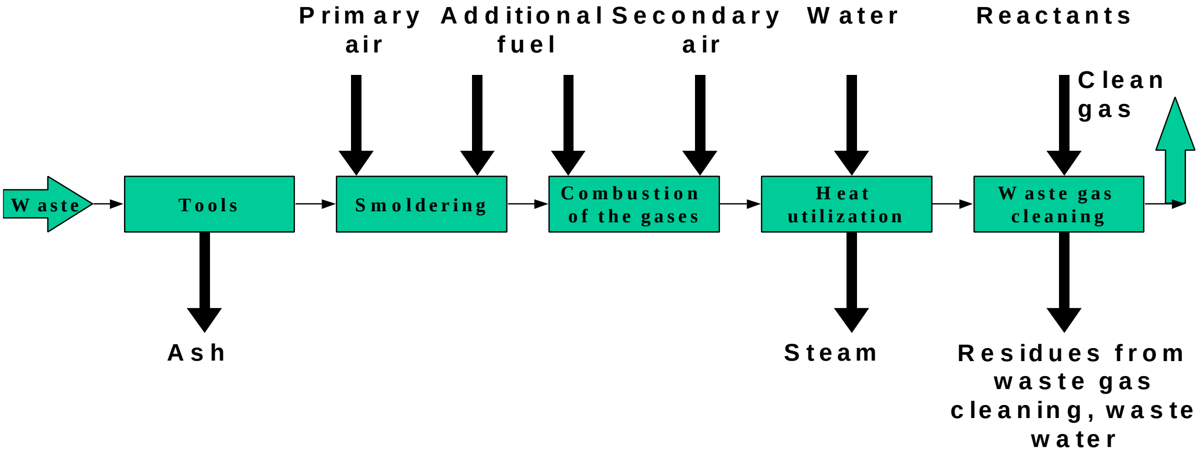
In traditional incineration, the material is conducted through zones of drying, degassing, gasficiation and incineration, as well as incineration of solid and gaseous incineration products concentrated in principle on the area of the furnace after the wastes are supplied under a surplus of air (primary air supply). The incineration process is mainly deployed on a continuous basis, in contrast to the smoldering process.

Basic flow chart of combustion processes



In the smoldering process (Pyrolyse) the process steps of drying, degassing, and partial steps of gasification must be physically separated from the actual incineration process in typical smoldering chamber processes. Thermal conversion of the waste occurs when a deficit of oxygen is present (under stochiometric) at a temperature range of 500 to 600° C. Smoldering gas is produced, as well as an ash residue. The complete incineration of smoldering gas occurs in a separate incineration chamber.

Basic flow chart of smolder processes



Both process types employ specific methods of operation as quasi-central plants for the thermal treatment of hospital-specific wastes from a larger geographical area. Depending upon the location, one could decline its own heat utilization and waste gas cleaning by using larger waste incineration plants where the produced waste gas is conducted to the waste gas flow of a larger incineration plant and the combined gasses are treated. This linkage can go so far that separate incineration units for hospital-specific wastes are integrated physically into a larger waste incineration plant. Examples for such plant combinations can be found in the incineration processes of the MVA Bielefeld-Herford where the grate furnace is part of the total incineration with grate rails (System Fröhling-Siegofa). The smoldering process (System Hoval) can be seen in two plant examples in Germany. At the Kiel-Wellsee location, there is a two-street treatment plant complete with heat utilization and waste gas cleaning (17.BImSchV). Another plant of the same type is part of the MVA Augsburg as a partial plant (without heat utilization and waste gas cleaning).

In each case, the waste supply and subsequent treatment processes are planned in such a way that the requirements of Article 6, paragraph 7 of Guideline 2000/76EG are taken into account, whereby infectious clinical wastes are introduced into the furnace without previous mixing with other waste types and without direct handling.

2.10 Co-incineration of Waste in the Cement and Lime Industries

2.10.1 Waste Pre-treatment

In order to deploy waste in the cement and lime industries, partially comprehensive pre-treatment is required to convert the waste into a form that corresponds to that of primary fuel or which approaches it. Only a few types of waste can be deployed without pretreatment (some old tires, but they must also be crushed into small pieces).

Fuels for the production phase are lignite or bituminous coal or similar material, such as petroleum coke in powder form. Secondary fuels must therefore be transformed in such a way that they can be deployed in a powder burner or in a multi-fuel burner. In addition to the appropriate physical characteristics, the chemical composition of the wastes (secondary fuels) are especially important to ensure that emission limits are not exceeded in co-incineration and that they do not reach an unacceptable limit of toxic material content.

Further requirements could derive from the desired color of the product (burned lime or white cement). Unwanted chemical reactions (e.g., the enrichment of phosphor) and specific reactions or enrichment processes in some technologies (e.g., alkaline chloride evaporation and recondensation) must be taken into account.

It might be advantageous for the accepting plant if a quality assurance system were available for the frequently heterogeneously-combined original material with which the waste producer could offer standardized fuel qualities.

The co-incinerating plant is responsible for setting the physical requirements for the waste (see specifically, the BREF on the cement and lime industry). A short version can be found below).

For deployment in burners, only those wastes can be used that would also qualify for use in modern multi-component burners, which require a kernel size of approximately 10 mm. In addition, there is the possibility of adding them to raw materials during processing, rather than feeding them to the burners. Such waste fuels could contain significantly coarser pieces as regular fuel (old tire cuttings). If the wastes are added to the raw materials, one must consider that cement and lime plants are not equipped with post-connected after-burner chambers, meaning that the wastes that are deployed here must be appropriate. The utilized pyrolyse of organic ingredients must not lead to an encumbrance of the gas. The TOC content in the waste gas at cement plants is defined through the pyrolyse of organic raw material ingredients (e.g., marl).

2.10.2 Waste Storage

2.10.3 Overview, in which Wastes can be deployed in the Process

2.11 Co-incineration of Wastes in the Iron and Steel Industries

2.11.1 Waste Pre-treatment

2.11.2 Waste Storage

2.11.3 Overview, in which Wastes can be deployed in the Process

2.12 Co-incineration of Wastes in Power Stations

2.12.1 Preamble

In principle, the possibility of co-incineration of wastes exists in a variety of power stations. The co-incineration of waste gasses in power stations will not be described here, as a “horizontal BREF“ exists. Gas power stations are not included in waste deployment.

There is little information available on the possibility of co-incinerating liquid wastes for the deployment of primary liquid fuels. In chemical industry power stations, liquid wastes are deployed consisting mainly of solvents and distillation residues. The same is valid for the petrochemical industry. The deployment of fats from the treatment of animal parts at a heavy oil power station is a new development.

At power stations where primary solid fuels are used, solid waste and to a certain extent, liquid wastes, can be deployed. In practice, certain applications are being considered; they will be described below.

As the power stations have not been designed for the deployment of wastes as fuel, waste gas treatments are directed toward the requirements of energy conversion. This must be considered, as different emission limit values exist for traditional waste incineration plants and others exist for power stations. In addition, there are differing requirements concerning the continuous measurements of toxic substances in waste gasses for power stations, depending on the deployment location of the wastes.

Due to the combinations of wastes, or additional emissions during incineration in power stations, it might be necessary to take the following additional measures:

- Deployment of additional waste gas cleaning equipment to fulfill the requirements of a waste incineration guideline, and

- A determination of the fuel composition if the plant is operated without additional waste gas cleaning equipment.

The first variable is safer but might also be more expensive. The second variable could be more expensive based on the required fuel quality controls, but can achieve the same protective target with good conversions and controls.

2.12.2 Waste Pre-treatment

Based on the different furnace technologies in power stations that depend on the kernel size of the spent solid fuels, there are different requirements covering pre-treatment of the applied fuels. The following fuel types can be differentiated:

- Fluff (kernel size 10-100 mm)
- Soft pellets (kernel size approximately 10 mm)
- Hard pellets (kernel size approximately 10 mm)

Fluff is especially useful in fluidized bed furnaces but is not appropriate for dust and melt chamber furnaces given the present state of knowledge. **Soft- and hard pellets** are useful as pre-material for dust and melt chamber furnaces. Insofar as these fuels can be used directly, or whether they need further crushing in a coal mill, depends among other things on whether independent burner systems are available for auxiliary fuels or whether they can be installed. In addition, the geometry of the incineration chamber is important, as well as the residence time of the fuel in the incineration chamber. Significantly smaller kernels have often been primary fuels. Less flammable wastes (auxiliary fuels) are therefore incinerated faster than those of a larger size and do not burn completely during the residence time in the incineration chamber.

The co-crushing of wastes in coal mills is possible in some cases where the physical characteristics do not differ greatly to those of coal, which is not so in all cases (e.g., plastics). Whether such a co-crushing is feasible, and if so, to what extent, can only be discovered in practice.

2.12.3 Co-incineration of Sewage Sludge in Coal Power Stations

Sewage sludge has been co-incinerated for several years in coal power stations. This is true for hard coal-, as well as for lignite power stations. These power stations are approved for continuous operation. In additional locations, co-incineration has taken place successfully in hard coal or lignite power stations and applications have been submitted for continuous operation (compare with Table 19).

In German coal power stations, approximately 58 million Mg of hard coal and 159 million Mg of lignite are combusted annually. Theoretically, all of the accumulated sewage sludge in Germany could be co-incinerated. This would mean that approximately 1% of the incineration heat capacity of power stations would be used for such purposes. In relation to the dry substances in sewage sludge, this would constitute a share of 1.4% of incinerated coal. Assuming a dry substance content of 25% in sewage sludge, this would constitute approximately 6% of the coal that could be replaced through co-incineration. The following Table 20, gives an overview of the coal power stations in Germany that co-incinerate sewage sludge.

Number of Plants	Regular Fuel	Incineration Type	Continuous operation (approved)	Deployed Sewage Sludge
17	Hard coal (10) Lignite (7)	Dust furnace, mill dust furnace, melt chamber furnace, circulating fluidized bed furnace, grate furnace	6 Hard coal power stations 5 Lignite power stations with various furnaces	Dry substance content, normally between 30-98%

Table 20: Co-incineration in Coal Power Stations

Lignite power stations executing or planning co-incineration are either equipped with a grate furnace, a mill dust furnace, or a circulating fluidized bed furnace. In incinerations with lignite, the sewage sludge must be drained and mixed because of similarities in heat value and relative high water content. The two substances can be processed and incinerated together as in the Industriekraftwerk Hürth-Berrenrath, using a circulating fluidized bed furnace. The sewage sludge is added with a solid material pump via ash recycling shafts to the circulating ash flow and then to the incinerator. Some power stations only accept communal, stabilized (meaning digested) sewage sludge whose heavy metal content lies within the values of the Sewage Sludge Ordinance (AbfKlärV) [26] (e.g., PreußenElektra).

For co-incineration of sewage sludge at power stations, the mixture emission limit values must be determined according to the Share Rule of 17. BImSchV up to a (sewage sludge) share of 25% of the furnace heat capacity (FWL). Assuming heat values for fabric bituminous coal of approximately 20 MJ/kg, and for sewage sludge of approximately 10 MJ/kg, up to 50 Gew.-% of the coal in the supply to the furnace must be replaced by sewage sludge. For bituminous coal with a heat value of 30 MJ/kg, this value will increase to 75%. In order to avoid further straining the power station operation, and especially not the waste gas values and the recovery of power station residues (slag, REA-plaster), a maximum of 5 Gew.-% (≈ 2% of FWL) of sewage sludge should be deployed.

Due to the high ash content in sewage sludge, the circulating fluidized bed furnace is especially appropriate for co-incineration. Successful incineration takes place using this technology, and the ash can be removed under controlled circumstances. As the ash share in sewage sludge is significantly higher (50% related to the dry substance) than that of lignite, appropriate measures must be taken in the separation of dust and the removal of slag.

The composition of the sewage sludge determines whether the toxic substance emissions change significantly with co-incineration in the power station. Here, very volatile heavy metals and HC1 are potentially important. In drainage through lime conditioning, sulfur emissions can be reduced by increasing the lime share in the sewage sludge.

No drying is required in the co-incineration of sewage sludge in a grate furnace for bituminous coal. Sewage sludge is delivered into the incineration chamber via a belt-charging machine, or together with the coal using the same conveyor equipment. Due to low expenses, this is a very economical process where a sewage sludge share of 5% incineration heat capacity is recommended. Previous drying of the sewage sludge in a dust furnace is required. The materials can be mixed in a coal mill and then blown together into the furnace.

Details concerning the co-incineration of wastes in power stations can be found in Chapter 8 of the draft for the BREF “Large Incineration Plants.“

2.13 Co-incineration of Wastes in Other Industries

2.13.1 Waste Pre-treatment

2.13.2 Waste Storage

2.13.3 Overview, in which Wastes can be Deployed in the Process.

3 EMISSIONS AND CONSUMPTIONS IN THE COURSE OF WASTE INCINERATION

3.1 Introduction

Decisive factors for the emissions in the course of waste incineration are the structure of the waste combusted, furnace-technical parameters and the capacities of the waste gas cleaning facilities. The typical chemical structures of the different groups of waste have already been treated in detail in Chapter 1.7.1 (cf. table 5). The following sections include descriptions of typical crude gas structures and clean gas emissions from incineration plants. Municipal waste incineration plants require between 4,500 and 6,000 m^3 of air per tonne of waste to be burnt if operated optimally. For hazardous waste incineration plants, this value is between 6,500 and 10,000 m^3, depending on the average thermal value.

The HCl, HF, SO_2, NO_x, PCDD/PCDF and heavy metal emissions depend mainly on the structure of the waste and the waste gas cleaning quality, whereas the CO and C_{ges} are determined primarily by furnace-technical parameters.

Depending on the type of waste gas cleaning, emissions into the medium water may also occur if wet waste gas cleaning without evaporation or condensation is used. At 2 of the present 60 municipal waste incineration plants, waste water used for waste gas cleaning is let off. In the case of hazardous waste incineration plants, the portion of plants with wet waste gas cleaning is considerably higher due to structure of the waste. The waste water from waste gas cleaning is pretreated together with waste water from other areas in accordance with the provisions of the Water Resources Act in consideration of the leading-in requirements of the waste incineration guidelines.

For the operation of the waste incineration plants and, in particular, of the waste gas cleaning, energy and a number of process materials are required, of which the amounts used will also be treated in detail in the following.

3.2 Distribution of the Elements in the Incineration Process

As a result of their chemical properties, the different elements contained in the waste are distributed differently en the products of the incineration process. the following table 20 gives an idea of this distribution on the basis of Austrian examinations at the waste incineration plant of Spittelau.

Even though this distribution varies from plant to plant, depending on the waste gas cleaning method used, these figures provide a rather good orientation for other plants as well. There may also be differences resulting from different structures of waste, especially in the case of hazardous waste incineration facilities.

	Clean gas	E filter dust	Waste water	Filter cake	Slag
Carbon	98 (+/-2)	<1	<1	<1	1,5 (+/-0,2)
Chlorine	<1	35	54	<1	11
Fluor	<1	15 (+/-1)	<1	<1	84 (+/-1)
Sulphur	<1	38 (+/-6)	8 (+/-1)	6 (+/-1)	47 (+/-7)
Phosphor	<1	17 (+/-1)	<1	<1	83 (+/-1)
Iron 1)	<1	1 (+/-0,5)	<1	<1	18 (+/-2)
Copper	<1	6 (+/-1)	<1	<1	94 (+/-1)
Lead	<1	28 (+/-5)	<1	<1	72 (+/-5)
Zinc	<1	54 (+/-3)	<1	<1	46 (+/-3)
Cadmium	<1	90 (+/-2)	<1	<1	9 (+/-1)
Mercury	<1	30 (+/-3)	<1	65 (+/-5)	5 (+/-1)

1) the remaining approx. 80% are sorted out as scrap

Table 21: Distribution of the elements in the incineration process (in mass %)

3.3 Structure of Crude Gas in Waste Incineration Plants

The structure of crude gas in waste incineration plants depends on the structure of the waste and on furnace-technical parameters. In the case of municipal waste, the structure depends, among other things, on the systems used for the collection of different fractions of waste. For example, the separate collection of different fractions influences the thermal value of municipal waste in the following way:

- → Glass and metal: Reduction of the ash content, resulting in an increase in the thermal value
- → Paper: Reduction of the thermal value
- → Light packaging: Reduction of the thermal value
- → Organic waste: Increase in the thermal value

Parameters such as the chlorine content and heavy metals are also influenced, but the changes remain within the typical range of variations. In the case of non-hazardous waste from commercial enterprises, however, the ranges of variations can be considerably greater, as examinations in several incineration plants have shown. This must be taken into account for the mixing in the bunker.

The composition of hazardous waste may vary within a considerably greater range. Besides, other parameters can also be significant in the case of hazardous waste, e.g. fluor, bromine, iodine or silicon. Unlike in the case of municipal waste, however, the structure is known in advance and is normally verified at the incineration plants by means of a check analysis of all essential parameters. Due to the possible variations, a hazardous waste incineration plant is designed with regard to an average waste structure (menu), in some cases with considerable reserves for waste gas cleaning.

Such a incineration menu can then be created by intentionally mixing the arriving waste in the tankage or the bunker or by intentionally feeding the waste individually and leading it to the furnace in separate pipes in hourly amounts corresponding to the design of the plant. This must also be taken into account accordingly if waste is fed in barrels. The design of special plants for regaining HCl and SO_2 from waste containing chlorine or sulphur, respectively, may clearly deviate from this. The following table provides an overview of typical crude gas concentrations after the boiler and before the waste gas treatment.

Components	Units	Incineration plants for		
		Municipal waste	Hazardous waste	Sewage sludge (fluidized bed)[13]
Dust	g/Nm³	1 - 5	1 - 10	30 – 200
Carbon monoxide (CO)	mg/Nm³	5 - 50	<30	5 - 50
TOC	mg/Nm³	1 - 10	1 - 10	1 - 10
PCDD/PCDF	ng/Nm³	0,5 - 10	0,5 - 10	0,1-10
Mercury	mg/Nm³	0,05 - 0,5	0,05 - 3	0,2
Cadmium + thallium	mg/Nm³	< 3	< 5	2,5
Other heavy metals (Pb,Sb, As, Cr, Co, Cu, Mn, Ni, V, Sn)	mg/Nm³	< 50	< 100	800
Inorg. chlorine compounds, counted as HCl	g/Nm³	0,6 - 20	3 - 100	
Inorg. fluor compounds, counted as HF	mg/Nm²	5 - 20	50 - 550	
Sulphur compounds, total of SO_2/SO_3, counted as SO_2	mg/Nm³	200 - 1000	1500 - 50000	
Nitrogen oxides, counted as NO_2	mg/Nm³	250 - 500	100 - 1500	< 200
Dinitrogen oxides	mg/Nm³	<40	<20	10 - 150
CO_2	%	5 - 10	5 - 8	
Water steam (H_2O)	%	10 - 20	6 - 20	

Table 22: Waste gas concentrations as daily averages after the boiler (crude gas) at waste incineration plants in Germany (O_2 reference value 11 %)14

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[13] Plants for the incineration of industrial sewage sludge

[14] The information in the table refers to German plants. Especially in the case of emissions influenced by furnace-technical parameters, the emissions facilities of older types can be considerably higher.

3.4 The Individual Emissions

3.4.1 Carbon Monoxide

Carbon monoxide (CO) in the waste gas of incineration plants is the product of an incomplete incineration process. For this reason, CO emissions occur in particular if the available oxygen is not sufficient. In particular, this can be the case if spontaneously evaporating or fast-burning substances are within the system. The purpose of the continuous measuring of the CO (and C_{gas}) emissions is to check the efficiency of the incineration process. In the atmosphere, CO is oxidized to CO_2 very fast. Particularly high concentrations of CO (> lower explosibility limit) must be avoided as they can create explosive mixtures in the waste gas. At hazardous waste incineration plants, increased CO emissions can occur especially in connection with the incineration of waste stored in barrels.

3.4.2 Total Carbon

This parameter includes a number of gaseous organic substances, the individual detection of which is hardly possible or very complicated. During the incineration of organic waste, a large number of chemical reactions, which are never complete and which lead to an extremely complex pattern of compounds in the trace area, take place simultaneously. A complete account of the materials within the parameter total carbon (TOC) is not possible according to present knowledge. In the incineration of these substances, however, a incineration efficiency of > 99.9999 % is achieved. In almost all cases, waste incineration plants observing the emission limits of the guideline 2000/76/EU therefore emit lower quantities into the air of the surrounding area than is the case in other industrial processes or, for example, in the burning of coal or wood.

3.4.3 Hydrogen Chloride and Other Hydrogen Compounds

Much of the waste led to the incineration process contains chlorinated organic compounds or chlorides. In the incineration process, these compounds are destroyed, and the chlorine is converted to HCl. Part of the HCl may react further to metal chlorides on inorganic compounds which are also contained in the waste. The formation of Cl_2 (Deacon process) is of minor importance under normal incineration conditions. This can, however, be different in special plants for recycling highly chlorinated residues.

3.4.4 Hydrogen Fluorides

The formation mechanism of HF in incineration plants corresponds to that of HCl. The main sources of HF emissions in municipal waste incineration plants are probably fluorinated plastic or fluorinated textiles and, in individual cases, the decomposition of CaF_2 in the course of the incineration of sludge. In hazardous waste incineration plants, various kinds of fluorinated waste are disposed of. Besides, two special plants for the utilization of waste containing fluor, in which the fluor is regained in the form of HF or CaF_2, exist in Germany.

3.4.5 Hydrogen Iodide and Iodine, Hydrogen Bromide and Bromine

Municipal waste usually hardly contains any bromine or iodine compounds so that bromine or iodine emissions are of minor importance to municipal waste incineration plants. In hazardous waste incineration plants, however, organic and inorganic waste containing bromine or iodine is also combusted. For example, bromine compounds can still be contained in consumer electronics devices as flame protection agents, and iodine can be contained in medicine or be used for the treatment of metal surfaces. On the whole, however, their quantity is small in relation to chlorine organic compounds.

Due to the fact that elementary bromine or iodine can be created besides halogen acid one in the process of the conversion of bromine or iodine organic compounds, the waste gas plume can be expected to be coloured. For this reason, special measures must be taken in the case of the incineration of such waste in order to prevent the formation of elementary bromine or iodine, respectively.

3.4.6 Sulphur Oxides

If the waste contains sulphur compounds, mainly SO_2 is created during the incineration of the waste. Under appropriate reaction conditions, portions of SO_3 can also be created.

3.4.7 Nitrogen Oxides

The NO and NO_2 emitted from waste incineration plants originates from the conversion of the nitrogen contained in the waste (so-called fuel NO_x) and from the conversion of atmospheric nitrogen from the furnace air into nitrogen oxides (thermal NOx). In municipal waste incineration plants, the portion of thermal NOx is very low due to the lower temperatures in the afterburner chamber.

The mechanisms for the formation of NOx out of the nitrogen contained in the waste are very complicated, among other things because nitrogen can be contained in the waste in many different forms of linkage which can react either to NOx or to elementary nitrogen, depending on the chemical environment. One usually assumes a conversion rate of approx. 20 % of the fuel nitrogen. The portion of No in the total NO_x emissions is usually approx. 5 %, whereas the one of No_2 is 95 %.

3.4.8 Dust

Dust emissions from waste incineration plants mainly contain the fine parts of the ash from the incineration process. Due to the current speeds in the incineration process, these fine parts are entrained. Depending on the reaction balance, the corresponding elements and compounds are concentrated in this airborne dust. This is indeed a desired process with which these compounds (e.g. metal chlorides) are kept outside the ecosystem by means of separation of dust.

As far as the distribution of grain sizes is concerned, one can assume that the main part of the dust emissions consists of respirable dust (PM_{10}). Due to the highly effective separation of dust which is applied in waste incineration plants, the relative portion of respirable dust (PM_{10}) in clean gas is almost 100 %. With the effective dust filters used at waste incineration plants, the absolute respirable dust (PM_{10}) emissions are, of course, also reduced considerably. In relation to the total respirable dust emmissions, the portion created at waste combustion plants is virtually unimportant.

3.4.9 Mercury and Mercury Compounds

Mercury can currently still be found in municipal waste in the form of batteries, thermometers and similar items. This also applies if this hazardous waste is collected separately as this cannot be done with a collection rate of 100 %.

In hazardous waste incineration, there are several specific streams which may contain increased concentrations of mercury:

→ Tars from coking plants
→ Waste from chlorine alkaline elecctrolyses (amalgam process)
→ Oil sludge from refineries
→ Chemicals containing mercury

The form of the mercury emissions depends strongly on the chemical environment in the waste gas as a balance between metallic mercury (Hg_o) and $HgCl_2$ normally develops. In the case of a sufficiently high concentration of HCl in the waste gas, also in relation to the reduction agent SO_2, mercury will mainly be contained in the waste gas as $HgCl_2$, which can be separated significantly more easily than metallic mercury. If, however, HCl is contained in the waste gas, e.g. in sewage sludge incineration plants, mercury exists in the waste gas mainly in metallic form.

While metallic mercury is virtually not soluble in water independently of the pH value (59µg/l at 25°C), mercury (II) chloride is well soluble with 73 g/l. Mercury (II) chloride can therefore be separated well in wet scrubbers, whereas the separation of metallic mercury may require further treatment stages (airborne current process, activated coke stage etc.).

3.4.10 Cadmium and Thallium Compounds

Sources of cadmium in municipal waste incineration plants are electronic devices (including accumulators) and cadmium-stabilized plastic. Thallium is virtually not contained in municipal waste.

3.4.11 Other Heavy Metal Compounds

This term comprises the heavy metals antimon, arsenic, lead, chromium, cobalt, copper, manganese, nickel, cadmium, tin and their respective compounds as they are evaluated in the same group in discontinued emission measurements according to European and many national regulations. This group contains cancerogenous metals and metal compounds such as arsenic and chromium (VI) compounds as well as metals to which no environmental relevance can be ascribed.

The retaining of these metals depends largely on an effective separation of dust as they are bound in dust due to the steam pressures of their compounds contained in the waste gas (mainly oxides and chlorides).

3.4.12 Polychlorinated Biphenyls

Low qunatities of polychlorinated biphenyls (PCBs) can exist in all streams of waste, Waste with large portions of PCBs, however, only exists in cases in which the PCB destruction programmes which are binding in Europe have not been completed on a national level.

In hazardous waste incineration plants, waste with a PCB content of up to 60 % can be combusted. The same applies to special plants for the incineration of highly chlorinated hydrocarbons. It can be assumed that all PCBs are destroyed in a highly efficient way if a sufficiently high incineration temperature and suitable processes are used. PCBs contained in the crude gas of waste incineration plants should be the result of recombination reactions in a way similar to dioxins and furan (cf. Chapter 3.4.14).

PCB emissions are classified as potentially toxic by some international organizations (e.g. WHO) as a toxic potential similar to that of dioxins and furan is ascribed to some of the PCBs (coplanar PCBs). This judgement, however, is still disputed among experts.

3.4.13 Polyaromatic Hydrocarbons

Polyaromatic hydrocarbons are typical products of incomplete incineration processes and have been known as such for many years. They are significant because some of the compounds are considered to be cancerogenous.

3.4.14 Polychlorinated Dibenzo Dioyins and Furan

Dioxins and furan (PCDD/PCDF) have played a main part in the debate about waste incineration for almost 15 years after it had been found in Europe-wide examinations that compounds which were classified as poisonous and cancerogenous in the accident at the town of Seveso in northern Italy are also formed in all waste incineration processes.

Meanwhile., it has become cleat that this is not a process specific to waste incineration but one which occurs in all thermal processes under appropriate process conditions. As a result, it is understandable that, in many countries, waste incineration is no longer the main source of dioxin and furan emissions by far – if it has ever been at all.

The formation mechanisms of the dioxins and the furan in thermal processes, especially in waste incineration, were disputed for a long time. Meanwhile, it can be considered to be sure that dioxins and the furan entering the process over the waste are destroyed very efficiently if sufficiently high incineration temperatures and appropriate process conditions exist. The dioxins and the furan found in the crude gas of waste incineration plants are the result of a recombination reaction from the constituents carbon, nitrogen, oxygen and chlorine. In some cases, suitable precursor substances (e.g. from chlorophenols) can also react to dioxins and furan. In the formation of the substances, certain catalysers in the form of transitional metal compounds (e.g. copper) also play an important part. In Chapter 3,7, the entry of PCDD/PCDF in a municipal waste incineration plant and the different forms of discharge are summarized and, as a result, accounted for.

3.4.15 Other Emissions

In the public debate, it is often claimed that, besides the above-mentioned emissions, other emissions, especially organic ones, are significant. The opinions on whether or not examinations of the clean gas of waste incineration plants would support these assumptions diverge.

As has already been explained in Chapter 3.4.2, numerous organic materials are created in the course of the incineration of organic materials as the incineration processes are not complete as a rule. For this reason, these compounds in the fuel gas can be detected in the trace area (fg/m^3 to µg/m^3) even if the best available crude gas cleaning technology is used. If, however, the results of measurements at waste incineration plants with those performed at other facilities, it becomes clear that, in the course of waste incineration at a plant with state-of-the-art equipment, fewer organic trace materials than in the course of the burning of coal or wood or in other industrial processes are emitted in many cases. Furthermore, it can be said very generally that virtually every waste gas cleaning measure constitutes a reduction of toxic agents, i.e. fewer toxic agents than have entered the plant over the waste are emitted from the plant.

3.4.16 Emissions of Gases Relevant to Climate

3.4.16.1 Sources and Total Emissions Relevant to Climate in Germany

The total emissions relevant to climate in Germany in the year 1999 and the emissions from waste incineration (related to the fossil portion of the waste which is relevant to climate) are summarized in table 23. In the following figures, the waste sector, and especially waste incineration, has, apart from methane, not been recorded separately but included in the energy sector.

The sources of **CO_2 emissions** in Germany which should be considered to be relevant are the energy sector with 641,000 Gg (including households and small consumers), traffic with 191,000 Gg and industrial processes with 26,000 Gg. The sources of **dinitrogen oxide (N_2O)** are agriculture and the waste sector with 83 Gg, the energy sector with 20 Gg as well as solvents and other products with 6 Gg. The relevant **methane sources** are agriculture with 1,468 Gg, the production and distribution of fuels with 923 Gg and the waste sector with 794 Gg. In the case of **nitrogen oxides (NO_2)**, traffic with 1,045 Gg and the energy sector with 580 Gg are also dominant, whereas industrial processes contribute only 12 Gg. In the case of **carbon monoxide (CO)**, traffic with 2,792 Gg and the energy sector with 1,602 Gg are also dominant, followed by industrial processes with 558 Gg. The main sources of non-methane **volatile organic compounds** (NMVOC) are solvents and their products with 1,000 Gg, traffic with 387 Gg, the energy sector with 72 Gg and industrial processes with 138 Gg. The relevant sources of **SO_2 emissions** are the energy sector (including households and small consumers) with 722 Gg and industrial processes wit 78 Gg.

Pollutants in 1999	Total emissions [Gg/year]	Global warming potential (GWP) CO_2 equivalents [Gg/year]	Waste incineration (fossil portion) of the total emissions [Gg/year]
Carbon dioxide CO_2	858.511	858.511	8.685
Dinitrogen oxide N_2O	141	43.710	0,81 (252)*
Methane CH_4	3.271	68.691	n/a
Fluorinated hydrocarbons	3,284	4.290	
CF_4 (perfluorinated hydrocarbons)	0,186	1.209	
C_2F_6 (perfluorinated hydrocarbons)	0,046	423	
C_3F_8 (perfluorinated hydrocarbons)	0,011	77	
SF_6 (sulphur haxafluoride)	0,229	5.473	
Total GWP		**982.384**	**(ca. 9000)***
Indirectly effective greenhouse gases			
Nitrogen oxide NOx (as NO_2)	1.637		15,2 (122,24)*
Carbon monoxide CO	4.952		3,82 (11,46)*
NMVOC (non-methane volatile organic compound)	1.651		0,76 (8,36)*
Ammonia NH_3	624		0,3
Aerosol formers			
Sulphur dioxide SO_2	831		n/a

(..)* in brackets: the converted emission value in CO_2 equivalents for comparison with the GWP

Table 23: Total emissions relevant to climate in Germany in the year 1999

In the future, the annual emissions relevant to climate in one state must be determined on the basis of the requirements of the new IPCC guideline "Good Practice Guidance and Uncertainty Management in National Greenhouse Inventories": This guideline agreed on an international level was passed as part of the **I**ntergovernmental **P**anel on **C**limate **C**hange IPCC/OECD/IEA Programme for National Greenhouse Gas Inventories in the year 2000. It prescribes which emissions relevant to climate from the different sectors (e.g. energy, industry, agriculture, waste) are to be calculated and how this is to be done. For waste incineration, only CO_2 and N_2O have been classified as gases relevant to climate so that appropriate calculation formulas were given for them.

3.4.16.2 Carbon Dioxide (CO_2)

If one Mg of municipal waste is combusted, approx. 0.7 to 1.2 Mg of CO_2 is generated. this CO_2 is released directly into the atmosphere and, as a result, actually contributes to the greenhouse effect; on a global scale, however, only the CO_2 emissions from fossil sources which have an effect on the climate are considered as a rule. As municipal waste combusted is a heterogeneous mixture of waste, carbon of biogeneous and of fossil origin are distinguished with regard to the origins of the CO_2 from these plants. In the literature, the portion of CO_2 to which a fossil origin (e.g. plastic) can be ascribed and which must therefore be considered relevant to climate is stated with 33 to 50 %. This distinction does not take into account the fact that, in the case of waste of biogeneous origin, a fossil part of the development of the product also exists. This part has its origin in production and transport (e.g. of textiles, paper/cardboard, compound materials, wooden furniture) and must be assigned to the original product or the fraction of waste, respectively, as relevant to climate and counted as such. As, however, this portion is already included in the relevant branches of industry (production and traffic), it will not be considered here.

3.4.16.3 Dinitrogen Oxide (N_2O)

Besides the above-mentioned carbon dioxide compounds, the dinitrogen oxide N_2O (laughing gas) is also relevant from the point of view of international climate. From municipal waste incineration, N_2O emission values of 1 to 12 mg/m^3 in individual measurements and averages of 1 to 2 mg/m^3 are known. Individual measurements in hazardous waste incineration plants have resulted in N_2O emission values of 30 to 32 mg/m^3. For the incineration of sewage sludge in fluidized bed plants, the measured N_2O emission values (individual measurements) are considerably higher.

3.4.16.4 Carbon Monoxide (CO)

If municipal waste is combusted at municipal waste incineration plants, carbon monoxide CO is created as a product of the incomplete incineration. The CO is a leading component of the incineration and must be considered an important quality criterion for the gaseous incineration. As a rule, the CO in the plants is measured continuously. The daily averages of the CO emissions are below 50 mg/m^3 . At BAT plants, the daily averages are within a range <10 mg/m^3 .

3.4.16.5 Nitrogen Oxides (NOx)

If waste is combusted at municipal waste incineration plants, nitrogen oxides NO_x (NO, NO_2) are created; they are mainly formed with the nitrogen contained in the waste, during the incineration process and as so-called prompt NO_x. As a rule, nitrogen oxides are measured continuously in the waste gas of the plants. If nitrogen removal measures were not taken in an municipal waste incineration plant, there would be emissions of 350 and 400 mg/m^3. With targeted waste gas cleaning measures (SNCR, SCR), an emission value of 200 mg/m^3 can be kept with certainty. At BAT plants with SNCR technology, the emission values range from 100 to 150 mg/m^3, at plants with SCR technology < 70 mg of NO_x/m^3.

3.4.16.6 Non-Methane Volatile Organic Compound – NMVOC

During waste incineration, the organic compounds (organic C) are measured continuously in the waste gas as the sum parameter total carbon. It constitutes a leading component for the quality of the incineration in a incineration process. Although the emissions are limited to 10 mg/m^3 in Germany, they are normally about 5 mg/m^3 or, at BAT plants, about 1 mg/m^3.

3.4.16.7 Ammonia (NH_3)

If waste is combusted, ammonia emissions result from the addition of ammonia (including ammonia water) as part of secondary nitrogen removal measures (see Chapter 4.4). The emissions (measured as individual emissions) normally range from 1 to 10 mg/m^3, an average of 4 mg of NH_3/m^3 is assumed.

3.4.16.8 Methane CH_4

It can be assumed that, if waste is combusted in municipal waste incineration plants under oxidative incineration conditions (air excess of 1.7), methane emissions are not contained in the waste gas and therefore not emitted. Methane emissions can be created in the waste bunker; due to the low pressure in the waste bunker, however, they enter the incineration chamber as primary air together with the bunker air and are incinerated there.

In the following, an estimation will be performed for the storage of municipal waste on deposits in order to determine the relevance of CH_4 emissions relevant to climate compared with the total emissions and the GWP on the basis of the annual amount produced and deposited. For the portion of the municipal waste which was stored directly on deposits in 1990 (approx. $14.7x10^6$ Mg), the following can be stated with regard to the methane emissions resulting from it:

14,7 $x10^6$ Mg of municipal waste x 52 kg of CH_4/Mg of waste = 764,4 Gg methane/year. For 1998, total methane emissions from all sources amounting to 3,555 Gg of CH_4 are stated, resulting in a portion of approx. 21.5 % originating from the storage of waste on municipal waste deposits. The share of methane emissions from the storage of municipal waste in the **g**lobal **w**arming **p**otential (GWP) in Germany (764.4 Gg x 21 = 16,052.4 Gg of CO_2 equivalents out of a total of 1,022,346 Gg of CO_2 equivalents) was 1.6 % in 1998. If only this release of CH_4 is considered, this results in a CO_2 equivalent load relevant to climate of 1.092 Mg of CO_2/Mg of waste – without taking into account the CO_2 emissions which are also released during the deposition. In contrast to this, the CO_2 equivalent load resulting from the thermal treatment of municipal waste only amounts to 0.415 Mg of CO_2 per Mg of waste. This means that, in contrast to waste incineration, 62 % more CO_2 emissions relevant to climate are released as a result of the CH_4 load from the storage on deposits alone.

3.4.17 Summary of Typical Emissions from Municipal Waste Incineration Plants

Table 24 represents the results of a survey among German and European operators of plants (from countries with standards comparable to those of Germany) with regard to typical emissions from plants. Besides the thirty-minute and daily averages prescribed for the recording of measured values according to the European regulations, the annual averages are also shown.

Parameter	Type of measure-ment	Daily averages [mg/m^3]		Thirty-minute averages [mg/m^3]		Annual averages [mg/m^3]
	C: cont. D: discont.	Limits according to guideline 2000/76/EU	Typical range of values	Limits according to guideline 2000/76/EU	Typical range of values	Typical range of values
HCl	C	10	0,1-10	60	0,1-80	0,1-6
HF	C/D	1	0-1	4	0-1	0,01-0,1
SO_2	C	50	0,5-50	200	0,5-250	0,2-20
NOx[15]	C	200	30-200	400	30-450	30-180
Dust	C	10	0,1-10	20	0,1-15	0,1-4
TOC	C	10	0,1-10	20	0,1-25	0,1-5
CO	C	50	1-50	100	1-150	2-30
Hg	C/D	0,05	0,0005-0,03	n.a.		0,0002-0,05
Cd+Tl	D	0,05		n.a.		0,0002-0,03
Σ other heavy metals	D	0,5		n.a.		0,0002-0,05
PCDD/PCDF (ng TE/m^3)	D	0,1		n.a.		0,0002-0,08

Table 24: Typical range of clean gas emissions from municipal waste incineration plants

3.4.18 Summary of the Typical Emissions from Hazardous Waste Incineration Plants

Table 25 represents the results of a survey among German and European operators of plants with regard to typical emissions from plants. Besides the thirty-minute and daily averages prescribed for the recording of measured values according to the European regulations, the annual averages are also shown.

Parameter	Type of measure-ment	Daily averages in [mg/Nm^3]		Thirty-minute Averages [mg/Nm^3]		Annual averages [mg/Nm^3]
	C: cont. D: discont.	Limits according to guideline 2000/76/EU	Typical range of values	Limits according to guideline 2000/76/EU	Typical range of values	Typical range of values
HCl	C	10	0,1-10	60	0,1- 70	0,3-5
HF	C/D	1	0,04-1	4	0,1- 2	0,05-1
SO_2	C	50	0,1-50	200	0,1- 150	0,1-30
Nox	C	200	50-200	400	50-400	70-180
Dust	C	10	0,1-10	20	0,1-15	0,1-2
TOC	C	10	0,1-10	20	0,1-30	0,01-5
CO	C	50		100	5-150	5-50
Hg	C/D	0,05	0,0003-0,03	n/a		0,0004-0,05
Cd+Tl	D	0,05	0,0005-0,05	n/a		0,0005-0,05
Σ other heavy metals	D	0,5	0,0013-0,5	n/a		0,004-0,4
PCDD/PCDF (ng TE/m^3)	D	0,1	0,002-0,1	n/a		0,0003-0,08

Table 25: Typical range of clean gas emissions from hazardous waste incineration plants

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[15] In several memberstates there are no emission limit values in force for NOx. For installations in such countries a typical range of values is 250-550 mg/Nm^3 based on discontinous measurements.

3.5 Emissions into the Medium Water

3.5.1 Emissions from Waste Gas Cleaning

Water is used in waste incineration for various purposes. Table 26 shows typical values of the amount of scrubbing water from the waste gas cleaning of waste incineration plants. Besides, readers are referred to the horizontal BREF "waste water treatment", in which the treatment of waste water from waste incineration plants is dealt with in detail.

Plant	Type of waste gas cleaning	Amount of waste water
Municipal waste incineration plant with a throughput of 250,000 Mg/a	2 stages, with milk of lime	approx. 0.15 m^3/Mg of waste (design value)
Municipal waste incineration plant with a throughput of 250,000 Mg/a	2 stages, with soda lye (before condensation facility)	approx. 0,3 m^3/Mg of waste (operating value)
Hazardous waste incineration plant with a throughput of 60,000 Mg/a	2 stages, with milk of lime	approx. 0,15 m^3/Mg of waste (annual average)
Hazardous waste incineration plant with a throughput of 30,000 Mg/a	2 stages, with soda lye	approx. 0,2 m^3/Mg of waste (annual average)

Table 26: Typical values of the amount of scrubbing water from the waste gas cleaning from waste incineration plants

3.5.2 Other Water from Municipal and Hazardous Waste Incineration Plants

Besides the waste water from the waste gas cleaning, waste water from a number of other different sources, which is summarized in table 27, is produced.

Waste water	Amount	Occurrence
Chimney condensates after wet scrubbing	approx. 20 m^3/d / 6.600 m^3/a	(c)ontinuous
Wet ash removing / wet declining	approx. 5 m^3 /d / 1650 m^3/a*)	c
Reversible flow water from ion exchanger	approx. 10 m^3 / 4 weeks / 120 m^3 /a	(d)iscontinuous
Clearing water from boiler	approx. 500 m^3/a	d
Blocking and cleaning water from the cleaning of storage containers	approx 800 m^3/a	d
Blocking and cleaning water	approx. 300 m^3/a	d
Contaminated rain water	approx. 200 m^3/a	d
Laboratory water	approx. 200 m^3/a	d

*) calculated with 330 operating days per year

Table 27: Other water from municipal and hazardous waste incineration plants

3.5.3 Plants Free of Process Water

In many municipal waste incineration plants, the waste water from the treatment of waste gas is condensed in an internal process together with other waste water or led over a spray drier, for which additional heat from the incineration process can be used. The residues from this will be treated in more detail in Chapter 3.6. In this context, the treatment of the element mercury can be particularly significant. In order to prevent the development of an internal mercury cycle, which bears the risk of an increase in the amount of mercury in the process and of consecutive instances of breaking through, it must be ensured that the mercury is led out of the system at an appropriate point.

An operation of incineration plants which is free of process water is prescribed by law in some member states. Another reason for deciding in favour of such an operation can be the fact that there is no suitable draining ditch into which the waste water from the incineration process could be led after it has been pretreated in accordance with the provisions of the law. In Germany, the legal requirements for leading in process waste water from the waste gas cleaning of waste incineration plants are stipulated in Annex 47 to the waste water ordinance applicable in Germany [26]. It stipulates, among other things, that "waste water from the fuel gas cleaning of a household waste incineration plant man not be led in". Exceptions are only permitted if the residues from the fuel gas scrubbing (e.g. mixed salt, sludge or gypsum) cannot be disposed of properly and without contamination. Due to the fact that appropriate possibilities for a disposal (deposits, offset) exist in Germany and, as a result, a proper disposal without contamination is possible, the above-mentioned exceptional case can hardly be depicted.

Parameter	Concentration in qualified random sample or 2-hour composite sample [mg/l]	Freight [mg/Mg of waste]
Cadmium	0,05	15
Mercury	0,05	15
Chromium	0,5	150
Nickel	0,5	150
Copper	0,5	150
Lead	0,1	30
Zinc	1,0	300

Table 28: Requirements according to Annex 47

In as research project of the Federal Environmental Agency concerning "The Treatment of Environmental Contamination in Certain Industrial Processes in Different Media", the question in what respect processes free of waste water are more advantageous economically and ecologically in relation to treating waste water and leading it into a draining ditch was treated with regard to municipal waste incineration plants with different types of waste gas cleaning (e.g. wet waste gas cleaning with and without leading-in, dry and quasi-dry waste gas cleaning). According to this, an operation free of waste water has clear ecological advantages in relation to the leading.-in. If, however, the scope of considerations is extended to a system level in which the additional requirements of energy and operating resources as well as the disposal of waste are included, this ecological advantage of the wet processes free of waste water in relation to dry and quasi-dry waste gas cleaning processes may shift.

In the case of hazardous waste incineration plants, plants with a successive waste gas cleaning stage prevail.

3.5.4 Plants with Chemo-physical Waste Water Treatment

The treatment of waste water from the waste gas cleaning in waste incineration plants is not fundamentally different from the treatment of waste water from other industrial processes (cf. horizontal BREF "waste water treatment").

Waste gas from municipal waste incineration plants mainly contains the following substances requiring treatment:

- Heavy metals
- Inorganic salts (chlorides, sulphates etc.)
- Organic compounds (phenols, PCDD/PCDF)

The following table 29 shows typical contaminations of waste water from waste gas cleaning facilities of municipal and hazardous waste incineration plants before the treatment of waste water.

Parameter	Municipal waste incineration[16]			Hazardous waste incineration[17]		
	Minimum	Maximum	Average	Minimum	Maximum	Average
PH Value	< 1					
Conductivity (µS)		> 20000				
CSB [mg/ml]	140	390	260			22
TOC [mg/ml]	47	105	73			
Sulphate [mg/ml]	1200	20000	4547	615	4056	
Chloride [mg/ml]	85000	180000	115000			
Fluoride [mg/ml]	6	170	25	7	48	
Hg (µg/l)	1030	19025	6167	0,6	10	
Pb [mg/ml]	0,05	0,92	0,25	0,01	0,68	
Cu [mg/ml]	0,05	0,20	0,10	0,002	0,5	
Zn [mg/ml]	0,39	2,01	0,69	0,03	3,7	
Cr [mg/ml]	<0,05	0,73	0,17	0,1	0,5	
Ni [mg/ml]	0,05	0,54	0,24	0,04	0,5	
Cd [mg/ml]	<0,005	0,020	0,008	0,0009	0,5	
PCDD/PCDF						

Table 29: Typical contaminations of waste water from waste gas cleaning facilities of waste incineration plants before the treatment of waste water

According to some operators of plants in Europe, the separation of mercury can constitute a particular problem as mercury may, apart from its easily separable form as Hg(1) chloride, also exist as elementary mercury in forms bound in a complex way. However, waste water treatment methods (activated carbon, selective ion exchanger) with which these problems can be solved are available.

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[16] Source: EGK Krefeld (values from the acid scrubber)

[17] after pretreatment

3.6 Residues from Waste Incineration

Picture 24 provides an overview of which residues may exist at which points and in which quantities at an municipal waste incineration plant. The individual types of waste will be described in detail in the following, with the differences between different incineration plants being treated as well if applicable.

3.6.1 Introduction

The primary aim of waste incineration is to transfer waste into a form which makes a safe further treatment of their residues possible. In this process, the organic material existing in the waste is to be destroyed as thoroughly as possible and transferred into its constituents CO_2 and H_2O and a number of other organic substances (HCl, SO_2 etc.).

Waste is created inevitably in the incineration process. With appropriate processes, the waste gas cleaning can be used during the creation of this waste to regain a number of heavy metals and to exclude the remaining ones from the cycle of utilization by means of a safe deposition outside the ecosystem.

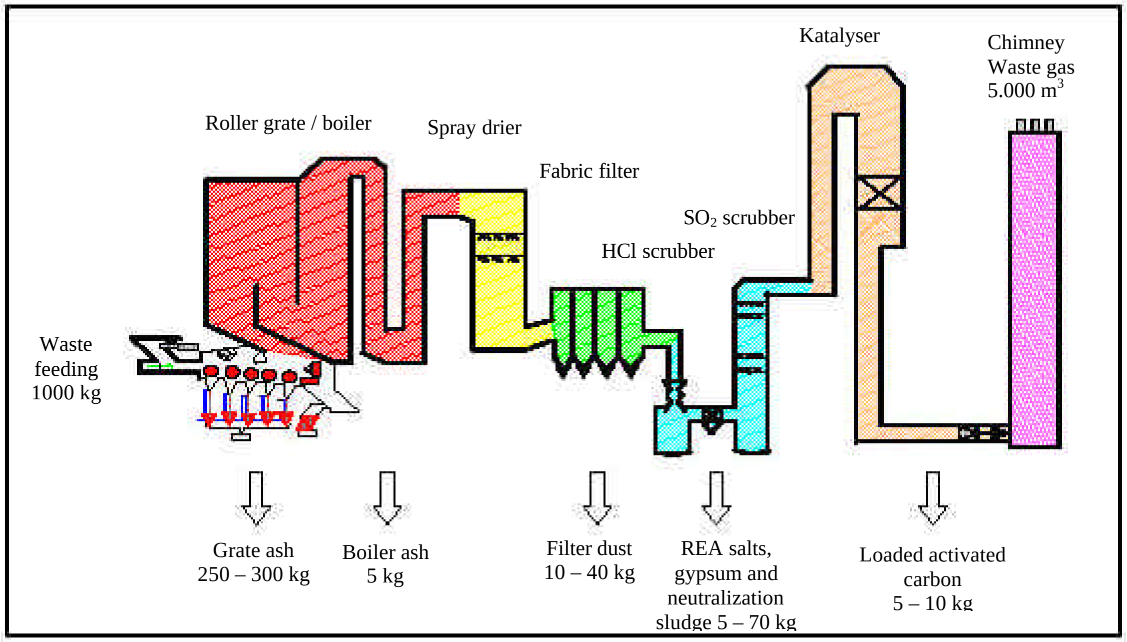

Figure 23: Overview of the typical residues in an municipal waste incineration plant

A number of technologies for the further treatment of waste from waste incineration are available, either with the aim of regaining individual materials or for eliminating or utilizing this waste. As most of these technologies are not used practically in Germany, they will be described in Chapter 6.

However, the utilization of this waste from waste incineration is possible in principle. This applies, in particular, to incineration ash or slag (the usage of the terms depends on the incineration temperature), to gypsum from the waste water treatment in the SO_3 scrubber and to hydrochloric acid for the processing of the scrubbing water from the HCl scrubber.

The positive or negative effect which such a incineration, e.g. of ash and slag as constituents of building materials,. has on the environment is, among other things, determined by the requirements of the water management industry. These requirements vary in the member states, which also leads to different requirements regarding the possibility to elute certain materials from the slag and, as a result, to the further treatment of slag.

The utilization of gypsum from the waste gas cleaning of municipal waste incineration plants, however, is the state of the art. Large-scale testing of processes for the generation of hydrochloric acid is being performed. Here, it is doubted if such a generation of hydrochloric acid is economically reasonable at all

3.6.2 Residues from Municipal Waste Incineration

Requirements concerning the quality of the residues from the incineration process can be deduced from the European incineration guidelines. According to these guidelines, a loss on ignition of = 5 % or a TOC of = 3 % must be observed. In table 30, some typical data on residues from municipal waste incineration plants is summarized.

Types of waste	Specific amount (dry) [kg/Mg of waste]
Slag/ash (fallen onto or through the grate)	250-350
Filter dust from dust removal	20-40
Reaction products of the separation of toxic gas:	
Wet sorption	8 – 15
Quasi-dry sorption	15 – 35
Dry sorption	25 – 45
Reaction products, incl. filter dust, from:	
Wet sorption	30 – 50
Quasi-dry sorption	40 – 65
Dry sorption	50 – 80
HCl (30%), if processing is done	10
loaded activated carbon	5-10

Table 30: Typical data on residues from municipal waste incineration plants

The following table 31 represents the structure of the waste regarding the original substances and the eluates (SEV-D4), taking a German municipal waste incineration plant as an example.

3.6.3 Residues from Hazardous Waste Incineration

Residues from hazardous waste incineration are not fundamentally different from those from municipal waste incineration. However, the following differences can be observed:

- In the case of ash and slag: the incineration of hazardous waste in drums is usually performed at temperatures higher than those of municipal waste incineration. Although the specific amount of this slag can be subject to variations much bigger than those in municipal waste incineration plants.
- In the case of filter dust: as the concentration of heavy metals is normally higher in hazardous waste, the filter dust may also contain considerably higher concentrations of filter dust.
- In the case of hydrochloric acid: hazardous waste may contain clearly higher concentrations of fluor, bromine and iodine; as a result, it can be clearly more difficult to produce hydrochloric acid from the created crude hydrochloric acid in a way adequate to market requirements, and HF, HI, Br_2, HBr and I_2 separation stages must be included.

Components	Bottom ash		Mixture of residual materials from waste gas cleaning	
	Eluate (mg/l)	Original substance (mg/kg)	Elute (mg/l)	original substance (mg/kg)
pH value	11,8		12,3	
Conductivity (µS/cm)	1170		35000	
DOC	7,3	--	3,9	--
Loss on ignition (550°C)		1,1 %		6,0 %
TOC	15,5	0,73 %	n/a	2,45 %
TIC	0	0,21 %	n/a	0,95 %
TC	15.5	0,94 %	n/a	3,4 %
Total cyanides	<0,005	<0,5	<0,005	<0,1
Sulphate	460	5100	1010	approx. 45 000
Sulphide	n/a	n/a	55	6000
Chloride	120	1600	8660	approx. 120 000
Al	n/a	n/a	0,12	23 000
As	<0,005	4	<0,005	11
Pb	0,07	1380	18,0	1900
Cd	<0,005	<1	0,001	110
Cr (total)	<0,005	57	0,043	88
Cr (VI)	<0,05	<0,5	0,043	<0,05
Cu	0,06	635	0,04	380
Ni	<0,005	47	0,039	43
Hg	<0,0002	<1	<0,0001	15
Zn	0,08	2300	1,2	5100
Sb	0,05	52	<0,001	200
Co	<0,05	8	<0,007	7,6
Mn (total)	0,02	440	<0,003	520
Sn	<0,005	<0,5	<0,02	370
Tl	<0,005	<0,5	<0,005	0,4
Ca	170	n/a	approx 5200	300 000
Mg	5,2	n/a	0,002	7 500
K	25	n/a	948	19 000
Ag	n/a	n/a	--	15

Table 31: Analysed values of residues from a German municipal waste incineration plant

Table 32 on the right represents typical eluate values of slag from hazardous waste incineration plants. It must be noted that the German eluate process was used for the determination of the results

Parameter [mg/l]	Minimum	Maximum
Cr (VI)	<0,03	2,87
Cr (total)	<0,001	2,87
As	<0,01	0,08
Pb	<0,01	0,18
Cu	<0,01	1,50
Hg	0,00	<0,01
Zn	<0,01	0,3
Cd	<0,001	0,001
Ni	<0,01	0,02
Cl$^-$	2	450
F$^-$	0.8	13
SO4^{--}	5	300

Table 32: Typical eluate values of slag and hazardous waste incineration plants[18]

The following Table 31 represents the structure of slag and ash (in %) from hazardous waste incineration plants by stating the main components. The overview represents 4 different plants.[19]

		SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O
Ash 1	Min	10,80	72,92	4,16	0,83	0,01	3,61	2,41
	Max		88,93	4,88	0,98	0,02	4,28	2,63
	Average		80,35	4,40	0,93	0,02	3,89	2,53
Ash 2	Min	24,81	36,31	3,14	1,09	0,08	4,11	3,04
	Max		52,33	3,70	1,65	0,17	4,35	3,20
	Average		44,81	3,36	1,34	0,12	4,26	3,14
Ash 3	Min	25,24	51,76	3,97	2,25	0,07	2,73	1,81
	Max		55,19	10,43	4,23	0,60	4,33	2,01
	Average		52,90	6,40	3,04	0,27	3,52	1,92
Ash 4	Min	42,36	61,76	4,08	3,36	0,11	4,31	0,92
	Max		64,34	6,08	4,53	0,20	4,59	0,96
	Average		63,19	5,00	3,99	0,14	4,45	0,94
Ash 5	Min	14,38	41,75	2,00	1,47	0,11	0,98	0,46
	Max		44,04	2,12	1,62	0,13	1,12	0,53
	Average		43,26	2,05	1,55	0,12	1,06	0,49
Ash 6	Min	32,30	32,88	3,97	1,57	0,07	4,50	1,13
	Max		39,17	4,72	1,94	0,10	5,21	1,23
	Average		36,69	4,38	1,76	0,08	4,80	1,18
Ash 7	Min	62,25	35,17	6,46	4,46	0,30	3,35	1,90
	Max		35,74	10,92	5,36	1,14	4,33	2,60
	Average		35,54	8,34	4,87	0,68	2,73	2,18
Ash 8	Min	43,00	28,37	5,90	3,82	0,22	3,04	1,52
	Max		35,46	17,31	6,42	1,38	3,66	1,83
	Average		31,94	10,53	4,99	0,67	3,37	1,68

Table 33: Structure of the slag and ash from hazardous waste incineration plants (here: main components)

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[18] Source: VCI ICP measurements of eluates, data of 2001

[19] Source: VCI, data of 2001

3.6.4 Residues from Sewage Sludge Incineration

Besides the gaseous emissions, solid incineration residues are also produced at sewage sludge incineration plants. These residues can be divided into bed and oven ash, flue ash / filter dust produced in electrostatic and fabric filters, and reaction products of waste gas cleaning such as gypsum, salts, acids and heavy metal sludge. If a utilization is not possible, the ash must be dumped without the well of the public being impaired; the requirements of the municipal waste TA or the waste TA, respectively, must be taken into account.

From a survey among operators in 1995, it could be determined that the amount of residues from the approx. 620,000 Mg of sewage sludge treated in mono incineration plants at present is 51.8 % of the annual throughput. This residual waste is distributed as follows:

Average annual sewage sludge	Ash (mixed)	Gyp-sum	Gypsum sludge	Adsorbent and other residues	Total residues
approx. 620.000 Mg m_T/a	48 %	2,6 %	0,1 %	1,1 %	51,8 %

Table 34: Types and amounts of the solid residues from mono sewage sludge incineration

Of the amounts of dry substances combusted, an average of 48 % in all plants are ash. Part of the ash can be removed directly from the incineration ovens. The so-called bed ash (fluid bed furnace and multiple hearth cyclone) and furnace ash (multiple hearth furnace) can be enriched with coarse materials and is normally characterized by a lower heavy metal content. The remaining part of the ash, the amount of which is, however, considerably different in the fluidized bed furnace and in the multiple hearth furnace, is carried out of the furnace with the waste gas stream and removed from the waste gas in appropriate facilities. In the case of the fluidized bed, the entire amount of ash is normally carried out of the furnace as flue ash.

Depending on the location at which they are produced, flue ash from the boiler lines and cyclones and filter dust from the electrostatic and fabric filters must be distinguished. The flue ash has fine grains (average Ø of 70 µm) and does not contain coarse materials. Its contamination is approximately the same as that of the bed ash if the waste gas is not cooled before the separation of the ash. After the reduction of the waste gas temperature before the separation of the ash, vapour material contained in it, which preferably settles down on fine solid particles and cause a higher heavy metal load in the flue ash, condense.

In order to ensure the quality of the airborne dust, it is possible to add a high-temperature dust removal stage with a cyclone after the first stage of waste heat utilization. For example, 85 % of the airborne dust is retained before the beginning of the Denovo synthesis without an increased heavy metal load. The depleted flue ash can then be led to utilization easily.

Fabric filters can only be operated with waste gas temperatures of up to 250 °C. Although the structure of the filter dust then corresponds to that of the flue ash, the filter dust contains higher heavy metal loads. Flue ash and filter dust separated after the cooling of the waste gas have a greater risk potential and must be dumped if collected separately.

In practice, the different types of ash (furnace / flue ash, filter dust and bed ash) are mainly collected together and disposed of or utilized as mixed ash. As most plants are conceptualized according to the fluidized bed process, the flue ash and the filter dust form the main mass stream of ash. Only the bed and furnace ash from multiple hearth furnaces is performed separately.

The possibilities to utilize this mixed ash must be examined in each individual case as the structure and the contamination of the ash depend mainly on the sewage sludge combusted, the structure of which is, for its part, influenced by the location and the season. Besides, variations exist in the concentration of toxic agents in the ash from sewage sludge incineration plants and must be examined regularly in the case of utilization.

In a project conducted in the year 1998, the quality variations of the fluidized bed ash of four mono sewage sludge incineration plants were examined over a period of one year [3]. In the course of it, the chemical structure of 52 weekly composite samples could be determined and correlated to the entry of inorganic materials in the course of the municipal drainage or the water cleaning so that general statements about the formation of the raw material sewage sludge ash could be made. The average ash qualities and the respective standard deviations are shown in table 35.

The chemical structure of sewage sludge ash is influenced considerably by the weather, i.e. the amount of rain. In the case of rainy weather, larger amounts of clay and fine sand enter the sewerage system. pass the grit chamber, are sedimented in the preliminary sedimentation basin and reach the sludge incineration over the primary sludge. As a result, the silicate content of the ash is increased considerably, and the contents of other components diluted, in periods of rainy weather. In the ash, a clear correlation between the SiO_2 and the P_2O_5 contents, which can serve as a measurement of the freight entry of organic materials into the sewage works here, could be determined. In the case of a municipal drainage according to the mixed process, these effects were very well detectable, and they were still recognizable in the case of the separation process.

On two plants, it could be shown that an estimation of the silicate content of the ash is possible very well over the residue on ignition. Furthermore, inorganic precipitation chemicals for the elimination of phosphor influence the chemical structure of the ash directly. In all of the plants examined, the chemical structure of the ash varied very strongly in the course of the year. This is unacceptable for a high-quality utilization of the ash, e.g. in the ceramic industry. For this reason, methods for the equalization of the qualities should be looked for.

Element	Analysis	Unit	Ash A		Ash B		Ash C		Ash D		Clay IV
			Average	Rel.stand.dev(%)	Average	Rel.stand.dev(%)	Average	Rel.stand.dev(%)	Average	Rel.stand.dev(%)	
SiO_2	RFA	M.-%	36,19	20,85	36,46	13,47	30,31	11,28	35,23	13,44	61,10
TiO_2	RFA	M.-%	0,69	7,94	0,70	19,26	0,59	10,59	0,66	9,75	0,92
Al_2O_3	RFA	M.-%	14,17	46,40	12,32	33,73	16,20	6,66	16,86	14,17	19,29
Fe_2O_3	RFA	M.-%	17,95	35,13	15,09	33,45	2,83	10,32	5,58	46,66	6,15
MnO	RFA	M.-%	0,11	7,58	0,16	33,10	0,06	13,28	0,09	12,07	0,06
MgO	RFA	M.-%	1,54	7,38	1,49	9,19	2,51	11,45	2,76	5,21	0,97
CaO	RFA	M.-%	10,04	15,69	13,15	9,22	20,83	6,98	16,71	14,06	0,41
Na_2O	RFA	M.-%	0,72	10,36	0,63	12,55	1,06	45,32	0,69	10,48	0,32
K_2O	RFA	M.-%	1,25	16,39	1,39	10,16	1,42	12,65	1,55	13,38	4,27
P_2O_5	RFA	M.-%	11,46	21,43	13,23	11,04	18,39	13,33	13,82	18,90	0,13
Ba	RFA	mg/kg	823	7,97	922	8,02	1205	10,03	1093	6,39	1386
Cr	RFA	mg/kg	407	23,06	104	17,14	171	31,43	258	13,69	111
Ni	RFA	mg/kg	133	23,58	71	30,07	96	40,79	67	6,21	53
Pb	RFA	mg/kg	330	20,34	172	21,34	157	15,17	210	9,71	18
Sr	RFA	mg/kg	423	18,89	474	8,28	651	8,23	1124	17,72	138
V	RFA	mg/kg	64	18,99	43	21,87	45	18,02	57	23,96	136
Zn	RFA	mg/kg	2121	13,24	2327	8,91	3030	11,89	2644	13,15	76
As	ICP-MS	mg/kg	19	13,42	30	16,11	19	23,83	26	9,98	4
Bi	ICP-MS	mg/kg	7	20,60	10	8,75	7	24,86	9	15,47	<1
Cd	ICP-MS	mg/kg	6	16,08	4	9,41	5	21,13	6	14,94	<1
Co	ICP-MS	mg/kg	19	14,80	14	19,73	12	11,49	16	10,65	49
Cu	ICP-MS	mg/kg	672	14,12	1332	11,55	1618	165,25	767	10,73	25
Mo	ICP-MS	mg/kg	24	18,73	104	42,88	19	10,94	16	15,39	1
Sb	ICP-MS	mg/kg	16	16,51	11	17,03	14	22,55	18	24,18	1
Se	ICP-MS	mg/kg	19	32,87	11	20,92	33	49,54	26	31,98	5
Tl	ICP-MS	mg/kg	1	23,21	1	47,41	0	52,96	1	27,21	1
Hg	AAS	mg/kg	<0,2	-	<0,4	-	<0,9	-	<0,2	-	-
CO_2	GC-MS	M.-%	1,36	20,32	1,19	20,68	4,06	24,82	0,79	21,76	1,82
H_2O	GC-MS	M.-%	0,98	34,93	0,68	15,73	0,83	58,01	0,54	21,24	4,52
S	GC-MS	M.-%	0,28	28,55	0,50	10,75	0,44	48,10	0,45	22,08	0,13

Table 35: Chemical structure of four fluidized bed ashes from sewage sludge incineration – averages and relative standard deviations of 52 weekly composite samples within one year per plant [20]

Reaction products of dry and quasi-dry waste gas cleaning are produced together with the filter dust in the electrostatic and fabric filters concerned. Due to possible increased contents of heavy metals and soluble salts, it may become necessary to dump the gypsum created within the waste gas cleaning stage. Otherwise, the gypsum could be used as building material. The gypsum sludge produced and the old adsorbent are stored in underground deposits, with the coke or coal adsorbent loaded with toxic agents is partially combusted as well. The salts from the waste gas scrubbing of the plants examined are also dumped and not used externally.

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[20] For the combusrtion of industrial sewage sludge in fluidized bed plants, the following deviating values have been determined (in mg/kg): Cr 860 – 3000, Ni 200-800, V 500 – 2000, Co 40 – 600; Cu 1000 – 4000, Tl 10

3.7 Account of the Dioxin Emissions on the Example of an Municipal Waste Incineration Plant

PCDD/PCDF is contained in the input (municipal waste) as well as the output (outgoing air, waste water and waste) of municipal waste incineration plants. As the dioxin emissions dominate a major part of the political debate on waste incineration and still do in some member states, the attempt to account for them is worth while. This is especially true due to the fact that most of the PCDD/PCDF input is destroyed during the incineration process but that PCDD/PCDF can be created again after the incineration process.

The accounting is performed for a plant complying with the German state of technology because old plants with potentially larger PCDD/PCDF contents are no longer operated in Germany since 1996 (provisional regulations for old plants according to 17. BImSchV). After the implementation of the European waste incineration guideline even for old plants by 28/12/2005 at the latest, the accounting can be applied to all plants in Europe.

As most German municipal waste incineration plants operate free of process water, a zero emission could be assumed here for the accounting.

Assumed **entry** over the waste: 50 ng TE/kg of waste			
Discharge streams	Amount per kg of waste	Specific load	Specific account stream
Waste gas	6.0 m³	0.08 ng/m³	0.48 ng/kg
Slag and ash	0.25 kg	7.0 ng/kg	1.75 ng/kg
Waste water	0	n/a	0
Filter dust and other residues from waste gas cleaning	0.07 kg	220 ng/kg	15.40 ng/kg
Discharge: 17.63 TE/kg of waste. This corresponds to 35.3 % of the entry, resulting in a reduction by 64.7 %.			

Table 36: PCDD/PCDF account of a municipal waste incineration plant in Germany

3.8 Noise

The buildings and the equipment of waste incineration plants in Germany must be designed, erected and operated so that they comply with the state of technology with regard to noise reduction and that the standard emission values contained in the Technical Instructions for the Protection against Noise [27] are observed in the area affected by the plant.

The following parts of plants relevant to noise (main emitters), which are listed in table 37, are the principal parts which may undergo measures for protection against noise:

Area relevant to noise / main emitters	Reduction measures	Noise level L_{WA} in dB(A)
Delivery of waste - noise from lorries	Tipping hall closed to all sides	109
Shredding	Scissors in tipping hall	99
Waste bunker	Noise insulation of the building with gas concrete, gates with tight design	81
Boiler building	Enclosure with multi-shell construction or gas concrete, ventilation channels with connecting link silencers, tight gates	80
Machine building	Use of low-noise valves, noise-insulated tubes, noise insulation of the building as described above	85
Waste gas cleaning	Noise insulation of the aggregates, enclosure of the facility e.g. with sheets with trapezoidal corrugations, use of blimps for the suction draft and silencer for the chimney	
- E filter		85
- Scrubbing		85
- Suction draft		84
- Chimney		85
Disposal of residues	Enclosure, loading in the bunker	
- Slag discharge		72
- Loading		78
- Transportation from the plant		95
Air cooler	Silencers on the suction and pressure sides	96
Transformation facility	Low-noise design	80
Total level of the plant		
Day		110
Night		99

Table 37: Sources of noise at waste incineration plants

With the noise reduction measures described in the table above, it is possible to observe the emission value of 35 dB(A) permitted in pure residential areas during the night with waste incineration plants at a minimum distance of 160 m.

3.9 Ooperating Resources

3.9.1 Electricity (Generation and Consumption)

In most cases, the heat produced in the course of waste incineration has been used for many years. In this context, the following possibilities of use are possible:

→ Conversion into electricity
→ Generation of process steam
→ Power heat coupling
→ Alternative generation of electricity or process steam
→ Short-distance heat

All mentioned possibilities of use have been realized in Europe. Which of them is the optimum form of use in each case depends on a number of factors, mainly on whether a local demand exists for the products to be used locally such as steam or heat.

Besides, in the countries of northern Europe, the generation of short-distance heat from waste is supported massively by appropriate tax policies, which has led to the erection of incineration plants designed specially with regard to energy efficiency there.

The energy efficiency of waste incineration plants is often – but falsely – compared with power stations or other thermal industrial processes. The conversion of the steam into electricity is limited by two factors in particular:

- Due to the structure of non-hazardous as well as hazardous waste, high-temperature corrosions may occur in the heat conversion area (boiler, economizer etc.) due to the contents of certain materials, including chlorine, in the waste. However, factors other than chlorine are also important.
- As a rule, the temperature range between approx. 400 and 250 °C cannot be used for the generation of steam as it is considered to be the range in which new dioxins can be formed.

The steam parameters of incineration plants ate therefore limited, and a steam pressure of 60 bar can be considered a maximum at present; it is for supply reasons as well that not the entire energy contained in the waste should be converted into electricity. The number if incineration plants without heat utilization has fallen strongly in Europe. Two major types of plants without heat utilization exist:

- hazardous waste incineration plants in which heat is not used intentionally in order to prevent the new formation of dioxins and furan by taking these primary measures (three plants in the United Kingdom)

- Older, mostly relatively small municipal waste incineration plants (especially in France, some in Italy)

In principle, approx. 300 to 6400 kWh of electricity can be generated with 1 Mg of municipal waste in a municipal waste incineration plant, depending on the size of the plant, steam parameters and degrees of steam utilization. In the case of coupled electricity / heat generation, approx. 1,250 kWh of additional heat per Mg of waste can be used during the hours of full load, taking into account the location-related possibilities for heat to be emitted from the incineration plant and the times of utilization of (distance) heat (e.g. 1,300 to 1,500 h/a out of a possible 8,760 h/a in Germany), which depend on the geographical location of the country concerned.

If the basic load operations of a incineration plant are performed, the gross degree of utilization can be increased to 75% to 76% of the energy used (thermal value) in the case of an energetic utilization as steam, electricity or hot water or of an exclusive release as steam. In this energetically favourable case, up to 2 MWh per Mg of waste can be generated and emitted as process steam or as an energy mix (electricity and water). However, in the case of an exclusive emission of steam from a waste incineration plant to a power station, the degree of coverage of the power station, e.g. in the generation of electricity (max. 0.4) must be taken into account when considering the degree of utilization so that the above-mentioned information have to be corrected for the optimized emission of heat energy.

The average energy content of hazardous waste is 50 to 70 % higher than that of municipal waste so that the specific energy yield of the relevant incineration plants is greater. Apart from this, the above-mentioned considerations also apply. The plant's own consumption of electricity naturally varies strongly, depending on the construction of the plant. Older plants with "grown" waste gas cleaning systems may consume more electricity compared with modern plants with integrated systems. In the literature (Dirks, UBA), a specific electricity consumption of 100 to 150 kWh/Mg of waste is specified. for industrial plants for hazardous waste incineration, a range from 132 to 476 kWh/Mg of waste is specified (VCI).

3.9.2 Water

Sufficient information concerning this chapter is not yet available.

3.9.3 Other Operating Resources

In order to be able to compare different waste gas cleaning systems, it is reasonable to define plants of an average technical size as the basis of waste gas cleaning. For this purpose, one departs here from a typical municipal waste incineration plant with a grate furnace and a boiler, the capacity has been chosen so that it products a waste gas amount of 100,000 m^3 after the subtraction of waste gas humidity with a usual operating oxygen content of 8 % O_2. At a water content of 15 % at the end of the boiler, this results in a wet gas amount of 118,000 m^3/h. These assumptions correspond approximately to average conditions in municipal waste incineration plants and an annual throughput of municipal waste amounting to approx. 150,000 Mg. For a typical hazardous waste incineration plant, the following assumptions have been made:

- For the estimation of the consumption of operating resources, it is necessary to determine toxic agents contained in incineration gases for comparison. For this purpose, typical crude gas contents of a modern incineration plant have been determined and depicted in table 38. In the table, the mass ... is also [incomplete sentence].

- For the calculation of the operating resources for the conversion reactions of the conversion of the toxic agents with the absorbent, the component with the largest quantity in the gross reaction is specified, e.g. the sulphur oxide of SO_2.

- Whereas lime is normally used for neutralization in municipal waste incineration plants, NaOH is normally used for this purpose in hazardous waste incineration plants.

Toxic agents	Incineration plants for			
	hazardous waste		Municipal waste	
	mg/m^3 i. N. dry	kg/h	mg/m^3 i. N. dry	kg/h
Dust			2.000	200,0
CO			20	2,0
HCl			800	80,0
SO_2			400	40,0
NO_x			350	35,0
$C_{org.}$			3	0,3
HF			5	0,5
PCDD/PCDF [ng I-TE/m^3]			1	$1x10^{-7}$
Hg			0,4	0,04
Cd			1	0,1
Tl			0,1	0,01
As			0,1	0,01
Pb			20	2

Table 38: Average contents of toxic agents in waste gas before waste gas cleaning

With these assumptions, the following amounts used and residual products stated in table 39 can be calculated for the **stoichiometric conversion** of the absorptions occurring during waste gas cleaning:

Toxic agent		$Ca(OH)_2$	Residual product		Water
	[kg]	[kg]		[kg]	[kg]
HCl	1	1,014	$CaCl_2$	1,521	0,493
HF	1	1,850	CaF_2	1,950	0,900
SO_2	1	1,156	$CaSO_4$	2,125	0,283
Toxic agent		NaOH	Residual product		Water
HCl	1	1,097	NaCl	1,600	
HF	1	2,000	NaF	2,100	
SO_2	1	1,249	Na_2SO_4	2,217	

Table 39: Stoichiometric calculation of amounts used for the absorptions occurring during waste gas cleaning

For other toxic agents, the conversion is not stoichiometric; in this case, physical additions (adsorptions) occur primarily, proceeding in proportion to the existing surface of the adsorbent in areas of low concentration.

3.9.3.1 Neutralizers

As neutralizer for the acid conctituents contained in the waste gas, either NaOH, lime hydrate or milk of lime is used. As explained above, their consumption depends on the specific structure of the waste as well as the efficiency of the processes used.

For lime hydrate, 6 kg/Mg of waste or 15 to 22 kg/Mg of waste (quasi-dry waste gas cleaning), depending on the type of use, are stated in the literature.

3.9.3.2 Nitrogen Removal Agents

Typical utilities for the removal of nitrogen from the waste gas are ammonia, ammonia water (25 % NH_3) and urea solution. The latter, in particular, is, depending on the producer, often supplemented by additional ingredients which are supposed to increase efficiency. The use of these materials must be performed in a targeted manner and supervised for the mere purpose of preventing an excessive formation of ammonia or the direct slippage of the excess ammonia. For ammonia water, 2.5 kg/Mg of waste are stated in the literature [1]. The result of some research has been 0.5 to 5 kg/Mg of waste.

Whether waste containing ammonia can be used as a substitute for primary material depends, among other things, on the point in the system at which these chemicals can be used.

3.9.3.3 Fuel Oil and Natural Gas

For transportation to and from the plant and for supportive furnaces (if any), EL fuel oil is used almost exclusively. Especially for operating the supportive furnaces during normal operations, waste solvents, which should have a thermal value of >25 MJ/kg, can also be used. This possibility to reduce the consumption of EL fuel oil is used by hazardous waste incineration plants.

If the waste gas is re-heated for individual process steps (e.g. SCO catalysers), this is mainly done with natural gas.

3.9.3.4 Utilities for Waste Water Treatment

This issue is treated extensively in the horizontal BREF "waste water treatment".

4 CUSTOMARY PROCESSES AND TECHNIQUES FOR REDUCING EMISSIONS FROM WASTE INCINERATION AND CO-INCINERATION

4.1 Preliminary note

In addition to the reaction products carbon dioxide and water vapour, waste gas from incineration plants contains other gaseous, vapourous and dusty substances. The waste gas contents of these substances are to be reduced by appropriate installations to the standards prescribed by the European Waste Incineration Guideline before they are discharged into the atmosphere.

The key components for configurating the waste gas cleaning process are dedusting, nitrogen removal, desulphurization, halogen deposition, separation of PCDD/PCDF and elimination of mercury compounds.

Emissions from any furnace depend upon the input of toxic agents into the furnace on the one hand and on the other upon the products generated in the process of incineration and thus upon the furnace system. The emissions discharged through the chimney are, however, most substancially affected by the method of waste gas cleaning applied. The following toxic agents contained in waste gas, of relevance as defined by the German Federal Emission Protection Law, must be taken into consideration: carbon monoxides (CO), oxides of nitrogen (NO_x), sulphur dioxides (SO_2), hydrogen chlorides or fluorides respectively (HCl, HF), dust, organic components, dioxins and furans and heavy metals. Many techniques for reducing these toxic agents are identical to those used in power plants**.** We would therefore like to refer explicitely to the description of these techniques in BREF ‘Large Incineration Plants’.

The emissions of CO, $C_{organic}$ und NO_x depend on temperature, among others, and may be influenced by incineration. The content of CO in the waste gas is, apart from temperature, influenced substancially by the oxygen content. A lack in oxygen as well as excess oxygen (so called steaming) change the CO content and may thus affect emissions. As a rule, the CO content decreases with increasing incineration temperatures and a sufficient oxygen content. There is a reverse influence of the two parameters temperature and oxygen need on the formation of oxides of nitrogen.

4.2 Techniques for reducing particulate emissions

The selection of deposition equipment for particulate substances from the waste gas is determined mainly by the average grain size and possibly by the grain size distribution of the substances. Possible treatment or dumping of the deposited substances may also determine selection. Mass depositors are in most cases only suited for pre-depositing coarse dust.

With dry deposition, the required concentrations in the waste gas after waste gas cleaning are effected by electrostatic or fabric filters. The required emission values can also be attained using scrubbers, in particular venturi or rotation scrubbers. As a rule, however, filtering depositors will be pre-installed to allow residues to be removed separately.

4.2.1 Electrostatic filters

Electrostatic filters produce a nearly constant deposition degree over the whole range of grain sizes. The efficiency of electric filters is substancially influenced by the resistence of the dust. If the dust layer resistance rises to values above appr. 10^{11} bis $10^{12}\Omega$cm, satisfying deposition is rendered difficult. The dust layer resistance is influenced by waste composition. It may thus change rapidly with a changing waste composition, particularly in hazardous waste incineration. Sulphur in the waste often reduces the dust layer resistance as SO_2 (SO_3) in the waste gas und thus facilitates deposition in the electric field.

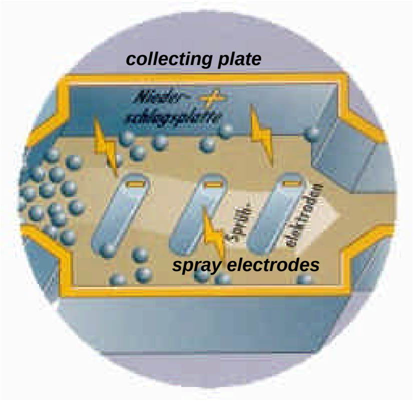


Figure 24: Operating principle of an electrostatic filter

For the deposition of ultra-fine dust (PM_{10}) and aerosols, installations that sustain the effect of the electric field by drop formation in the waste gas (pre-installed condensation and wet electrostatic filters, condensation electrostatic filters, electro-dynamic venturi scrubbers, ionized spray coolers) can be used to advantage.

4.2.2 Wet electrostatic filters

Wet electrostatic filters are based upon the same technological working principle as electrostatic filters. With this design, however, the precipitated dust on the collector plates is washed off using a liquid, usually water. This may be done continuously or periodically. Employing this technique is advantageous in cases where moist or cooler waste gas enters the electrostatic filter. The safety of this unity is thus ensured in all operating conditions.

4.2.3 Condensation electrostatic filters

The condensation electrostatic filter is used to deposit very fine, solid, liquid or sticky particles, for example in the waste gas from hazardous waste incineration plants. Unlike conventional wet electrostatic filters, the collecting surfaces of condensation electrostatic filters consist of vertical plastic tubes arranged in bundles and water-cooled externally.

The dust-containing waste gas to be treated is first cooled down to dew-point temperature in a quench by direct injection of water and then saturated with vapour. By cooling the gases in the collecting pipes further down, a thin, smooth liquid layer forms on the inner surface of the tubes as a result of condensation of the vapour. This is grounded and thus serves as the passive electrode.

Particles are deposited through the influence of the electric field between the spray electrodes suspended in the tube axes and the condensation layer in continuous flow. At the same time the layer also effects continuous removal of deposited particles from the deposition area. Even water-insoluble dust and poorly wettable soot are washed off. The constantly renewed wetting prevents dry spots and adherence which cause sparkover. This allows for a higher depositon voltage, which in turn leads to improved and consistent high deposition performance (cf. figure 26).

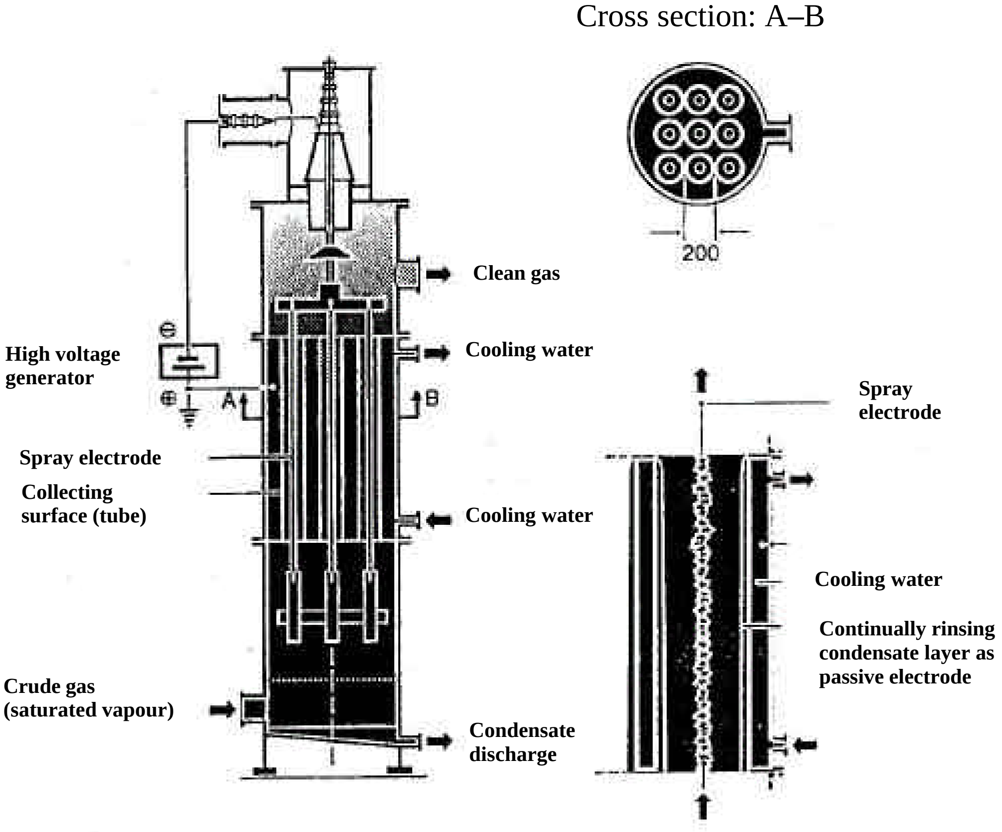


Figure 25: Condensation electrostatic filter

4.2.4 Ionization wet scrubber

The purpose of the ionization wet scrubber (IWS™) is to eliminate toxic agents from the flue gas flow. The IWS™ combines the existing principles of

- electrostatic charging of particles, electrostatic attraction and deposition for aerosols (smaller than 5 µm),
- vertical deposition for coarse, liquid and solid particles (larger than 5 µm), and
- absorption of hazardous, corrosive and malodorous gases.

The IWS™ system requires little energy and has a high depositon efficiency for particles in the submicron as well as the micron range. It is a combination of an electrostatic filter and a packing scrubber. In this case, a high voltage zone is installed before each given tower packing stage. Its function is to ionize the particles (dust, aerosols, submicron particles) contained in the flue gas. This means for the particles which are neutral as such to become negatively charged by the strongly electric field. The particles are then deposited in the subsequent tower packing stage. During this, the negatively charged particles induce opposing charges on the neutral surface of the wettened packing material and the falling water drops respectively. Through this they are attracted and washed out. This is referred to as Image/Force Attraction (IF attraction), i.e. attraction through electron shift. Hazardous, corrosive and malodorous gases are absorbed in the same scrubber fluid and chemically combined.

4.2.5 Fabric filters

Filtering depositors (cf. figure 27) also have a nearly constant deposition degree. One vital condition for keeping concentrations in the waste gas behind a filter low is the harmonization of the filter medium with the dust to be deposited and its properties, as well as the conditions of operation. In addition to the mechanical and thermal stressability of the filter material, it is the efficiency of the waste gas cleaning process that determines service life and energy and maintenance costs in the operation of filtering depositors. In continuous operation filtering depositors may - regardless of the efficiency of the waste gas cleaning process - suffer an increasing loss of pressure, which may be due to an irreversible deposit of respirable dust in the filter material.

The application of dry deposition only is limited for dusts which are hygroscopic already at high temperatures (300 to 600 °C) and become sticky at these temperatures. This type of dust forms deposits in the depositon equipment, which cannot be extracted sufficiently by conventional cleaning techniques during operation, but may need to be removed by sandblasting. These may be dusts from polysalts and complex salts (from wastes containing phosphorus, sulphur or silicium), to name but a few.

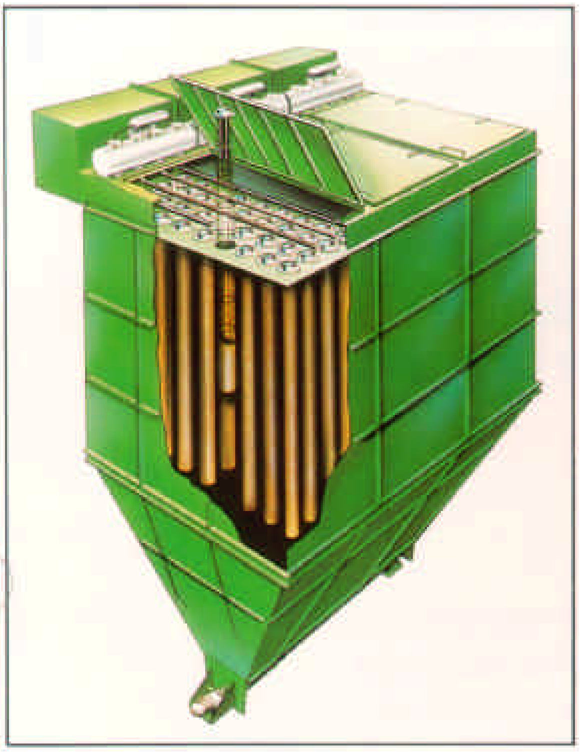


Figure 26: Tissue filter

4.3 Techniques for the reduction of HCl, HF und SOx emissions

Anorganic, gaseous toxic agents can be deposited applying different processes; the actual deposition process is absorption over a sorption agent. The sorption agent used depends upon the type of cleaning. The following waste gas cleaning processes are applied:

- **dry processes:** A dry sorption agent (e.g. lime) is added to the waste gas flow. The reaction product is dry, too.
- **quasi-dry processes:** The sorption agent added to the waste gas flow is a solution (e.g. lime milk). The solution evaporates and the reaction products is dry.
- **wet processes:** The waste gas flow is fed into a washing solution containing the sorption agent (e.g. sodium hydroxide solution). The reaction product is watery.

4.3.1 Deposition of halogens and sulphur dioxides

Gaseous substances are deposited through absorption in a liquid. As a rule, chemical or physical sorption agents are brought into contact with the waste gas. According to technique, the reaction products are dissolved or dry salts.

In dry sorption processes the sorption agent (lime, hydrate of lime or limestone) is fed into the reactor as dust. An over-stoichiometric dose (two or three times the stoichiometric amount related to the substance to be deposited) of the sorption agent is needed to meet the emission value because the waste gas composition, depending upon the waste compositon, varies considerably for the most part, and to level out inevitable concentration peaks in the waste gas. This overdose leads to a corresponding increase in the amount of residues. Particles as part of the waste gas are adsorbed if there is no predeposition, so that the composition of the dry residual material impedes further use or disposal. Dry sorption processes are only rarely applied for waste gas cleaning behind hazardous waste incineration plants, because with high crude gas concentrations it cannot be guaranteed that the prescribed emission values are always observed.

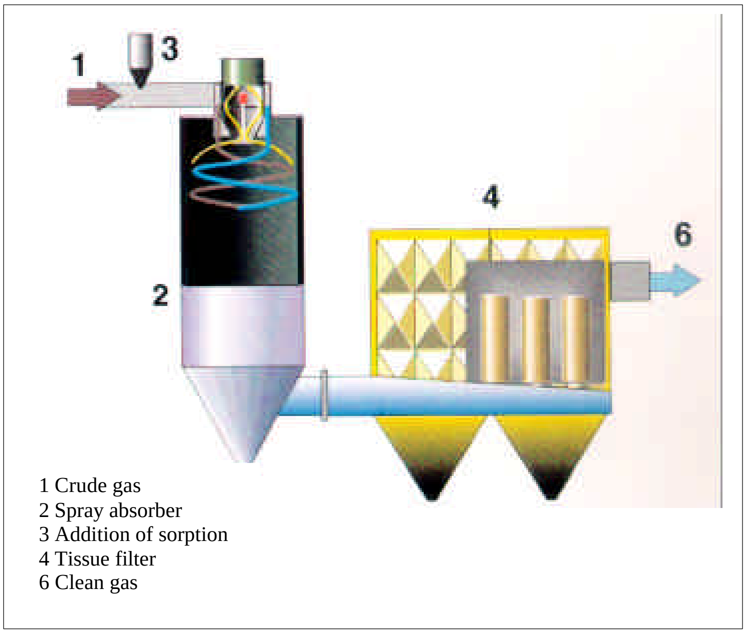


Figure 27: Operating principle of a spray absorber

In spray absorption processes, the sorption agent is injected either as suspension or solution into the hot waste gas flow in a spray reactor. This type of process utilizes the heat of the waste gas for the evaporation of the solvent (water). The reaction products generated are solid and need to be deposited from the waste gas as dust in a subsequent stage. These processes require overdoses of the sorption agent of 1.5 to 2.5. The same problems as described above will occur.

Wet waste gas cleaning processes for the reduction of HCl, HF and SO_x emissions are absorptive processes using different types of scrubbers such as jet scrubbers, rotation scrubbers, venturi scrubbers or packed tower scrubbers. Using water as washing solution, these perform very well in the deposition of HCl, HF and SO_3. The washing solution is strongly acidic due to the acids forming in the process of deposition. In this acidic medium, deposition of SO_2 is low.

Sufficient deposition of sulphur dioxide is achieved in a washing stage set to neutral or alkaline, in which caustic soda solution or lime milk is added to the washing liquid. For technical reasons this deposition takes place in a separated washing stage, in which, additionally, there occurs further deposition of HCl and HF. The incineration products of the elements, like chlorine, fluorine, bromine, iodine, phosphorus, nitrogen and sulphur, may form aerosols in the waste gas.

If waste contains bromine and iodine, these elements can be deposited from the flue gas flow if waste containing sulphur is combusted simultaneously. In addition to sulphur compounds, water-soluble salts of bromine and iodine will form, which can be deposited through the wet SO_2 flue gas cleaning processes. Additionally, the deposition of bromine and iodine may be improved by specific employment of reductive washing stages (sulfite solution, bisulite solution). In any case it is vital to be aware of which wastes contain iodine or bromine.

If lime milk is used as a neutralizing agent in the wet flue gas cleaning stages, sulfate (gypsum), carbonates and fluorides will accumulate as water-insoluble residues, which may be utilized to easily reduce the salt load in the waste water through depositon of solids. Water-insoluble salts increase the risk of encrustations within the scrubbing system. Using caustic soda solution (which is more expensive) there is no such risk because the reaction products are water-soluble. The availability of a caustic soda solution wash is higher by comparison and less maintenance is necessary. If NaOH is used, $CaCO_3$ may form depending upon water hardness, which will again lead to deposits within the scrubber. These deposits need to be removed discontinually by acidification.

To maintain scrubbing efficiency and prevent encrustations within the scrubber system, a portion of the washing solution must be removed from the circuit as waste water. This waste water must be subjected to special treatment (neutralization, precipitation of heavy metals), before it meets the requirements for discharge or may be used internally. Here, mercury must be given special attention. Volatile Hg compounds, such as $HgCl_2$, will condense when waste gas is cooled, and dissolve in the washing water.

Elemental mercury forms over reductive compounds, e.g. SO_3^2. This may lead to corrosion in the circuit (by amalgam formation) and is hazardous to the health of operating staff when cleaning and mainentance work is carried out on the scrubber. Appropriate chemicals such as sulfide or TMT 15 (trimeric captotriazine) transform the mercury into a difficultly soluble form to counteract a reductive attack.

4.3.2 Direct desulphurization

Desulphurization in the fluidized bed can be effected directly by integration into the furnace and/or indirectly through waste gas desulphurization in the dry or quasi-dry cleaning system and in the washing process. In the so-called direct desulphurization, sulphur dioxide is bound immediately after formation into a sorbens (sodium or calcium compound) injected into the incineration chamber. Additives such as limestone dust, calcium hydrate and dolomitic dust are preferred here. The arrangement of the jets and the injection speed influence the distribution of the sorbens and thus the degree of sulphur dioxide deposition. The resulting reaction products are removed in filter installations downstream. However, the clean gas values required by the Federal Emission Protection Law No. 17 (FEPL 17) or the European Waste Incineration Guideline cannot be met. But ideal conditions for direct desulphurization exist in a cycloid furnace due to the constant temperature level.

4.4 Techniques for the reduction of nitric oxide emissions

One possible way of reducing harmful substances is furnace control. Thus, graded incineration was chosen for an industrial sewage sludge incineration plant as primary nitrogen removal to observe the requirements of the FEPL 17. This means a reduction of the O_2 content in the fluidized bed to values lower than 3 volume percent of O_2. Above the fluidized bed the O_2 content is increased by supplying secondary air to the secondary reaction zone**,** to achieve good incineration of the waste gases. At the same time the CO concentration is reduced so that the content of harmful substances in the waste gas can be set below the required limit values for NO_x and CO.

A reduction of the oxygen supply in a fluidized bed leads to higher CO emissions and a higher concentration of burning material. Both effects cause an obvious reduction in the NO_x emission because any NO that has already formed can be reduced to nitrogen by carbon as well as carbon monoxide over carbon.

Reaktion equation:

$2\,NO + 2\,C \rightarrow N_2 + 2\,CO$ (over carbon)
$2\,NO + 2\,CO \rightarrow N_2 + 2\,CO_2$ (over carbon monoxide)

During the two-stage incineration, the CO emissions which are initially rather high must be reduced to values below the limit values of the FEPL 17 by supplying secondary air to the upper part of the incineration furnace. In principle, the limit values of the FEPL 17 can be met when two-stage incineration is applied. On the industrial scale, however, it must be taken into consideration that unburnt sludge parts are discharged into the free space together with the waste gas. Thus, there will be an afterburning in the area of secondary air supply where new NO_x will be formed to some extent which is determined by the mode of operation of the furnace.

The FEPL 17 requires an NO_x clean gas value of 200 mg/m^3 which can often not be met by mere furnace regulation. Secondary measures are then required. For most processes the application of ammonia or derivates of ammonia as reduction agent has proved successful. The nitrogen oxides in the waste gas basically consist of NO and NO_2 and are reduced to harmless nitrogen N_2 and vapour H_2O by the reduction agent.

Reaction equations:

$$4\ NO + 4\ NH_3 + O_2 \rightarrow 4\ N_2 + 6\ H_2O$$
$$2\ NO_2 + 4\ NH_3 + O_2 \rightarrow 3\ N_2 + 6\ H_2O$$

Two processes are important for the removal of nitrogen from waste gases – the Selective Non-Catalytic Reduction (SNCR) and the Secondary Catalytic Reduction – which will be explained in the following paragraphs.

4.4.1 SNCR process

In the SNCR process nitrogen is removed by selective non-catalytic reduction. With this type of process the reduction agent (e.g. ammonia) is injected immediately after the actual incineration and reacts with the forming nitrogen oxides. The reactions will run at temperatures between 850 and 1000 °C.

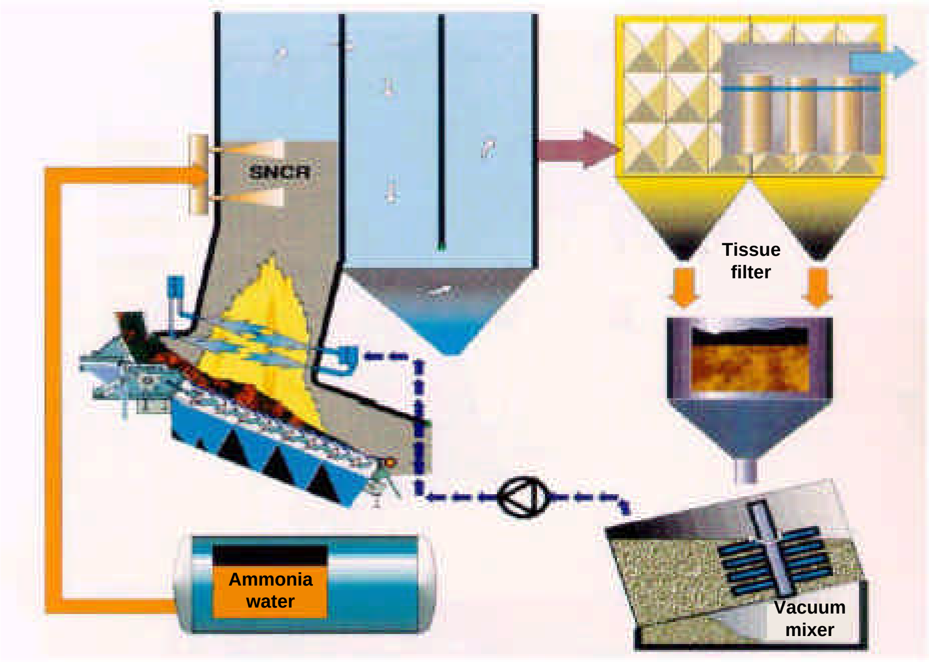


Figure 28: SNCR operating principle

Deposition degrees of more than 80 per cent, however, require an over-stoichiometric addition of the reduction agent. This excessive need for a reduction agent may, if ammonia is used, lead to additional emissions of ammonia, also known as slip of ammonia. The licensing authority in charge needs to take this fact into particular consideration when determining limit values for NO_x

4.4.2 SCR process

SCR is a catalytic process during which ammonia mixed with air (reduction agent) is added to the waste gas and the waste gas containing ammonia is directed over a catalyst. When passing through the catalyst, ammonia is reduced to nitrogen and vapour. The catalyst has a temperature of between 250 °C and 450 °C. The SCR process yields high deposition degrees with nearly stoichiometric additions of the reduction agent. Depending upon the position of the denox installations relative to other harmful gas deposition installations there are processes with crude (before) or clean gas installations (behind).

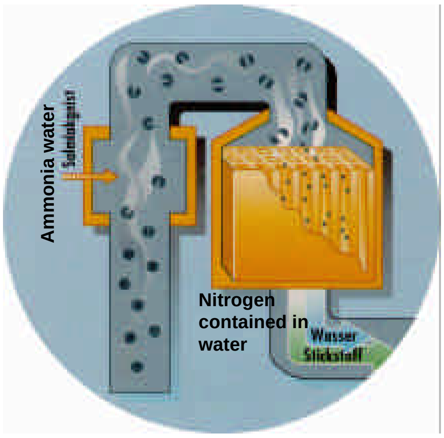


Figure 29: SCR operating principle

The waste gases discharged by the reactor may be directed through a gas-gas heat exchanger to preheat the entering gases in order to maintain the operating temperature of the catalyst and to save foreign energy.

4.5 Techniques for the reduction of mercury emissions

Mercury is considered one of the most harmful substances for the environment today. This is why the FEPL 17 requires a very low emission limit value of 0.03 mg/m^3 as a daily average value. It is impossible for many plants to meet this limit value without any special components for the deposition of mercury from waste gas.

Mercury is completely furnace-ready, i.e. it vapourizes at a temperature of 357 °C and remains gaseous in the waste gas after passing through furnace and boiler. In principle, the difference between ionogenic compounds (mainly Hg^{2+} as a chloride) and elemental mercury must be considered, even though it is almost completely elemental above temperatures of 700 °C.

The selection of a process for mercury deposition depends very much upon the load fed in and upon the chlorine content of the burning material. If there is a high chlorine content, mercury in the crude gas will be almost entirely ionic and can be easily deposited in scrubbers. This has to be taken into consideration especially with sewage sludge incineration plants. If the chlorine content in the water- and ash-free sewage sludge is 0.3% by mass or higher, only 10% of the mercury in the clean gas is elemental. With such burning material, elimination of the ionic mercury would suffice. In the plants examined, metallic mercury is either transformed into ionic mercury by adding oxidants and then deposited in the scrubber or directly deposited on sulphur doped activated carbon or hearth furnace coke. Adequate ways of disposal must be found for the loaded activated coke. Tests have shown that sulphur dioxide may already be neutralized in the furnace by adding lime stone, and thus the portion of metallic mercury may be reduced.

In incineration plants for municipal waste and hazardous waste the chlorine content in the average waste is higher, and high enough in normal operating states to make sure there is ionic mercury only. However, specific inputs of certain waste may change the situation and metallic mercury may need to be deposited. The diminishing agents for mercury in waste incineration are activated carbon and/or washing water which is then fed to waste water treatment plants with heavy metal deposition.

In the incineration of waste with a high mercury content in hazardous waste incineration plants Hg deposition degrees of 99.9% can be ensured only by co-incineration of highly chlorinated waste – harmonized with the Hg load – in a multistage wet washing process typical of this type of plants. The high Hg_{ion} species portion of > 99.9% in the boiler crude gas before wet washing, brought about by co-incineration of highly chlorinated waste, is decisive.

Of the entire load of chlorine, appr. 4 per cent by weight exist – even before flue gas entrance into the convection heating plates, which means in the upper area of the idle stroke (boiler flue gas before super heater) – for some time as Cl_2 useful for Hg chlorination. This free chlorine, desirable as it may be for Hg chlorination, needs to be (and can be through sufficient supply of SO_2) suppressed to a high degree in the boiler already.

igh chlorine total loads and a therefore high interim Cl_2 supply lead to Hg chlorination and thus Hg deposition of almost 100% (cf. figures 31 and 32). As a rule, the interim Cl_2 supply should always be sufficient, even with high SO_2. However, with low to minimal chlorine total loads and a correspondingly reduced interim supply of Cl_2, the Hg deposition degree may go down to values << 100%. In this (avoidable) case, the portion of water-soluble Hg_{ion} in the boiler flue gas may vary with its SO_2 content.

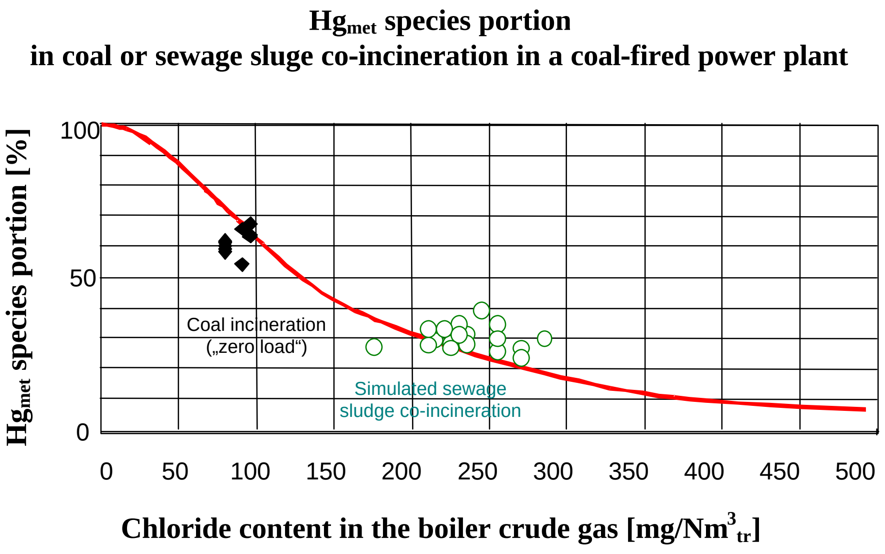


Figure 30: Measuring and calculating results behind a hard coal power plant

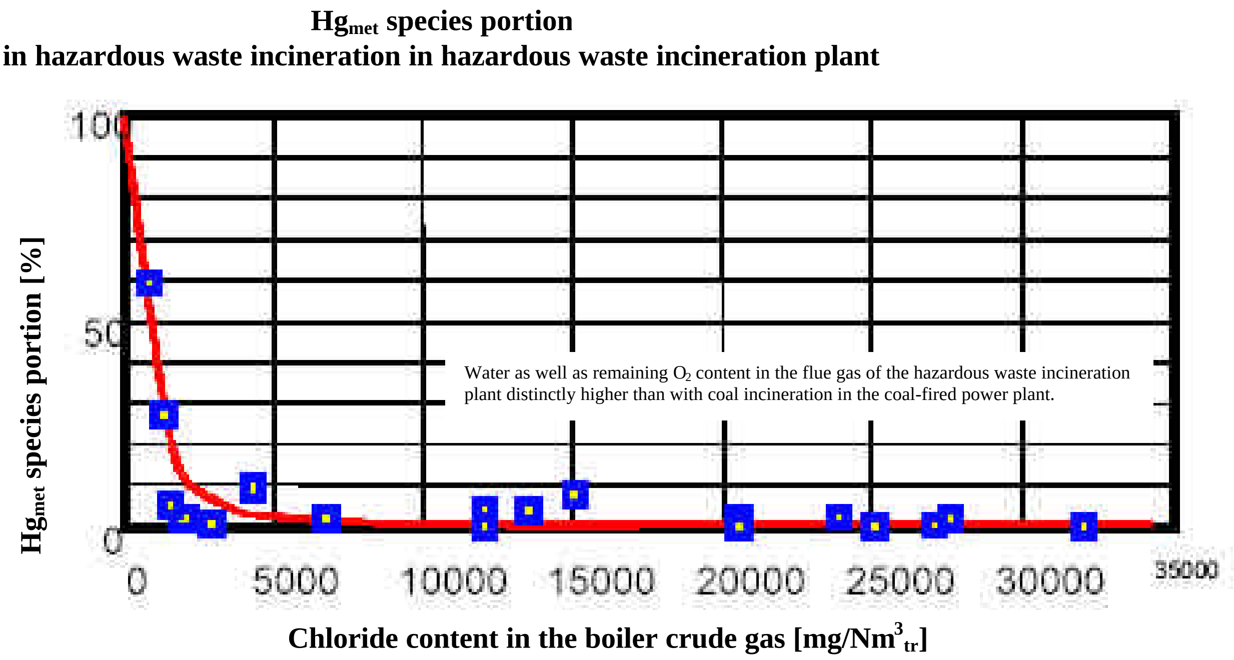


Figure 31: Measuring and calculating results behind a hazardous waste incineration plant

4.6 Techniques for the reduction of other emissions of heavy metals

Other heavy metals in incineration are converted mainly into non-volatile oxides and deposited with flue ash. Thus, the main diminishing agents usually are the corresponding electrostatic filters of different types. Deposition is continued further in the downstream aggregates such as scrubber, tissue and active coke filters.

4.7 Techniques for the reduction of emissions of organic carbon compounds

Proper operation of the incineration installation provided, organic carbon compounds measured as C total exist in concentrations below the limit values of the FEPL 17. These organic carbon compounds include special components which occur in traces only but must be given particular consideration because of their persistence as well as their cancerogenic or toxic effect.

Waste gas from hazardous waste incineration plants is also examined for
- polyhalogenated aromatic hydrocarbons
- polycyclic aromatic hydrocarbons (PAH) and
- benzene, toluene und xylene (BTX),

as some substances of these groups may have cancerogenic effects.

Polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF) may form behind the furnace from precursor compounds. Precursor compounds are, for example, polychlorinated biphenyls (PCB), polychlorinated diphenylmethanes (PCDM), chlorobenzenes and chlorohydroxybenzenes..

PCDD and PCDF may also form in catalytic reactions of carbon or carbon compounds with anorganic chlorine compounds over metal oxides, e.g. copper oxide (new formation or denovo synthesis). These reactions will run especially on flue ash or filter dust at temperatures between 200 and 450 °C.

The following three ways have been known to lead to the formation of dioxin/furan in waste incineration:

1. Incomplete destruction of the PCDD/ PCDF supplied with the burning material.

2. Formation of PCDD/PCDF from chlorinated hydrocarbons already existing or formed in the furnace, such as chlorohydrobenzene or chlorobenzene.

3. De-novo synthesis in the low-temperature range (boiler, electrostatic filters).

Optimum waste gas incineration largely destroys the precursor compounds. The formation of PCDD/PCDF from the precursor compounds is thus suppressed. As for process technology, the incineration is determined by the following parameters: incineration temperature, residence time and turbulence of the waste gases. The formation through catalytic reactions of carbon and carbon compounds may be reduced by a thorough incineration of the flue dusts and minimization of the amount of flue dusts.

The emission limit value for the total of dioxins and furans is 0,1 ng I-TEQ/m^3 according to the FEPL 17 as well as the European Incineration Guideline. Adsorption processes and oxidizing catalysts are available, amongst others, to be able to meet this limit value.

Among the substances mentioned above are some whose cancerogenic potential has been proved. Benzo[a]pyrene and dibenz[a,h]-anthracene may serve as examples whose concentration by mass in the waste gas may not rise above 0,1 mg/m^3 according to the Technical Instruction on the Protection of Air (TI Air). According to the present state of the art, the values produced by waste incineration plants are far below this value. However, these substances have been recorded in a large varying range, so that an evaluation can only be given on an individual scale. Owing to their effect potential, emissions of special components must generally be minimized.

Emissions of organic hydrocarbon compounds may, apart from the processes explained in paragraph 2.4.2., be reduced by further dust and aerosol deposition if they are bound to particles (PCDD, PCDF, PAH), and by enforced waste gas cooling (condensation).

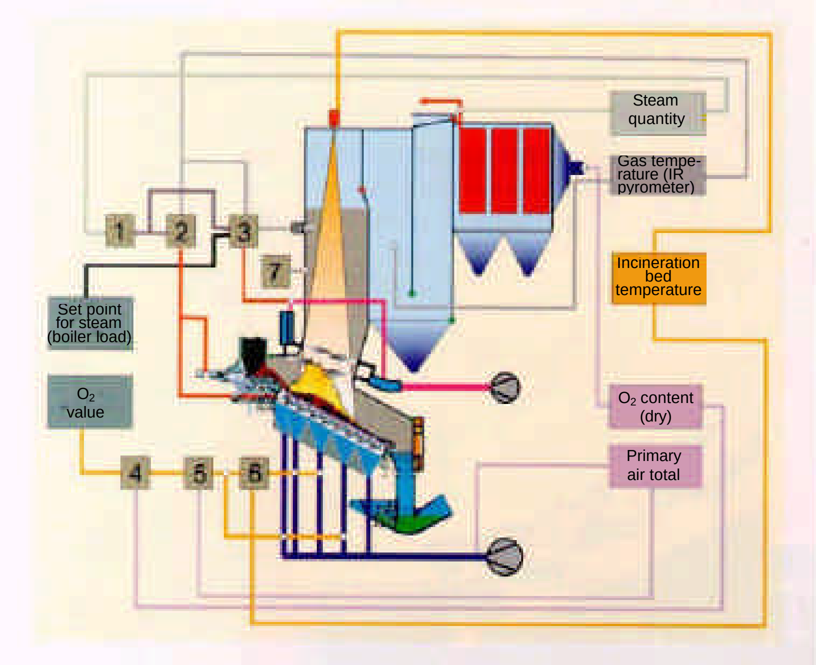
4.7.1 Furnace-technical measures

Process-technical measures in the incineration chamber may contribute to distinct reductions through optimized furnace technique with corresponding sufficient temperatures and residence times, an oxygen content harmonized with the incineration process and adequate intermixing of the gases to prevent cold streaks. These primary measures, directed at optimizing incineration of the gas phase and solid phase may also have favourable effects on the inertization of the grate slag and the residual carbon content in the flue dusts. At many German municipal waste incineration plants, furnace-technical optimization has been performed in the past. This also includes the following experiments, which are described as examples.

In a joint effort [4] promoted by the German Federal Minister for Research, three major plant manufacturers (Martin, Noell, Steinmüller) worked together on the optimization of the conditions for incineration in the furnace chamber of domestic waste incineration plants utilizing furnace performance control (cf. figure 33).

The investigations aimed at levelling out the process of thermal treatment and at further reducing the contents of toxic agents, in particular of halogen-organic compounds (e.g. dioxins), in the waste gas (meaning a reduction of toxic peaks or variations) and at the same time at simplifying the design of waste gas cleaning. Thermal treatment on the grate was to be made adjustable to an extent which allowed it to adapt to greatly varying compositions of municipal wastes. To do this, changes in the calorific value and consistency of the input must be taken into consideration much as well as the incineration quality of the slag on the grate and the waste gases in the secondary incineration.

One major precondition for improving the incineration process is the continuous adaptation of the distribution and amount of incineration air to the current state of the incineration in the individual grate zones. To be able to perform this adaptation, an infrared thermographic system was used in a plant with feed grate, which permitted automated recording of the furnace condition on the grate. An infrared camera is used to create a thermal image of the burning waste bed. Temperature distribution on the grate appears as an isothermal field gradated in colours. For the subsequent furnace performance control, characteristic temperatures of the individual grate zones are determined and passed on to the furnace performance controller as parameters for position and shape of the furnace. The furnace performance controller has been designed according to the method of fuzzy logic. With fuzzy logic, some variables (e.g. temperature, CO, O_2 content) and a sequence of rules are determined to set a best suited state. In addition, waste gas recirculation and equipment for the addition of tertiary air were installed at the plant.



1 Set-point controller with set point and control point of the steam quantity.

2 Control system for waste feeding and grate stoking, supplemented by the adaptation computer which optimizes charging and the stoking cycle.

3 Control system for waste feeding and grate stoking, supplemented by the adaptation computer which optimizes charging and the stoking cycle.

4+5 Control system with flame failure alarn the quantity and distribution of seconc air and recirculated waste gas

6 Optional upgrade of 4 and 5 with an infrared camera.

7 Control system to control the secondary burners.

Figure 32: Components of a modern furnace control system

At another plant with reverse feed grate tests were carried out with a comparable infrared thermographic system to monitor the main incineration zones and record the surface temperature of the incineration bed almost chronologically. This control concept, too, works with fuzzy logic.

By computer controlled image processing the video images provided by the IR camera could be transformed into signals which were integrated into a new furnace control, coupled with parameters such as oxygen content in the waste gas and steam quantity. The charging of the incineration chamber is controlled by recording the average temperature of the waste bed at the foremost part of the grate and additional evaluation of the O_2 value at the end of the boiler. With the help of camera-controlled incineration bed temperature recording over the first three grate zones, primary air is added according to demand (air quantity and distribution), which helped to even out the incineration process in the main incineration zone. In grate zone 2 (ignition zone), air demand is controlled as a function of incineration bed temperature and a constant temperature profile is set. Both adaptation of the air quantity in grate zones 3 and 4 and temperature of the incineration surface are supposed to lead to steady incineration and efficient slag incineration.

The results from the tests without (nomal operation) and with incineration control with the IR camera are shown in Table 43. In another partial project incineration tests were run with oxygen conditioned primary and secondary air and additions of nitrogen in the secondary air. A favourable influence on dust and CO concentrations and the total C contents in the waste gas behind the steam generator was recorded in particular with oxygenated primary air (O_2 contents between 25 and 28% by volume – cf. Table 38). Moreover, NO_x contents in the waste gas could be reduced owing to additions of nitrogen to secondary air. The results from this investigation have, in connection with the manufacturer’s reverse feed grate, led to the development of the so-called SYNCOM process, which consists of these process steps:

- Fully automatic incineration control through infrared camera and fuzzy logic,
- Waste gas recycling to the furnace via a secondary air system with 4 rows of jets, and
- Oxygenation of the primary incineration air in the main incineration zones using technical oxygen

and was realized at a municipal waste incineration plant in Coburg.

Measures introduced at another plant with feed grate included graded addition of incineration air, constant dosing of waste through height of layer control, incineration monitoring by optic sensors (so-called incineration sensors) in different grate zones, and flue gas recirculation. Compared to the plant’s conventional operation, the contents of waste gas components which depend upon the conduct of incineration could be reduced through the even conduct of incineration that was effected. To give an example, emission values recorded after the optimization of incineration in crude gas behind the steam generator (at the end of the boiler) are shown in Table 40 below.

Waste gas component (crude gas behind steam generator)	Normal operation	IR camera plus fuzzy logic	O_2 conditioning
Oxygen content [Vol.-%]	9,1 - 9,3	8,9 - 9,3	6,2 - 10,9
Carbon monoxide [mg/m^3]	12 – 32	9 – 26	20 – 27
Dust [g/m^3]	0,7 - 1,7	0,6 - 1,0	0,5 - 1,0
Total carbon [mg/m^3]	1,1. - 2,4	0,9 - 1,0	1,0 - 1,2
Dioxins/furans [ng I-TE/m^3]	1,5 - 2,7	1,0 - 1,3	2,0 - 3,5

Table 40: Crude gas measurements in normal operation, with IR camera and O_2 conditioning

4.7.2 Measures in the crude gas area for reducing dioxin emissions

A reduction in dioxins can be achieved through the following measures in the crude gas area:

- Addition of inhibitors (efficiency limited, consider secondary reactions)
- Employment of hot gas dedusters (so far only little experience from pilot tests)
- Ceramic filters or cyclones for temperatures of appr. 800°C (problem of pollution)
- Dedusting at temperatures around 450°C (e.g. with hot gas electrostatic filters)
- Reduction of deposits of airborne dust on the waste gas path (cleaning of waste gas vents, boiler, heating plates).

The following waste gas cleaning processes (cf. Table 41) may cause a specific reduction in dioxins and furans in waste gas incineration plants:

- Adsorption process with a lime/ hearth furnace coke mixture,
- Adsorption process based upon pure activated coke/carbon or pure hearth furnace coke or limestone/coke mixtures or by means of modified zeolites with technologies such as packed-bed or moving-bed reactor, current flow or filter bed system or circulating fluidized bed system,
- Catalytic oxidation with SCR system (e.g. using TiO_2 catalysts),
- High performance scrubbers (e.g. electrodynamic venturis), with addition of activated carbon particles if necessary,
- H_2O_2 oxidation process,
- Utilization of polypropylene balls (developed by FZK Karlsruhe).

During the past few years there has been a shift, particularly concerning clean gas values, towards the emission limit value of 0.1 ng I-TE /m^3 required by FEPL 17, sometimes even below this. In many plants (e.g. the domestic waste incineration plant HMVA Geiselbullach) with dry or plants with quasi-dry waste gas cleaning systems this has been achieved by adding coke or carbon to the limestone. Other plants have a packed-bed reactor installed downstream (e.g. the municipal waste incineration plant SAV Herten, waste incineration plant MVA

Düsseldorf) or a current flow reactor (e.g. MVA Zirndorf, Bonn, Ingolstadt) behind their waste gas cleaning system.

Some waste incineration plants also use SCR catalysts (e.g. MVA Vienna, Stuttgart, Krefeld) which simultaneously to nitrogen removal also destroy dioxins/furans. There are plans to use one of these in the MVA Munich.

Process	Emission values in crude gas	Emission values in clean gas		
	PCDD/PCDF [ng I-TE/m^3]	PCDD/PCDF [ng I-TE/m^3]	TOC [mg/m^3]	Dust [mg/m^3]
Packed-bed coke filter SNCR	1-3,5	0,024-0,05m	< 2	1
Adsorption system lime/coke	2-3	0,017-0,03	< 3	< 2
Current flow system	2-8	0,004-0,006	< 2	0,3
SCR system with oxidation stage	1-3	0,02-0,05	< 2	2
SNCR Current flow system	2	0,004	< 2	0,02
SCR catalysts Current flow system	3-6	0,002-0,02	n. b.	< 1

n. b. = not recorded

Table 41: Best available technology (BVT) waste gas cleaning systems for the deposition of dioxins/furans and dust

For a long time the question remained open which configuration ought to be chosen for equipment to supplement or make up waste gas cleaning systems in an effort to observe the dioxin limit value. This was particularly relevant when upgrading existing plants. Operational experience has now accumulated from a number of plants whose systems were supplemented correspondingly. According to this it is necessary to optimize the proper combination of devices and process stages for each individual waste incineration plant.

Table 42 shows the dioxin load in the year 2000 which resulted from the application of the best available system BVT in waste incineration plants.

Waste incineration	BVT Concentration	2000 Load
Municipal waste incineration	0.005 ng I-TE/m^3	0.4 g TE/a
Hazardous waste incineration	0.005 ng I-TE/m^3	0.04 g TE/a
Clinic waste incineration	<0.1 ng I-TE/m^3	0.0002g TE/a
Sewage sludge incineration	0.006 ng I-TE/m^3	0.03 g TE/a
Sum total		<0.5 g TE/a

Table 42: Result of PCDD/F reduction for the year 2000 through application of best available technology (BVT)

4.7.3 Static activated coke filter

The activated coke moving bed is used as a secondary cleaning process in the flue gas of municipal and hazardous waste incineration. Using this adsorption system it is possible to deposit substances contained in the flue gas in extremely low concentration with high efficiency. Lignite coke produced in the so-called hearth furnace coke process is used in moving bed adsorbers for technical and economic reasons.

The waste gases pass through a filling of grained hearth furnace coke – HFC – (fine coke with a granulation of 1.25 to 5 mm). The HFC's depositing effect is essentially based upon mechanisms of adsorption and filtration. It is thus possible to deposit almost all emission relevant flue gas components, in particular residual contents of hydrochlorid acid, hydrofluoric acid, sulphur oxids, heavy metals (e.g. mercury), sometimes below the detection limit. An essential feature of the moving bed system is its high efficiency with all emissions due to the large bulk of activated coke, so that variations from incineration and upstream waste gas cleaning caused by operation will not cause disadvantageous effects.

Corresponding to the routing of the waste gas through the hearth furnace coke filling, the reverse current absorber is used for secondary cleaning in hazardous waste incineration. The flue gas is guided to the activated coke filling over a distributor bed equipped with a multitude of double funnels. The gas flows through them from the bottom to the top, while the HFC passes through the adsorber from the top to the bottom. By this, an ideal distribution of the waste gas over the whole cross section of the adsorber and an optimal utilization of the adsorber capacity is achieved at a minimum consumption of activated coke. Operating results from plants of an industrial scale (municipal and hazardous waste incineration) have shown that the values – in particular for dioxins/furans – are well below the limit values of FEPL 17. However, the security-technical requirements for this process are very high.

4.7.4 Oil scrubber for the reduction of polyhalogenated aromatics and polyaromatic hydrocarbons (PAHs) in waste gases from incineration plants

Dioxins and furans are hardly water-soluble and will therefore not be deposited in waste gas scrubbers. At best there is a minimal depletion of the particularly high-boiling hepta- and octacongeneres by condensation into the comparatively cold washing medium (appr. 60 °C). However, this has not been proved beyond doubt, and exact balances are not as yet possible in this area of extreme trace analysis. But dioxins and furans are very lipophile and if a non-polar organic phase is applied, distinct depletion should be expected. A high-boiling non-toxic oil is an ideal washing medium. Pure natural oil feature these characteristics and moreover is a natural and inexpensive product.

In principle, all liquid and waste gas incineration plants have the same configuration. Burner, incineration chamber, steam boiler, quench, acid absorber and caustic neutralizer in this order form a incineration system. Acid absorber and caustic neutralizer are in most cases arranged as reverse current wash columns with tower packing. Supplementing these systems with a third reverse current washing column, operated with natural oil, will lead to the necessary dioxin deposition.

The oil scrubber at first sight seems to feature the same disadvantages as adsorption system based upon carbon, which is an accumulation of toxic agents rather than their immediate catalytic destruction. One must take into consideration, though, that such a system can be designed very easily and effectively as a closed system in accordance with the requirements of Supplement V No. 3.3 of the Hazardous Substances Ordinance [28] valid in Germany, and that the preparation of such a system for maintenance work can be provided comparatively easily. Moreover, the frequency of maintenance work to be expected is much lower than in plants that handle solids. The contaminated oil may be utilized energetically in a incineration plant without any problems. Incineration control and conditions in these plants provide for complete destruction of the oil and of all toxic components.

A plant on an industrial scale consists of a reverse current washing column as its tertiary cleaning stage (cf. Figure 34) with a closed oil circuit. To minimize the number of oil-carrying plant components it is advisable to use the sump of column as a sufficient oil reservoir. The circulating amount is determined according to the packing cross section and heated by a heat exchanger to appr. 15 °C–20 °C above the waste gas temperature to prevent water from condensing from the vapour-saturated gas. The natural oil duly enriched with dioxins and furans by current operation is exchanged and disposed of as soon as it reaches the limit value of 0.1 mg/kg as required by the Hazardous Substances Ordinance (Supplement V No. 3.1) The supply quantity is determined so that there is an oil exchange 3–4 times per year. This helps prevent excessive aging of the oil. Disposal of the contaminated oil is effected by incineration of oil charges in closed systems. To do this, the oil is pumped into a so-called slop wagon (a mobile tank with safety installations) and from there directly fed into a burner in a incineration plant. A water-oil mixture (emulsion) may be used to operate the reverse current washing column as an option to the operation with pure natural oil. This process has been patented and published under the international number WO 98/03247 of January 29, 1998.

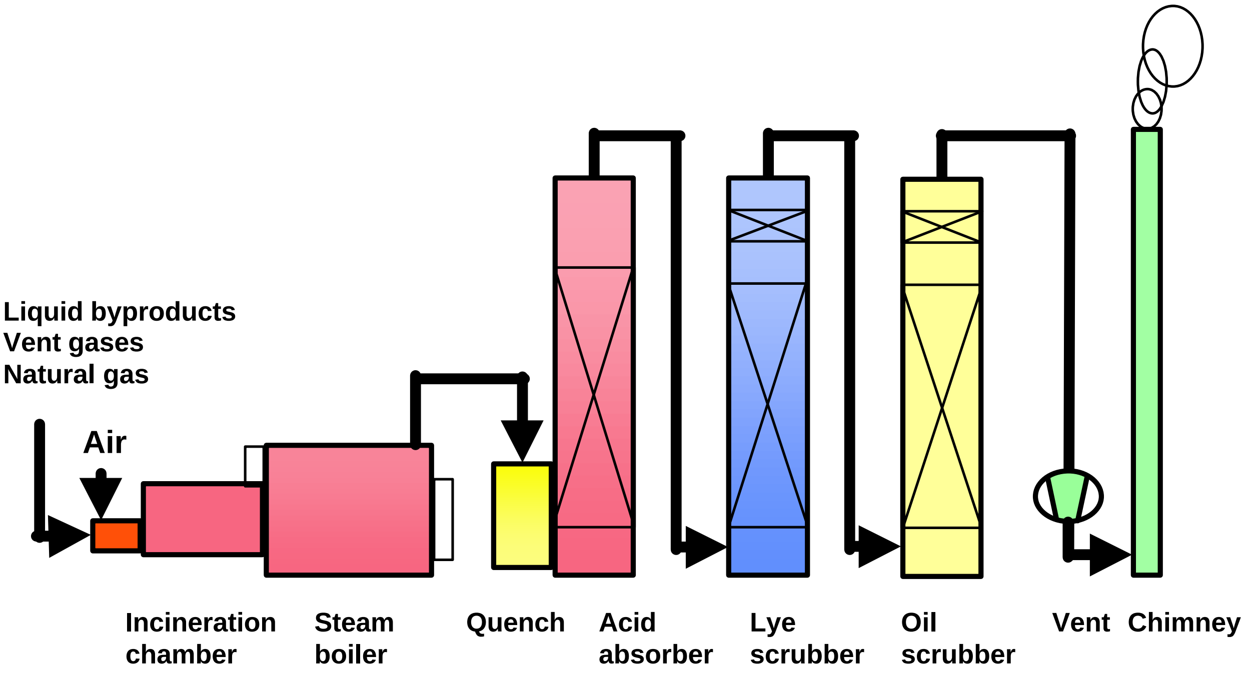


Figure 33: Block schematic diagramme of a waste incineration plant with downstream oil scrubber for dioxin deposition

4.8 Reduction of greenhouse gases (CO_2, CH_4, N_2O, SF_6)

Several diffent systems, processes and technologies for the reduction of greenhouse gases have been discussed in the past few years, but there are essentially two different systems for the reduction of greenhouse gases. The first way towards the prevention of CO_2 emissions is to increase the efficency of energy use and of energy storage. The second option is to control CO_2 emissions by way of flue gas cleaning, but this has so far not yet been used with incineration plants on an industrial scale. The plant’s efficiency may be optimized by higher steam parameters and higher pressure and thus higher turbine efficency. For waste incineration this does not seem to be the appropriate way, though. The other option is a better utilization of the energy produced by using combined heat and power. In this way efficiency ratios of waste incineration plants may be substancially increased. The problem with this is the fact that with some plants there is no demand for the energy produced, i.e. from local facilities. For new plants, however, the consideration of overall efficiency ought to be an important factor in planning.

4.8.1 Production of sodium carbonate

In the incineration of organic substances, carbon monoxide forms as one component of the flue gas. Part of the flue gas is brought into contact with caustic soda solution, and the carbon dioxide reacts with the sodium hydroxide to form sodium carbonate. A watery sodium carbonate solution will thus form. The liquid is odourless and colourless. The carbonate solution may be used as a raw material in different consumer installations of chemical plants.

In this process, the flue gas quantity required for the generation of carbonate is drawn off in controlled flow by a blast apparatus at the end of flue gas cleaning and directed into a CO_2 absorption column. The absorption column is made of glass-fibre reinforced plastic material and contains packing materials of plastics. Caustic soda solution is added to the head of the column. The caustic soda runs through the packing material and makes contact with the waste gas rising in the reverse current. This causes carbon dioxide and sodium hydroxide to react and form sodium carbonate and water.

$$CO_2 + 2\ NaOH \rightarrow Na_2CO_3 + 2\ H_2O$$

The waste gas escapes from the column into the atmosphere via a mist eliminator. The mist eliminator may be cleaned using soft water (fresh water) which is supplied via flow control in case of demand.

The carbonate solution is drawn from the sump of the column and pumped to the consumer installations with a pump via a level control installation. Quantity, pH value and NaOH and carbonate concentration are recorded with adequate measuring devices. The concentration values serve to control the caustic soda quantity to the column.

4.9 Techniques for the reduction of emissions into the water

4.9.1 Waste water treatment through chemical-physical treatment

The waste water from incineration plants, transferred outward from flue gas scrubbing, mainly contains

- Halogen compounds (fluorine, chlorine, bromine, iodine, as salts or acids depending upon the scrubbing system; bromine and iodine may be elemental),
- Sulphur dioxide compounds (sulfate, sulfit as salts or acids),
- Heavy metal compounds, as well as
- Phosphorus or silicon compounds.

The extent of waste water cleaning required depends upon the intended disposal of the waste water and the purity of the resulting wastes which is required for the disposal route.

The waste water is initially treated in a chemical-physical heavy metal precipitation before it may be – if this is possible – transferred to biological cleaning. Heavy metal precipitation is effected by alkalizing treatment and employment of precipitation and flocculation agents. Difficultly soluble metal hydroxides/sulfides will form which may be removed from the waste water through sedimentation or filtration. In the installations intended for this use, the waste water passes through the following stages of treatment:

- Two-stage neutralization with heavy metal precipitation
- Flocculation
- Clarification through separation of solid matter (sewage reducer)
- Secondary flocculation
- Lamella clarifier
- Sludge consolidation (chamber filter press)

To achieve particularly low heavy metal portions in the treated waste water, sodium sulfide is added in the second neutralization stage. From this, metal sulfide precipitates will result, which are more difficultly soluble than the hydroxidic deposits, e.g. mercury sulfides. Polysulfide or TMT-15 may be used optionally for precipitation.

Moreover, ferric salt solution is added in the flocculation stage, for example ferrichloride sulfate. Ferric salts hydrolyze to form iron hydroxide and a voluminous precipitate which binds the superfine and fewer precipitations of non-ferrous metals adsorptively to the iron hydroxide flakes formed, and sweeps them away. The liquid sludge formed in the sewage reducer is conveyed to a chamber filter press for dewatering.

As for the rest, we refer to the Horizontal-BREF ‘waste water treatment’.

4.9.2 Waste water treatment through spray drying and condensation

- Wet waste gas cleaning processes use two scrubbing stages for the separate collection of HCl (pH <1) and SO_2. The circulatory control management of the washing water in the individual stages results in an accumulation of the deposited substances. As absorption efficiency decreases with the increasing load on the washing water, a branch current is drawn off the washing circuits and supplied to the process water treatment. This treatment basically aims at depositing the heavy metals through neutralization and precipitation.

The extent of cleaning required depends upon the intended disposal of the waste water and the purity of the resulting wastes which is required for the disposal route. Of the manifold process combinations, we have given a short description of the current standard types below as examples.

With *in-process treatment* of the waste water through evaporation in the waste gas flow, e.g. in a spray drier, cleaning is usually effected through controlled neutralization with caustic soda or lime milk and heavy metal precipitation with a sulphidic precipitation agent in a continuous process. Heavy metal precipitation runs through several different stages. In the first reaction chamber, the pH value of the acid washing suspension is raised to pH 8–9 by adding a neutralizing agent. Most heavy metals will precipitate as hydroxides when thus treated. Some heavy metals like mercury, for example, mostly escape the hydroxide precipitation. The suspension is therefore passed on to another reaction chamber for further precipitation with a sulphidic precipitation agent, so that these heavy metals precipitate as sulphides.

Precipitation agent and process conditions (pH value of the waste water, temperature in the spray drier) should be selected so as to prevent reformation of volatile mercury compounds in the spray drier. Otherwise parallel dosing of a precipitation agent in the washing water circuit will be required. For the use of lime milk as neutralization agent, separate sedimentation of gypsum and dosed addition to the waste water have proved successful. Neutral salts and heavy metal compounds will then accumulate together as solid residue material to be disposed of. Isolation of heavy metal and sulphur compounds through an interposed filtration and sedimentation stage is possible.

When waste water is *treated* in a separate evaporator crystallization plant, waste water cleaning is also done in the process steps neutralization and heavy metal precipitation before the neutral salts contained are crystallized and separated. When a usable salt is produced, separation of the precipitated heavy metal compounds through filtration using auxiliary materials for flocculation and filtration and separate deposition of gypsum are generally required. In this combination of processes, neutral salts and heavy metal compounds may each be produced separately and as residual materials of high purity

With spray drying, the water leaves the plant directly with the waste gas flow. In the event of vapour condensation, the vapour condensate is used as process water for the scrubbers.

4.9.3 Production of NaCl or HCl

4.9.3.1 Production of hydrochloric acid with downstream cleaning

When wastes containing chlorine are combusted, hydrogen chloride is formed. Hydrochloric acid forms hydrogen chloride gas, which is absorbed in water. The hydrochloric acid thus produced is a colourless liquid, clear as water, with a stingy smell and free of impurities. It has a concentration of appr. 19% by weight HCl and can be used as a raw material in different consumer installations, for example for pH control in chlorine-producing plants.

In the production of hydrochloric acid, the waste gases leaving the steam boiler are first discharged into a quench and cooled down to a temperature of appr. 70 °C. The quench has an acid-proof brick lining. This lining contains jets through which hydrochlorid acid from the downstream washing column is sprayed into the flue gas. A portion of the hydrochloric acid is thus evaporated, which causes the waste gases to cool down.

The hydrochloric acid is transferred from the quench to the washing column together with the cooled flue gas. This column contains a tower packing and is made, like the quench, of glass-fibre reinforced plastics. In the washing column hydrogen chloride and other acid gases possibly contained in the flue gas are absorbed. The washing column is operated as a reverse current system. At the head of the column, freshwater and hydrochloric acid from the sump of the column are each supplied through flow control. The flue gas passes the column from the top to the bottom.

The hydrochloric acid is drawn from the sump of the column by a pump. A filter has been installed in the pump suction pipe to retain coarser solid particles that have been washed out of the gas flow. This pump transfers the hydrochlorid acid to the temporary storage tank of the hydrochloric acid cleaning system. Moreover, the spray jets of the quench are provided with hydrochloric acid and the circulation liquid is pumped to the head of the washing column. The flue gas, stripped of hydrogen chloride to very high degree, leaves the acid washing column via a mist eliminator installed at the head of the column and enters the ionization wet scrubber.

The hydrochloric acid generated in the acid washing column of the flue gas washing system is stripped of dissolved salts and solids in an evaporator system. This cleaning step enables the hydrochloric acid to be used once again as feed stock of high quality in a variety of production plants.

From the temporary storage tank the hydrochloric acid is transferred by the pump to an evaporator. Here the raw acid is upgraded in a vacuum to become an azeotropic mixture.

The excess water and small amounts of hydrogen chloride pass into the vapour phase and are condensed with water in an adsorption tower. The discharge from this adsorption column, being slightly acid and non-contaminated by heavy metals, may be used for neutralization, for example in a biological sewage plant. A steam-powered vacuum unit creates and maintains the vacuum. The driving steam is condensed with fresh water. From the vacuum unit, the process liquid is pumped into the plant waste water together with the excess water. The raw acid, upgraded to azeotrop, will evaporate, then condense again and finally reaches consumers. The remaining acid containing solids and heavy metals is drawn from the evaporator and pumped into a mixer for neutralization purposes. The live steam, used as an energy carrier in the evaporation system, is condensed. The condensate not being contaminated, it may be returned to the in-plant condensate network via the condensate collection system. This process was patented and published under US patent No. 5,174,865 of December 29, 1992.

4.9.4 Production of plaster

The plaster ($CaSO_4*2H_2O$) accumulating from waste gas cleaning in waste incineration plants (desulphurization), also known as REA plaster (REA = flue gas desulphurization plant) may be used in the plaster industry for the production of the whole range of plaster building materials to substitute natural plaster. Moreover, it may be used as a sulfate carrier in the cement industry. As a precondition, however, REA gypsum must be in keeping with the quality criteria required for plaster building materials, in particular regarding contents of specific toxic agents.

4.10 Techniques for the control of emissions discharged into soil

In Germany, test and limit values are determined for the protection of the soil in the Federal Soil Protection Ordinance (BBSchV).
Control of emissions into soil is effected through control and monitoring of emissions into exhaust air and water.

4.11 Impact of the introduction of hazardous and non-hazardous wastes on emissions from co-incineration plants

Municipal wastes and the ‘substitute or secondary fuels’ derived from them are appropriate for use in power plants as well as certain industrial production plants. In addition, there are a number of special manufacturing wastes whose consistency and physical and chemical properties render them less appropriate for grate incineration in power plants and which are therefore used preferrably in industrial furnaces.

4.11.1 Cement and lime industry

Cement works may claim to bind a major portion of anorganic toxic and foreign materials into the product. As for components which go over from the cement raw material into the product and whose concentration is not changed significantly by co-incineration, this process stream is acceptable.

This process being different in kind (heat treatment of an anorganic process flow to produce specific compounds) from the pure incineration process where incineration heat has to be transferred outward, allows for larger quantities to be used due to the comparatively high inventory of solids. This naturally has an impact upon the waste gas cleaning process where in this case mainly the product required must be retained. The differing distribution of quantity between toxic/foreign materials content and product has led to different priorities in the deposition technology. The emissions into the atmosphere are therefore still under discussion for these plants (NOx, SO_2, HCl).

Additions of foreign materials and toxic agents are partly bound into the product (cement). The amounts of substances emitted are thus smaller than in waste incineration before waste gas cleaning. Within the reactors proper, phenomena similar to those known from power plant furnaces and boilers may appear. There are experiences with co-incineration in cement works from some plants, two of which will be examined below in more detail.

Plant 1 consists of a drum-type kiln with cyclone intake heater and calcinator. Two-stage incineration with carbamide or renoxal injection for NO_x reduction is used as a measure for waste gas reduction on the primary side; an electrostatic filter is used on the secondary side. With this plant in operation, the emission values (composite limit values) shown in Table 43 below can be reached with waste co-incineration.

Parameter	Measure	Zero measurement)*	Operating values)* when utilizing wastes	Daily limit values	Annual limit values
Total dust	mg/m^3	4,3	3,9	37	19
HCl	mg/m^3	0,3	0,8	25,3	25,3
SO_x	mg/m^3	22,3	15	326,5	200
HF	mg/m^3	< 0,4	< 0,4	4,1	4,1
NO_x*	mg/m^3	842	378	500	500
Total C	mg/m^3	5,6	4,8		
PAH without BaP	mg/m^3	< 0,2	< 0,02	5,5	1
Benzo(a)pyrene	$\mu g/m^3$	< 0,001	< 0,002		
Benzene	mg/m^3	0,24	< 0,31		
Coplanary PCB	ng/m^3	< 0,3	< 0,7		
Cadmium, Thallium	mg/m^3	< 0,01	< 0,01		
Mercury	mg/m^3	0,021	0,022		
Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn	mg/m^3	< 0,1	< 0,1		
PCDD/PCDF, I-TE	ng/m^3	< 0,01	< 0,01		0,07

)* Individual measurements

Table 43: Emission values that may be reached in the clean gas (operating values) of a cement works

Plant 2 consists of a drum-type kiln with cyclone intake heater and calcinator as well as a circulating fluidized bed for weak gas generation. An electrostatic filter has been installed as a secondary waste gas reduction measure. Toxic agent contents are limited for the substitute fuels used, e.g. Hg 1,5 mg/kg m_T, chlorine 2% by weight. Operating this plant, the emission values (composite limit values from individual measurements) shown in Table 44 can be reached with waste co-incineration.

Parameter	Measure	Individual measurements	
		no utilization of wastes	utilization of wastes
Total dust	mg/m^3	2,8 – 12,9	12,0 – 15,9
HCl	mg/m^3	0,88 – 5,93	0,87 – 1,32
SO_x	mg/m^3	714 - 878	311 - 328
HF	mg/m^3	0,13 – 0,23	0,02 – 0,04
NO_x	mg/m^3	789 - 835	406 - 560
Total C	mg/m^3	11,7 – 23,2	5,7 – 7,1
PAHs	mg/m^3	--	0,0026
Benzene	mg/m^3	0,27 – 0,54	0,45 – 0,55
Cd	mg/m^3	< 0,005	< 0,007
Tl	mg/m^3	< 0,005	< 0,005
Hg	mg/m^3	0,014 – 0,044	0,003 – 0,006
Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn	mg/m^3	< 0,3	< 0,5
PCDD/PCDF, I-TE	ng/m^3	0,001 - 0,002	0,005 – 0,0065

Table 44: Emission values that may be reached in the clean gas (operating values) of a cement works

Development of High Dust SCR Technology in a pilot plant of the cement industry in Solnhofen

Selective Catalytic Reduction of NOx - SCR Technology

SCR technology is the most widely implemented process for NOx abatement in most of the industrial units such as power plants, municipal and hazardous waste incineration plants, metallurgical and glass industry. The selective reduction of NOx by NH_3 takes place in the range of about 300 to 400^{0}C in the presence of a catalyst. In the cement industry it is possible to install an SCR plant after the dedusting system i.e clean gas before chimney or after the cyclone preheater in a high dust area where a temperature range from 300 to 350^{0}C prevails. The installation of an SCR plant after the dedusting involves, on account of high preheating costs of the gas, with high capital and process costs. The second Option to install the SCR technique in the high dust area after the cyclone preheater where a temperature in the range of 300 to 350^{0}C prevails is economically the best solution for further investigation. In relation to high dust SCR technology many pilot plant test works were carried out in Europe as well as at „Solnhofer Portland Zementwerke AG” in Germany [9].
The results as reported confirm that the technology of high dust SCR in the cement industry is available. This applicability of the results to industrial plants was still not known. Based on the results of the pilot plant operation at „Solnhofer Portland Zementwerke AG” a full scale industrial demonstration plant is designed and constructed in Solnhofen.

Pilot Plant Installation

The high dust SCR pilot plant installed at ,,Solnhofer Portland Zementwerke AG” in Solnhofen consists of a NH_3 supply unit (liquid ammonia battery), the SCR reactor with 4 different chambers and a cleaning device with compressed air as well as measuring and control equipment. The pilot plant was installed in a side stream with 500 to 3000 m^3/h gas having approximately 80 g/m^3 dust after the cyclone preheater in the temperature range of 300 to 340^0C. With this reactor having 4 chambers it is possible to test 4 different catalysts at the same time.

Test Results

Pressure drop at catalysts

The test work with catalysts having different pitches showed that catalysts having pitch openings <6 mm are not satisfactory cleaned. On account of the blockage of catalysts even with continuous cleaning, very high pressure drop within short time occurs. These catalysts with pitch openings <6 mm are not suitable for the high dust SCR technology in the cement industry. Catalysts having pitch openings above 8 mm could be cleaned by the cleaning device with regular intervals. For the implementation in industrial plants it is necessary to keep the cleaning intervals dose to the pressure drop of max. 4 to 5 mbar.

Reduction of NOx

The raw gas in many cement plants after the preheater contains free ammonia. Without addition of ammonia, depending on the free ammonia in the plant it was possible to reduce NOx emissions up to 30 % (see tabl.). Further NOx reduction up to 90 % could be achieved with a
NH_3/NOx stoichiometry of 0.7 to 0.8. The ammonia slip stayed below 5 $mglm^3$.

Ammonium in Dust-Particles

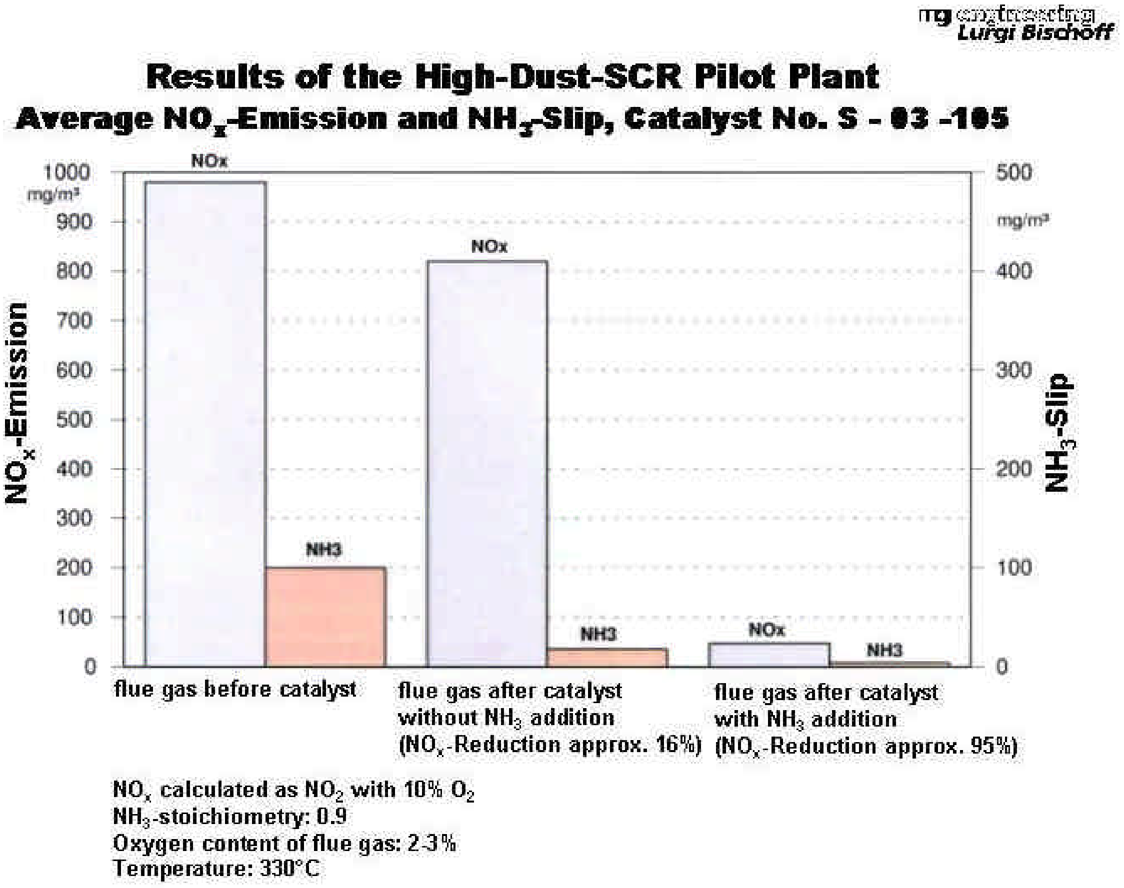
In all test runs no enrichment of ammonia or ammonium compounds was found in the dust particles after the catalysts.

Outlook

The German cement industry is involved at an early stage in the development of possible best available technologies to lower the nitrogen oxides in the exhaust gases from the rotary kiln plants. The operation of the High Dust SCR full scale demonstration plant at ,,Solnhofer Portland Zementwerke AG” in Germany after the commissioning period should prove the advanced technology with following criteria:

- effectiveness in respect of emission limitation
- plant reliability
- plant availability
- maintenance costs
- plant service life
- energy consumption
- capital and operating costs

The results will be ready after one or two years of operation.



Results of the High-Dust-SCR Pilot Plant
Average NO_x-Emission and NH_3-Slip, Catalyst No. S - 03 -105

NO_x calculated as NO_2 with 10% O_2
NH_3-stoichiometry: 0.9
Oxygen content of flue gas: 2-3%
Temperature: 330°C

Tabl.: Results of the high-dust-SCR catalyst in a cement plant

4.11.2 Iron and steel industry

In contrast to the two processes explained above, the fuel in the steel industry does not only serve the purpose of releasing heat, but the focus is on binding the oxygen from the ore to the carbon provided and thus on the reduction effect. Reutilization of wastes and substitute fuels in the steel industry is thus seen as material rather than thermal recycling of wastes.

In steel works, waste or substitute fuel (plastic wastes in general) is fed in together with coke/oil. The contents of foreign materials/toxic agents may partially be refound in the product (steel). Another part is emitted. Utilization limits for substitute fuels result from both together.

Parameter	Measure	Operating values when using substitute fuels
Total dust)*	mg/m^3	1
HCL)**	mg/m^3	2,4
SO_x)***	mg/m^3	37
HF)**	mg/m^3	0,08
NO_x)***	mg/m^3	30
Total C)*	mg/m^3	2
HBr)**	mg/m^3	0,07
Mercury)**	mg/m^3	0,0076
Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn)*	mg/m^3	n.n.
PCDD/PCDF, I-TE)*	ng/m^3	0,0008

)* Individual measurements
)** Measurement of max. 3 half hour average values
)*** Half hour average value

Table 45: Emission values that may be reached in the clean gas (operating values) of a blast furnace

Experiences from waste co-incineration in steel works have been gained from some plants. One of these plants is to be examined below in some more detail. It is a blast furnace with dedusting of the blast furnace gas and incineration in the air heaters and the power plant. Synthetic granules from the DSD (Dual System Germany) and lacquer sludge granules are utilized as wastes, the chlorine content in the synthetic matter being limited to 1.5% by weight. Operating this blast furnace plant, the emission values (composite limit values) shown in Table 45 can be reached with waste co-incineration.

4.11.3 Power plants

In Germany alone more than 350 sites of power plants offer a theoretical incineration capacity within the framework of currently valid legal conditions, which by far exceeds the volume of waste. There is some hesitation, though, about making use of this opportunity. Power plants as production plants for electric power are designed for the optimum utilization of fossile energy carriers. Even these often cause problems when handled and cause pollution and corrosion during operation, all of which are even aggravated when diverging fuels are used.

The usability of wastes and so-called substitute fuels derived from them is limited by storage facilities in the power plant, the need for pretreatment to attain a state appropriate for the individual furnace, their incineration behaviour (including pollution, corrosion and effects on the waste gas cleaning systems), their impact on the emissions, on the products from waste gas cleaning and on incineration residues.

4.11.3.1 Storage

Wastes and substitute fuels used in power plants must be stored in the appropriate form. Even though organizing delivery may help avoid extensive stores, special stores, silos or tanks may be required for individual wastes.

4.11.3.2 Pretreatment

Liquid wastes may be handled without any probles in most cases. Sewage sludge must be rotted completely for safety reasons (danger of explosion) as a rule. With solid substitute fuels, it must be possible to ground them, or to feed them directly over the main burner, or they may require their own solid burner, depending upon the furnace.

4.11.3.3 Impact on furnace

The melting behaviour of the coal is an important criterion for use in practically all coal furnaces. With melting chamber furnaces, changes in the melting behaviour may lead to a blockage in the discharge organs of the furnace as well as to damage when the fire-proof lining of the furnace melts because of diminishing viscosity. The melting behaviour will also change the fouling behaviour of the plant by glueing the flue gas borne ash particles together. This holds for melting chamber as well as dry furnaces. The operation of fluidized bed furnaces in particular may possibly be affected considerably. During incineration, volatile anorganic compounds are converted into the gas atmosphere. The contents of such compounds – salts as a rule – are usually considerably higher in wastes than in fossil fuels. When these compounds condense on heating surfaces, signs of corrosion will often evolve; strongly adhering, hard fouling may arise from the tendency to fill in cavities and pores.

4.11.3.4 Effect on the waste gas cleaning installations

In general, wastes are loaded with chlorine compounds by one dimension more than fossil fuels. These chlorides are safely deposited in flue gas desulphurization plants. It must be taken into consideration, though, that these reactors are not suited for this kind of impact. In addition, sublimated salts which are also found in REA products (plaster) must be considered. The quality requirements of the plaster industry are met by additional cleaning measures. The sublimated salts may also deactivate the DENOX catalysts.

The waste gas cleaning systems in power plants are very efficient also with regard to accompanying materials not typical of coal/oil, so that the extent of additional emissions of toxic agents compared to the incineration of regular fuels alone is hardly detectable. Since the deposition systems are not designed for wastes, there are inevitably materials which have to be watched in particular. Among them is mercury, which makes it impossible for substitute fuel to be used in power plants if found in certain concentrations. PCDD/F, on the other hand, are unproblematic since the main fuel generally contains sufficient amounts of sulphur, which will not allow reactions to form chlorinated aromatic compounds. Emissions into the aquatic system are mainly characterized by soluble compounds (salts). At this point impacts must be considered and countered.

4.11.3.5 Impact on ashes

Ashes from coal furnaces in particular are recycled to a large extent. An impairment of the recycling of melting chamber granules through contamination from co-incineration of wastes need hardly be expected. The recycling of flue ashes from dry furnaces may, however, be prevented by this. Today flue ashes are mainly used in concrete production and the cement industry and must therefore satisfy very strict quality requirements, observation of which is checked for each site individually. In view of the large amount, the licence for ash recycling must necessarily be aquired for co-incineration.

5 BEST AVAILABLE TECHNOLOGY FOR THE INCINERATION AND CO-INCINERATION OF WASTES

5.1 Preliminary note

The new European Guideline 2000/76/EG on the incineration of wastes aims at putting the idea of inter-media environmental protection from IVU Guideline 96/61/EG [21] into practice. This is why the European Guideline does not only determine requirements on the limitation of air pollution and on the protection of soil and surface and ground water. It also includes noise protection, for example. Moreover, Article 6 defines operating conditions which prescribe a incineration degree of grate ash/slag and determine minimum requirements with regard to incineration conditions. In addition, Article 6 Para. 6 defines the requirement for heat resulting from the incineration or co-incineration process to be utilized if this is feasible. With the emission requirements in Appendix II, a first regulation has been conceived for plants with waste co-incineration.

The waste incineration plants described below may serve as examples for the state of the art of the best available technology realized in Germany. The selection was agreed between the Federal Office for Environment Protection and the responsible authorities of the *Bundesländer*. The fact that a certain plant is not included in the following list does not indicate the plant does not come up to the state of the art. It is shown that, with different combinations of individual treatment and dedusting techniques, the valid limits for the protection of air, soil and water can be guaranteed. All of them are available on the market, i.e. they can be purchased; operators must make their choice, taking into account the capacities and the availability of the techniques in highly-demanding everyday operations.

5.2 Best available technology for the incineration of non-hazardous wastes

Of the 56 incineration plants for municipal waste in Germany, all of which are operated with the grate furnace system, data from 16 plants altogether were selected to describe the BAT standard for the incineration of non-hazardous wastes in Germany. The capacity of the selected plants is in the range between 85,000 and 650,000 Mg/a.

5.2.1 BAT standard with regard to operating conditions

All waste incineration plants are operated in such a way that with the incineration degree achieved in slag and grate ash, a content of organically bound total carbon (TOC) of less than 3% or a loss on ignition of less than 5% of the dry weight of the material combusted can be kept. The incineration conditions in the furnace chamber to achieve an optimized incineration of the incineration gases can be provided by all plants, as far as minimum temperature and residence time are concerned.

5.2.2 BAT standard for the observation of limit values for emissions into the air

Table 46 gives a survey of the ranges of emission values achievable in clean gas.

Parameter	Measure	Half-hour average value	Daily average value	Annual average value
Continuous measurement				
Total dust	mg/m^3	1 - 15	1 – 2,5	1 - 2
HCl	mg/m^3	1 - 30	1 - 7	1 - 3
SO_x	mg/m^3	1 - 100	1 - 20	1 - 6
HF	mg/m^3	< 1	< 1	< 1
NO_x	mg/m^3	60 - 220	61 - 120	36 - < 181
∑ C	mg/m^3	<1 - 10	<1 - 2	<1 - 2
CO	mg/m^3	<2 - 100	<1 - 38	< 2 - 17
Periodical measurement (Mittelwert über Probenahmezeit)				
NH_3	mg/m^3	< 1 - 3	< 4	<1 - 6
Cd, Tl	mg/m^3			0,001 - 0,0008
Hg 1)	mg/m^3	0,00015 – 0,003	0,0001	0,0004 – 0,005
∑ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn	mg/m^3			0,005 - 0,034
PCDD/PCDF, I-TE	ng/m^3			0,0011 - 0,029
Benzo(a)pyrene	mg/m^3			<0,0001
∑ PCB	$\mu g/m^3$			<0,005
∑ PAH	$\mu g/m^3$			<0,01
N_2O	mg/m^3			

[1] in Germany also continuous measurement

Table 46: BAT standard for emissions into the air (operating values)

5.2.3 BAT standard for the observation of limit values for waste water discharge from the waste gas cleaning system

Of the 56 municipal waste incineration plants in Germany, 4 plants are not operated with zero waste water discharge. Typical annual average values for cleaned waste water from such plants are listed below.

Parameter	Qualified composite samples as annual average value for cleaned waste water [mg/l]
Depositable substances (0.5 h)	< 0.1 ml/l
Suspended solid matter	37
Mercury Hg	< 0,002 – 0,008
Cadmium Cd	< 0,012 – 0,005
Thallium Tl	< 0,1
Arsenic As	0,015 - < 0,5
Lead Pb	0,01 - < 0,058
Chromium Cr	< 0,023 – 0,05
Copper Cu	< 0,061 – 0,14
Nickel Ni	< 0,0243 – 0,23
Zinc Zn	< 0,079 – 0,28
Tin Sn	n. k.
Dioxins and furans (ng I-TE/l)	0,07 - < 0,1
Fluoride	n.k.1)
N_{total}	n.k.
P_{total}	n.k.
Temperature	n.k.
pH value	8,6 – 10
Sulfate	n.k.
TOC	n.k.

1) not known

Table 47: BAT standard for emissions into the water (operating values)

5.2.4 BAT standard on the physical and chemical properties and the toxic agent potential in incineration residues

Table 48 shows some typical analytical values of grate ashes from incineration plants for municipal waste.

Parameter	Measure	Measured values
Solid contents		
TOC	% by mass	<0,1 - < 2,2
Loss on ignition	% by mass	< 3
PCDD/PCDF	ng I-TE/kg	< 3,3 - < 15
Arsenic	mg/kg	1 – 20
Lead	mg/kg	300 – 6000
Cadmium	mg/kg	1 – 25
$\text{Chromium}_{\text{total}}$	mg/kg	100 – 1000
Copper	mg/kg	500 – 5000
Nickel	mg/kg	30 – 600
Mercury	mg/kg	0,01 – 0,5
Zinc	mg/kg	30 – 10000
Eluate values		
Cl-	mg/l	84 - < 136
SO_4^{2-}	mg/l	260 - < 305
TOC	mg/l	13,8
Arsenic	mg/l	<0,006
Lead	mg/l	<0,001 – 0,00136
Cadmium	mg/l	<0,0001-<0,0005
$\text{Chromium}_{\text{total}}$	mg/l	<0,01-<0,025
Copper	mg/l	0,057 – 0,135
Nickel	mg/l	<0,001 – 0,003
Mercury	mg/l	<0,0002
Zinc	mg/l	0,01 – 0,034

Table 48: Analyses of grate ashes

5.2.5 BAT standard in energy utilization

The following table 49 shows the energy efficiency ratios achievable depending upon the type of heat utilization, internal requirements being included in each case.

Plants with only	Energy efficiency ratio in [%]		
	Electric power	Heat	Total
Power/heat generation	7 – 17 9 – 22,7[1]	17,2 – 33,8 22,9 - 45	29,4 – 45,6 39,3 - 60,7
Power/heat output[2]	4 - 18,4 5,3 - 24,5[1]	3,2 – 46 4,3 - 61,3[1]	12,5 - 56 16,7 - 74,7[1]
Heat generation		85	85
Heat output[2]		66,4 88,5[1]	66,4 88,5[1]
Power generation	17,5 - 25 23,3 - 33,3[1]		17,5 – 25 23,3 - 33,3[1]
Power output[2]	12 - 21,1 16 - 28,1[1]		12 – 21,1 16 - 28,1[1]

[1] Energy efficiency ratio taking into account a cumbustion efficiency ratio of 75% of the energy input

[2] excluding own consumption

Table 49: BAT standard in energy utilization

5.2.6 BAT standard in noise control

The following noise immission values can be achieved:

Sound assess level by day: 36 dB(A) – 56.8 dB(A)
Sound assess level by night: 29 dB(A) - < 45 dB(A)

5.2.7 Costs

In this case, treatment costs mean acceptance fees. There are no comparable data on the ‘real’ costs, meaning the actual costs for thermal treatment. The range of so-called treatment fees in incineration plants for municipal waste is between 180 and 700 DM/Mg.

5.3 BVT plants for the incineration of municipal waste (MVA)

5.3.1 Plant for the incineration of solid municipal waste (BAT1)

- Capacity appr. 320,000 Mg/a
- 2 incineration lines at 23 Mg/h each
- Central flow furnace with multi-step feed grate
- Incineration temperature 850 °C at a residence time > 2 seconds
- Start-up: 1999

5.3.1.1 Reduction of emissions into the air

The waste gas cleaning system consists of the following components:

- SNCR nitrogen reduction
- Boiler dust deposition
- Tissue filter as current flow adsorber (adsorption of dioxins/furans on hearth furnace coke (HFC))
- 2-stage HCl scrubber
- SO_2 scrubber
- Tissue filter with HFC metering for the adsorption of remaining dioxins, furans and heavy metals

Waste gas quantity line 1 76,137 m^3/h
line 2 78,464 m^3/h
Manufacturer: L & C Steinmüller GmbH

Parameter	Measure	Half-hour average value	Daily average value	Annual average value
Continuous measurement				
Total dust	mg/m^3	< 5	< 2,5	0,4
HCl	mg/m^3	< 10	< 5	0,1
SO_x	mg/m^3	< 50	< 20	2,44
NO_x	g/m^3	< 0,280	< 0,12	0,082
Total C	mg/m^3	< 15[1]	< 7	0,5
CO	mg/m^3	< 60[1]	< 20	8,0
Periodical measurement (Mittelwert über Probenahmezeit)				
HF	mg/m^3	< 0,06	-	0,03
NH_3 3)	-	-	-	-
Cd, Tl	mg/m^3	< 0,001	-	0,0006
Hg 2)	$\mu g/m^3$	< 1	-	0,5
Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V ,Sn	mg/m^3	< 0,014	-	0,0081
PCDD/PCDF, I-TE	ng/m^3	< 0,011	-	0,0023

1) higher values only for a short time with starts/stops at low temperatures (only gas furnace)
2) continuous measurement behind the 1st tissue filter, emission measurement repeated
3) Individual measurement < 1 mg/m^3

In all measurements, 100 % of the values specified were complied with.

Table 50: Average values measured in clean gas (operating values) – BAT1

5.3.1.2 Reduction of emissions into the water

Waste water from waste gas cleaning undergoes indirect condensation. Thus, the plant is operated with zero waste water discharge. The raw acid from the hydrochloric acid scrubber is upgraded to 30% hydrochloric acid in a hydrochloric acid reprocessing plant. Mixed salts are used in liquid form (brine) as stowing material in salt caverns. The plaster from the SO_2 scrubber is processed in the building industry.

5.3.1.3 Residues

Quantity of slag: 86,000 Mg/a (260 kg/Mg waste)
Reprocessing of slag: washing, crushing, metal separation, sifting
Further use: Utilization, e.g. in road construction
Quality: (cf.
Table 51)

Solid matter values:	
TOC	< 1%
Loss on ignition	< 3%
PCDD/PCDF	< 10 ng I-TE/kg
Eluate values:	
Cl^-	< 100 mg/l
SO_4^{2-}	< 350 mg/l
As	< 0.006 mg/l
Cd	< 0.0005 mg/l
Cr	< 0.05 mg/l
Cu	< 0.1 mg/l
Hg	< 0.0002 mg/l
Ni	< 0.004 mg/l
Pb	< 0.02 mg/l
Zn	< 0.01 mg/l

Table 51: Slag quality – BAT1

5.3.1.4 Energy utilization (reference year 2000)

Heat generation/output

Heat generation in total: 3,009,893 GJ/a
Internal consumption: 800,925 GJ/a
Heat output to thermal power plant: 1,346,577 GJ/a

Steam generation/output

Steam DE1: 493,105 Mg
Steam DE2: 488,834 Mg
Steam HDE3 (auxiliary DE, natural gas): 25,458 Mg
Steam HDE4 (auxiliary DE, natural gas): 33,908 Mg
Steam output to thermal power plant: 461,756 Mg

Electric power generation/output:

Electric power generation in total: 59,213 MWh
Internal consumption
(incl. additional supplies of appr. 7,398MWh): 36,715 MWh
Electric power output: 29,896 MWh

Waste quantity combusted: appr. 318,000 Mg		Energy in [MWh]		Energy efficiency ratio in [%]		
		El power	Heat	El. Power	Heat	Total
	generated	59.213	526.000	7/9,3[7]	66/88[1]	73/97,3[1]
	released	29.896	344.000	4/5,3[1]	42/56[1]	46/61,3[1]

[1] Energy utilization factor, taking into account a combustion efficiency of >75% of the energy input into the waste, first year of full operation, plants operation are not optimal.

Table 52: Energy efficiency ratio (supposed average calorific value Hu ≈ 9,500 kJ/kg)

5.3.1.5 Noise emissions/immissions

Distance of plant to immission site: m

Sound assess level: L_{aeq} = dB(A)
L_{AF} = dB(A)

5.3.1.6 Costs

- Investment costs (incl. planning and 50,000,000 DM for infrastructure measures): appr. $450*10^6$ DM
- Specific treatment costs: appr. 250 DM/Mg (plus VAT)

5.3.2 Plant for the incineration of solid municipal waste and sewage sludge (BAT2)

- Capacity 175,000 Mg/a
- 3 incineration lines, 2 with 12.5 Mg/h each and 1 with 15.5 Mg/h
- reverse current furnace with reverse grate or with water-cooled feed grate
- Incineration temperature 850 °C at a residence time of > 2 seconds
- Start-up: 1984, expansion: 1998 (line 3), modernization: 2000 (grate with water enclosure)

5.3.2.1 Reduction of emissions into the air

The waste gas cleaning system consists of the following components:

Line 1+2:
- Cyclone
- Evaporation cooler
- Current flow system with tissue filter
- DENOx catalyser

Line 3:
- SNCR
- Cyclone
- DENOx catalyser (high dust)
- Evaporation cooler
- Current flow system with tissue filter

Waste gas quantity per line: 2 x 70,000 m^3/h
1 x 88,000 m^3/h
Manufacturer: Noell KRC GmbH
Special features: Waste gas recirculation behind multi-cyclone (branch current appr. 20–25% of the waste gas quantity at 300–400 °C, economizer at 190 °C, injection into constriction between secondary incineration chamber and incineration chamber)

Parameter	Measure	Daily average value Minimum	Daily average value Maximum	Annual average value (reference year 2000)	Portion in % (over the annual operation time) hav[1]>lv[3]	dav[2]>lv
Continuous measurement						
Total dust	mg/m^3	0,04	15,15	0,45	0,0	0,0
HCl	mg/m^3	0,24	15,15	3,27	0,0	0,5
SO_x	mg/m^3	0,56	42,56	11,41	0,0	0,0
NO_x	g/m^3	15,42	249	166	0,0	2,2
Total C	mg/m^3	0,02	0,41	0,41	0,0	0,5
CO	mg/m^3	1,29	70,67	6,39	0,2	0,5
Hg[2)]	mg/m^3	0,00014	0,01717	0,00413	0,04	0,0
Periodical measurement (average value over sample taking period)						
HF	mg/m^3			< 0,1		
Cd, Tl	mg/m^3			0,0017		
Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V ,Sn	mg/m^3			< 0,01		
PCDD/PCDF, I-TE	ng/m^3			0,0053		

[1] hav – half-hour average value
[2] dav – daily average value
[3] lv – limit value

Table 53: Average values measured in clean gas (operating values) – BAT2

Toxic agent	Measuring device
Dust	Sick RM 210
HCl	Perkin Elmer MCS 100 E
C_{total}	M&A Thermo FID
SO_2	Perkin Elmer MCS 100 E
NO_x	Perkin Elmer MCS 100 E
CO	Perkin Elmer MCS 100 E
Hg	Perkin Elmer ACE 100 Mercem
O_2 (secondary incineration)	Perkin Elmer MCS 100 E
Temperature (secondary incineration)	NiCr-Ni
Temperature (waste gas)	Sensycon PT 100

Table 54: Measuring devices used for continuous measuring – BAT2

Toxic agent	Concentration in [mg/m³]		Deposition degree in %
	before cleaning	after cleaning	
HCl	1.700	10	99,4
HF	10	1	90
SO_x	400	50	87,5
NO_x	400	200	50
Dust	800	10	98,7
Cd/Tl	5	0,05	99
Hg	1	0,05	95
Other heavy metals	100	0,5	99,5
PCDD/PCDF [ng I-TE/ m³]	10	0,1	99

Table 55: Deposition degrees in waste gas cleaning – BAT2

5.3.2.2 Reduction of emissions into the water

There is no waste water resulting from waste gas cleaning, as the plant uses the conditioned dry process.

5.3.2.3 Energy utilization (reference year 1999)

Heat generation/output

Heat generation in total:	115,000 MWh
Internal consumption:	50,000 MWh
Heat output, external:	65,000 MWh

Steam generation/output

Fresh steam production:	580,000 Mg/a

Electric power generation/output

Electric power genration in total:	95,000 MWh
Internal consumption (additional supplies incl.):	23,100 MWh
Electric power output:	71,900 MWh

Waste quantity combusted: appr. 174,100 Mg		Energy in [MWh]		Energy efficiency ratio in [%]		
		El. power	Heat	El. Power	Heat	Total
	generated	95.000	115.000	17 22,7[1]	20,6 27,5[1]	37,6 50,2[1]
	released	71.900	65.000	12,9 17,2[1]	11,7 15,6[1]	24,6 32,8[1]

[1] Energy efficiency ratio taking into account a combustion efficiency ratio of 75% of the energy input

Table 56: Energy efficiency ratio (supposed average calorific value Hu ≈ 11500 kJ/kg)

5.3.2.4 Residues – slag

The contents of toxic agents are in the following ranges:

TOC	0.1 - 2%
Loss on ignition	< 3%
PCDD/F	15 ng I-TE/kg
Cl^-	4,100 mg/kg
SO_4^{2-}	21,000 mg/kg
Fluoride	600 mg/kg
As	1 - 20 mg/kg
Cd	1 - 25 mg/kg
Cr	100 – 1.000 mg/kg
Cu	500 – 5.000 mg/kg
Hg	0.01 – 0.5 mg/kg
Ni	30 - 600 mg/kg
Pb	300 – 6,000 mg/kg
Zn	300 – 10,000 mg/kg

Table 57: Slag quality – BAT2

5.3.2.5 Noise emissions/immissions

Allowable immission values according to Item 2.321 TI Noise are observed on the prominent immission sites.

5.3.2.6 Costs

- Investment costs incl. planning: 130x10^6 DM
- Spezific treatment costs: 120 to 339 DM/Mg

5.4 State of the art technology for the incineration of hazardous wastes

Of the appr. 30 hazardous waste incineration plants in Germany, usually operated with drum-type kiln and secondary incineration chamber, data from 8 plants have been selected to line out the BAT standard for the incineration of hazardous wastes in Germany. The capacity of the plants selected is between 15,000 and 13,000 Mg/a, (160000 Mg/a in the case of BASF).

5.4.1 BAT standard for operating conditions

All hazardous waste incineration plants are operated in such a way that with the incineration degree attained in slag and grate ash, a content of organically bound total carbon (TOC) of less than 3% or a loss on ignition of less than 5% of the dry weight of the material combusted is observed.

Deviating from the prescribed incineration conditions in the incineration chamber for an optimum combustion of the incineration gases, plants with temperatures or sojjourn times lower than the minimum temperature of 1,100°C or the residence time of 2 s, respectively, are also operated, provided that it has been proved that their emissions are not higher than with the regular requirements.

5.4.2 BAT standard for observin the limit values for emissions into the air

The following Table 58 gives a survey on the ranges of emission values attainable in clean gas.

Parameter	Measure	Half-hour average value	Daily average value	Annual average value
Continuous measurement				
Total dust	mg/m^3	- < 30	<1 - <6,1	< 1 -
HCl	mg/m^3	- <60	<3 - <3	< 1 -
SO$_x$	mg/m^3	- <200	<1 - <12	<1 - < 3
HF	mg/m^3	- < 4	< 1	< 0,01
NO$_x$	mg/m^3	<68 - <400	< 100 - < 200	75 - 118
$\sum$ C	mg/m^3	- <20	<1 - <2,2	< 1 -
CO	mg/m^3	- < 100	<4 - <50	<9 - 15
Periodical measurement (average value over sample taking period)				
NH$_3$	mg/m^3	<2		
Cd, Tl	mg/m^3		0,0002 - <0,012	< 0,0004
Hg[1)]	mg/m^3	- <0,05	0,00045 - <0,012	0,0017 - 0,0025
$\sum$ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn	mg/m^3		0,015 - <0,3	0,009 - 0,01
PCDD/PCDF, I-TE	ng/m^3		0,0022 - <0,1	0,00017 – 0,005
Benzo(a)pyren2	mg/m^3			<0,0001
$\sum$ PCB	ng/m^3			.
$\sum$ PAH	ng/m^3			
N$_2$O	mg/m^3			

[1] in Germany also continuous measurement

Table 58: BAT standard for emissions into the air (operating values)

5.4.3 BAT standard for the observation of limit values for the discharge of waste water from waste gas cleaning

Table 59 lists typical annual average values for the cleaned waste water from hazardous waste incineration plants.

Parameter	Random sample (12 x p.a.) / qualified composite sample / 24 h composite sample for cleaned waste water [mg/l]
Suspended solids	<0,5 - 30
Suspended matter	< 1
Settleable materials	<20
Mercury	0,001 - 0,05
Cadmium	0,009 - 0,2
Thallium	
Arsenic	0,005 - < 0,1
Lead	<0,1 - <0,5
Chromium	0,11 - 0,5
Copper	0,2 - 0,5
Nickel	0,1 - <1
Zinc	0,23 – <2
Tin	<0,01
Dioxins and furans [ng I-TE/m^3]	0,004
Fluoride	
N_{total}	
P_{total}	
AOX	< 0,1
CSB	22
Temperature	
pH value	
Sulfate	
TOC	< 4

Table 59: Emission values of the cleaned waste water before blending

5.4.4 BAT standard on the physical and chemical properties and the toxic agent potential of incineration residues

Table 60 gives a survey on the quality of ashes from hazardous waste incineration plants.

Parameter	Measure	Measured values
Solid contents		
TOC	% by mass	
Loss on ignition	% by mass	
PCDD/PCDF	ng I-TE/kg TS	
Arsenic	mg/kg	0,3 - 78
Lead	mg/kg	56 – 2.890
Cadmium	mg/kg	< 0,5 - 56
Chromium$_{total}$	mg/kg	75 – 6.933
Copper	mg/kg	40 – 36.300
Nickel	mg/kg	52 – 4.091
Mercury	mg/kg	
Zinc	mg/kg	241 – 22.855
Eluate values		
Cl-	mg/l	
SO_4^{2-}	mg/l	
TOC	mg/l	
Arsenic	mg/l	< 0,01 – 0,094
Lead	mg/l	< 0,01 – 0,27
Cadmium	mg/l	< 0,001 – 0,03
Chromium$_{total}$	mg/l	< 0,01 – 0,10
Copper	mg/l	0,029 – 0,90
Nickel	mg/l	< 0,01 – 0,018
Mercury	mg/l	0,037 – 0,082
Zinc	mg/l	< 0,01 – 0,094

Table 60: Analyses of grate ashes

5.4.5 BAT standard for heat utilization

The following table shows the attainable efficiency ratios depending upon the type of heat utilization, internal consumption included in each case.

Plants with only	Energy efficiency ratios in [%]		
	Electric power	Heat	Total
Power/heat generation			
Power/heat output	4 - 18,4 5,3 - 24,5[1]	3,2 – 46 4,3 - 61,3[1]	12,5 - 56 16,7 - 74,7[1]
Heat generation			
Heat output		65 86,7[1]	65 86,7[1]
Power generation	7 9,4[1]		7 9,4[1]
Power output	1,14 - 4,4 1,5 - 5,9[1]		1,14 - 4,4 1,5 - 5,9[1]

[1] Energy efficiency ratio taking into account a combustion efficiency ratio of 75% of the energy input

Table 61: BAT standard in energy utilization

5.4.6 BAT standard for noise control

Sound assess level by day:	38.5 dB(A) – 53 dB(A)
Sound assess level by night:	38.5 dB(A) – 40 dB(A)

5.4.7 Costs

Treatment costs in thermal plants for hazardous waste incineration range from 50 to 3000 DM/Mg and more.

5.5 BVT plants for the incineration of hazardous waste (SAV)

5.5.1 Plant with publis access (BAT3)

- Total capacity 110,000 Mg/a
- Drum-type kiln with secondary reaction space
- 2 incineration lines with 6.3 Mg/h each
- Start-up: 1997

5.5.1.1 Reduction of emissions into the air

The waste gas cleaning system consists of the following components:

- Electrostatic filter
- Quench
- HCl absorber (2-step scrubbing)
- SO_2 scrubber (2-step neutralization with lime milk)
- Activated carbon filter
- DENOx-SCR catalyzer

Waste gas per line:	61,800 m^3/h
Manufacturer:	

The average values measured in clean gas (operating values) of the plant are listed in the following Table 62.

Parameter	Measure	Half-hour average value	Daily average value	Annual average value
Continuous measurement				
Total dust	mg/m^3			0,2
HCl	mg/m^3			0,7
SO_x	mg/m^3			0,08
NO_x	g/m^3			0,075
Total C	mg/m^3			0,3
CO	mg/m^3			8,9
Hg	mg/m^3			0,002
Periodical measurement (average value over sample taking period)				
HF	mg/m^3			< 0,2
Cd, Tl	mg/m^3			0,0004
Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn	mg/m^3			0,009
PCDD/PCDF, I-TE	ng/m^3			0,005

Table 62: Average values measured in clean gas (operating values) – BAT3

5.5.1.2 Reduction of emissions into the water

The incineration plant is operated with a zero waste water discharge. The raw acid from the hydrochloric acid scrubber is upgraded to 18% hydrochloric acid in a chemical-physical reprocessing plant. The plaster from the SO_2 scrubber is reprocessed.

5.5.1.3 Energy utilization

With a waste quantity of 69,000 Mg combusted in the year 2000, a heat quantity of 192,000 was fed into the existing district heating system.

5.5.1.4 Noise emissions/immissions

Distance of plant to site of immision: 500 m

Sound assess level: L_{aeq} = 44.3 dB(A) - short-term (1 minute) events
L_{AF} = 56.5 dB(A)

5.5.1.5 Costs

- Investment costs (including modernization of the plant): appr. 400m DM
- Specific treatment costs: 400 to 800 DM

5.5.2 Plant for the incineration of residues of Bayer AG (BAT4) at Dormagen

5.5.2.1 Technical description

5.5.2.1.1 Incineration part and steam generation

The plant consists of a drum-type kiln with an annual capacity of appr. 50,000 Mg. The drum-type kiln measures 13 m in length and 4 m in diameter. It has a fireproof brick lining. At the head of the drum-type kiln there are the installations through which all combustible wastes (solid, liquid, pasty) are fed into the kiln. The round secondary incineration chamber connected to the drum-type kiln has a diameter of 6.5 m and a height of 28 m. It is equipped with 4 burners for liquid residues. Its fireproof brick lining even resists a temperature of 1200 °C, at which the flue gases are combusted.

The flue gases from the drum-type kiln and the secondary incineration chamber are cooled down from 1,200 to about 300 °C in the waste heat boiler. The steam thus generated is fed into the in-plant system and converted into electricity.

5.5.2.1.2 Waste gas cleaning

The flue gas scrubbing system consists of two ‘streets’ operated in parallel, with one spray cooler (quench) each and two rotation scrubbers. Here the flue gas is cooled further down to 65 °C by injection of water. During this process, dust and acid gases are already deposited. In the rotation scrubbers, the flue gas is conducted through an intensive spray film of water. During this, more toxic gases and dust are deposited.

In the condensation electrostatic filter, the flue gas, which has already been cleaned to a large extent, is again expanded in two parallel ‘streets’ and then conducted through an electric field (35,000 Volts). Here the remaining dusts and droplets (aerosols) still in the flue gas are electrostatically charged and deposited on electrodes. A permanent water condensate film continuoulsy transfers the dusts and droplets outward.

By injecting ammonia water, nitric oxides contained in the waste gas are converted into nitrogen and water with the help of a catalyst. In a second catalyst step, remaining dioxins and furans are reduced to values below 0.1 ng/m^3 (0.000,000,000,1 g/m^3). The cleaned flue gas is then discharged into the atmosphere with fans and through a chimney of 99 m of height. Waste gas cleaning is effected, mainly due to devices, in two independent ‘streets’ from the waste heat boiler to the nitrogen removal plant. However, this may also increase process safety in the event of possible technical failures in the plant.

5.5.2.1.3 Waste water treatment

All waste water accumulating in the plant is collected and cleaned in the waste water treatment plant. The waste water is neutralized and stripped of heavy metals, insoluble salts and solid matter in the following precipitation and filtration stage.

5.5.2.1.4 Licence/Plant safety

The licence for the plant for the incineration of residues, Dormagen (RVAD), was subject to an extensive plan approval process over several years, in which all realistically imaginable moments of danger were examined. For plant safety in particular, a safety analysis according to the regulations of the Incidence Ordinance was prepared. As required in the Incidence Ordinance, investigation was carried out as to which impacts would arise if safety precautions failed. Extensive measures for planning, manufacture, construction and operation of the plant were derived from this safety analysis. Some of these safety-practice measures are, for example:

- Continuous process monitoring
- Automatic shut-down of the plant or running towards a safe state in the event of a deviation of the operating parameters beyond the admissible range
- Automatic changeover of all safety-relevant units to a second supply network.

Apart from a large number of safety precautions in view of the system design, organizational measures complete the safety concept of the plant. Among others, these are in particular written directives for the following areas:

- Wastes reception
- Interim storage of wastes (supplies)
- Monitoring waste composition (analytics)
- Emission monitoring
- Wearing personal protective equipment
- Fire prevention
- Realization of regular tours of inspection

Staff from the areas of industrial safety, fire prevention and analytics continuously monitor the observation of these safety regulations and of governmental regulations. RVAD staff are involved in a training programme on preventive safety of the system, which is to be developed continuously. The combination of technical and organzational measures grants a maximum in safety.

The following flow chart (Figure 35) illustrates the individual parts of the plant as well as energy and mass flows.

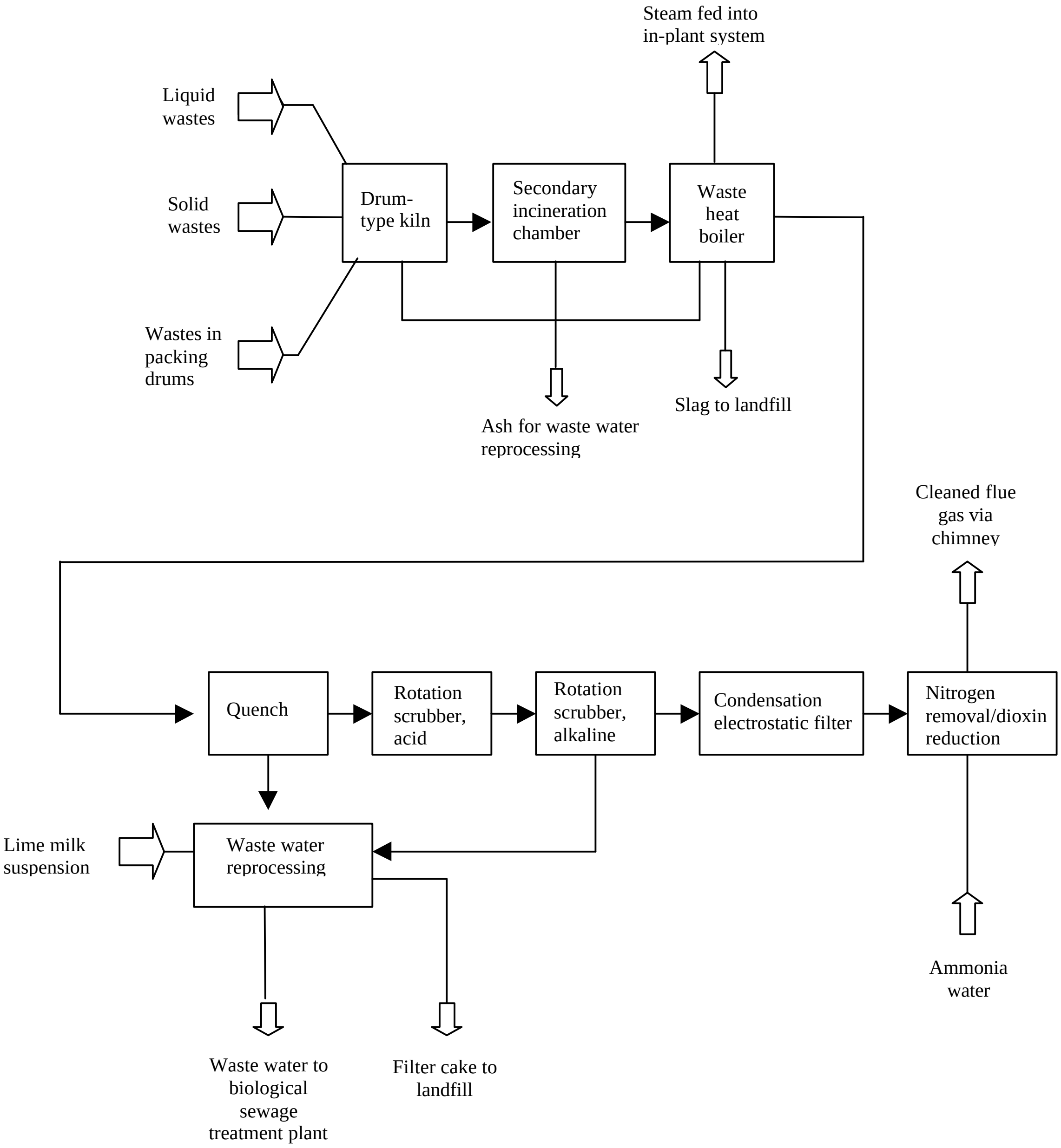


Figure 34: Flow chart of the plant for the incineration of residues, Dormagen

5.5.2.2 Reduction of emissions in the air

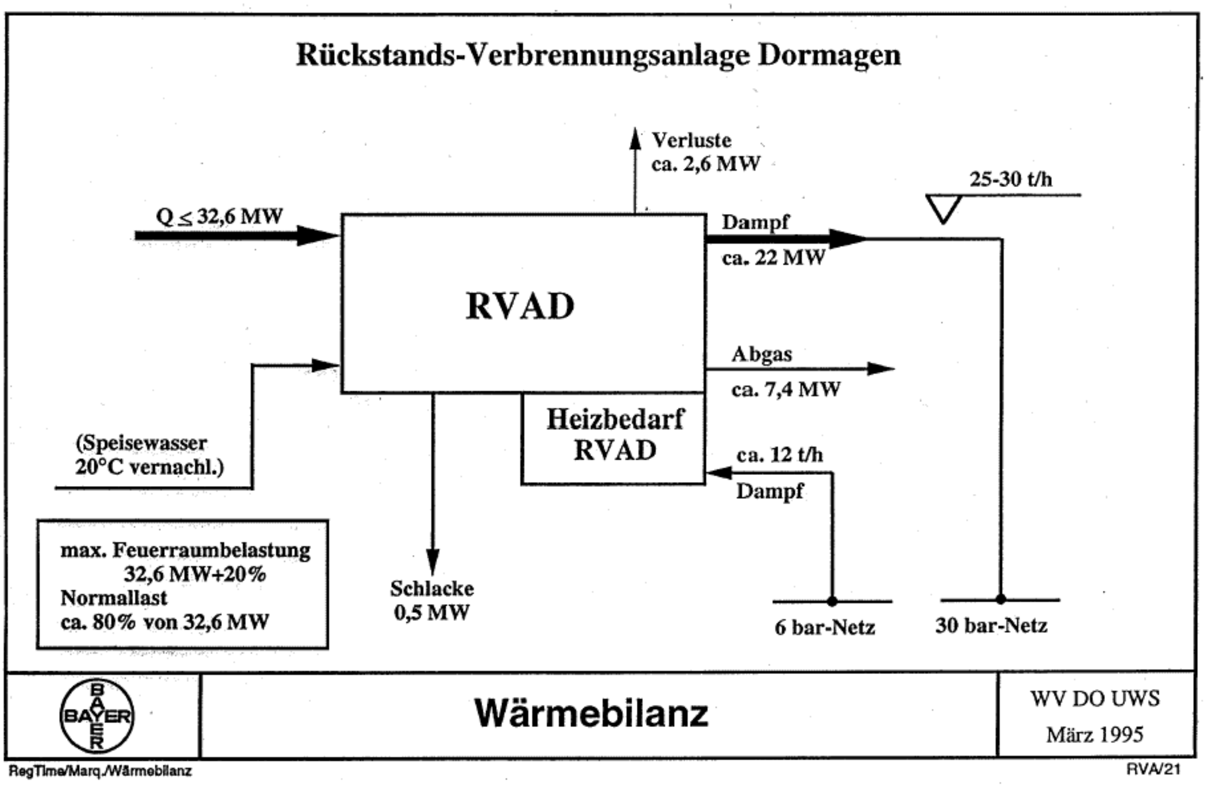
Emitted substance	admissible limit values	Measured values 1999 (annual average)	Measured values 2000 (annual average)
	Daily average values	Half-hour average values	
Dust	10	0,23	0,19
Carbon monoxide	50	6,2	4,9
Org. bound carbon	10	0,2	0,2
Sulphur dioxide	50	0,0	2,2
Nitrogen dioxide	200	55,5	67,3
Ammonia	5	0,9	1,3
Hydrochloric acid	10	0,5	0,5
Periodical measurement (Average values over sample taking period)			
Hydrofluoric acid	1	< 0,2	< 0,4
Cadmium and thallium	0,05	0,019	0,004
Mercury	0,05	< 0,001	< 0,001
Heavy metals	0,5	0,061	0,014
Dioxins/Furans[1)] [ng I-TE/m^3]	0,1	< 0,001	0,011

[1)] Minimum temperature 1050°C

Table 63: Average values measured in clean gas (operating values) – BAT4

5.5.2.3 Emissions into the water

5.5.2.4 Energy utilization



5.5.2.5 Noise emissions/immissions

5.5.2.6 Costs

5.6 State-of-the-art technology for the incineration of hospital waste

5.6.1 Reduction of emissions into the air

5.6.2 Reduction of emissions into the water

5.6.3 Energy utilization

5.6.4 Noise emissions/immissions

5.6.5 Costs

5.7 State-of-the-art technology for the incineration of sewage sludge

Of the appr. 22 mono sewage sludge incineration plants in Germany, predominantly operated on fluidized bed furnace, data from 6 plants have been selected to line out the BAT standard for the incineration of sewage sludges in Germany. The capacity of the selected plants ranges from 35,000 to 135,000 Mg m$_T$/a.

5.7.1 BAT standard with operating conditions

All mono sewage sludge incineration plants are operated in such a way that with the incineration degree attained in slag and grate ash, a content of organically bound total carbon (TOC) of less than 3% or a loss on ignition of less than 5% of the dry weight of the material combusted is observed.

The prescribed incineration conditions in the incineration chamber with regard to a minimum temperature of 850 °C and a residence time of 2 s for attaining optimum incineration of the incineration gases can be fullfilled by all plants.

5.7.2 BAT standard for observing the limit values for emissions into the air

Table 64 shows the ranges of attainable clean gas values in mono sewage sludge incineration plants.

Parameter	Measure	Half-hour average values	Daily average values	Annual average values
Continuous measurement				
Total dust	mg/m^3	12 - <30	2 - <10	<1 -3
HCl	mg/m^3	- <60	<1 - <10	<1 -
SO$_x$	mg/m^3	20 - <200	0,8 - <50	2 - 3,3
HF	mg/m^3	- <4	0,2 - <1	
NO$_x$	mg/m^3	250 - <400	90 - <200	43 - 66
Total C	mg/m^3	8 - <20	<2 - <10	<1 – 1,2
CO	mg/m^3	20 - <100	2 - <50	2,4 - 12
Periodical measurement (Average value over sample taking period)				
NH$_3$	mg/m^3		<1	
Cd, Tl	mg/m^3		0,001 - <0,05	0,0002
Hg	mg/m^3	- <0,05	0,016 - <0,03	0,0008 – 0,007
Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V ,Sn	mg/m^3		0,002 - <0,5	0,007
PCDD/PCDF, I-TE	ng/m^3		0,002 - <0,1	0,0012
Benzo(a)pyrene	mg/m^3			
∑ PCB	ng/m^3			
∑ PAH	ng/m^3			
N$_2$O	mg/m^3		12 - 139	

Table 64: BAT standard for emissions into the air (operating value)

5.7.3 BAT standard for observing the limit values for the discharge of waste water from waste gas cleaning

Of the appr. 22 mono sewage sludge incineration plants in Germany, the majority are not operated with zero waste water discharge. Typical annual average values for the cleaned waste water from several plants are listed below.

Parameter	Qualified composite sample as annual average value for cleaned waste water [mg/l]
Settleable matter (0,5 h) [ml/l]	
Hg	0,014 – 0,05
Cd	0,0011 – 0,05
Tl	
As	
Pb	<0,1
Cr	< 0,5
Cu	< 0,5
Ni	< 0,5
Zn	< 0,5 – 1,0
Sn	
PCDD/PCDF [ng I-TE/l]	
Fluoride	
N_{total}	
P_{total}	
Temperature	
pH value	
Sulfate	
TOC	

Table 65: BAT standard for emissions into the water

5.7.4 BAT standard on the physical and chemical properties and the toxic agents potential of incineration residues

The ashes from mono sewage sludge incineration plants have the following typical qualities:

Parameter	Measure	Measured values
Solid contents		
TOC	% by mass	
Loss on ignition	% by mass	< 3
PCDD/PCDF	ng I-TE/kg	
Arsenic	mg/kg	
Lead	mg/kg	
Cadmium	mg/kg	
$Chromium_{total}$	mg/kg	
Copper	mg/kg	
Nickel	mg/kg	
Mercury	mg/kg	
Zinc	mg/kg	
Eluate values		
Cl-	mg/l	
SO_4^{2-}	mg/l	
TOC	mg/l	
Arsenic	mg/l	
Lead	mg/l	
Cadmium	mg/l	
$Chromium_{total}$	mg/l	
Copper	mg/l	
Nickel	mg/l	
Zinc	mg/l	

Table 66: Analyses of ashes from mono sewage sludge incineration plants

5.7.5 BAT standard in energy utilization

The following table shows the energy efficiency ratios attainable depending upon the type of heat utilization, with internal consumption included in every case.

Plants with only	Energy efficiency ratio in [%]		
	Electric power	Heat	Total
Electric power/heat generation			
Electric power/heat output			
Heat generation			
Heat output			
Electric power generation			
Electric power output			

Table 67: BAT standard, attainable energy efficiency ratios - KVA

5.7.6 BAT standard for noise control

The following noise immission values can be achieved:

Sound assess level by day:	33 dB(A)
Sound assess level by night:	30 - 35 dB(A)

5.7.7 Costs

Treatment costs in thermal plants for the incineration of sewage sludge range between 90 and 850 DM/Mg m_T.

5.8 BAT plants for the incineration of sewage sludge

5.8.1 Plant for the incineration of municipal sewage sludge and rakings (BAT5)

- Total capacity 78,840 Mg m_T/a, currently 42,000 Mg of sewage sludge and 7,000 Mg of rakings
- Stationary fluidized bed furnaces
- 3 incineration lines with 26,280 Mg m_T/a each
- Start-up: 1997

Sewage sludge and rakings as incineration materials may be described as follows:

Parameter	Measure	Sewage sludge	Rakings
Calorific value	kJ/kg	3190-5300	2900-7000
Solid contents	% m_T	39-46	22-34
Loss on ignition	% by weight	48-56	-

Table 68: Characterization of the incineration materials

5.8.1.1 Reduction of emissions into the air

The waste gas cleaning system consists of the following components:

- SNCR nitrogen removal
- Flue gas recirculation
- Electrostatic filter (2-stage)
- HCl scrubber (pH value 2.3)
- SO_2 scrubber (1-stage neutralization with lime milk)
- Tissue filter with coke/calcium hydrate/calcium carbonate dosing

Waste gas quantity per line: 15,000 m^3/h

Manufacturer:

Parameter	Measure	Half-hour average values	Daily average values	Annual average values
Continuous measurement				
Total dust	mg/m^3	< 5	< 2,5	0,2
HCl	mg/m^3	< 10	< 5	0,2
SO_x	mg/m^3	< 50	< 20	3,3
NO_x	g/m^3	< 0,220	< 0,12	43
Total C	mg/m^3	< 10	< 7	0,7
CO	mg/m^3	< 100	< 20	2,4
Periodical measurement				
HF	mg/m^3	< 0,06	-	
Cd, Tl	mg/m^3	< 0,001	-	0,0002
Hg	mg/m^3	< 1	-	0,0008
Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V ,Sn	mg/m^3	< 0,013	-	0,007
PCDD/PCDF, I-TE	ng/m^3	< 0,011	-	0,0012

Table 69: Average values measured in clean gas (operating values) – BAT5

5.8.1.2 Reduction of emissions into the water

The waste gas cleaning system operates with zero waste water discharge.

5.8.1.3 Energy utilization

With a combusted sewage sludge total of 102,127 Mg (m_T content appr. 42%), there was an output of 48,000 MWh electric power and 62,630 MWh process steam.

5.8.1.4 Noise emissions/immissions

Distance of plant to immission site: m
Sound assess level: L_{aeq} = dB(A)
L_{AF} = dB(A)

5.8.1.5 Costs

- Investment costs: appr. $180*10^6$ DM
- Specific treatment costs:

5.8.2 Plant for the incineration of industrial and municipal sewage sludge (BAT6)

- Total capacity 100,000 Mg m_T/a
- Stationary fluidized bed furnaces
- 2 incineration lines with 30 Mg m_T/h each

5.8.2.1 Reduction of emissions into the air

The waste gas cleaning system consists of the following components:

- Electrostatic filters
- 4-stage waste gas washing

Waste gas per line: 62,535 m^3/h
Manufacturer:

The incineration material sewage sludge can be described as follows:

Parameter	Measure	Filter cake
Calorific value	kJ/kg	13000
Solid content	% m_T	45
Loss on ignition	% by weight	

Table 70: Characterization of the incineration material

Parameter	Measure	Half-hour average values	Daily average values	Annual average Values
Continuous Measurement				
Total dust	mg/m^3	< 30	< 10	
HCl	mg/m^3	< 60	< 10	
SO_x	mg/m^3	< 200	< 50	
NO_x	g/m^3	< 0,4	< 0,2	
Total C	mg/m^3	< 20	< 10	
CO	mg/m^3	< 100	< 50	
Hg	mg/m^3	< 0,05	< 0,03	
Periodical measurement (Average values over sample taking period)				
HF	mg/m^3		< 1	
Cd, Tl	mg/m^3		< 0,05	
Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V ,Sn	mg/m^3		< 0,5	
PCDD/PCDF, I-TE	ng/m^3		< 0,1	

Table 71: Average values measured in clean gas (operating values) – BAT6

5.8.2.2 Reduction of emissions into the water

The waste water cleaning system consists of a chemical (heavy metal precipitation) and a biological phase.

Parameter	2-hour composite sample [mg/l]
Suspended solid matter	
Hg	0,05
Cd	0,05
Tl	-
As	-
Pb	0,1
Cr	0,5
Cu	0,5
Ni	0,5
Zn	1,0
PCDD/PCDF [ng I-TE/l]	
pH value	
Temperature	

Table 72: Emission values of the waste water from the waste gas cleaning system before mixing (BAT6)

5.8.2.3 Energy utilization

Heat generation/output

Total heat generation:	70,000 MWh
Internal consumption:	

Power generation/output

Total power generation:	80,000 MWh
Internal use (additional supplies included):	20,000 MWh
Power output:	60,000 MWh

5.8.2.4 Noise emissions/immissions

Distance of plant to immision site: 1,200 m

The immission values admissible according to Item 2.321 TA Noise are observed at the prominent immission sites.

5.8.2.5 Costs

- Investment costs (planning incl.):
- Specific treatment costs:

5.9 Best Available Techniques for the Co-incineration in the Cement and Lime Manufacturing Industry

In the Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste, **minimum requirements for the state of the emission reduction techniques of co-incineration plants** are laid down. **Annex II.1** to this EU Directive stipulates special regulations for the total emissions **C** into the air for the co-combustion in the cement and lime manufacturing industry. Best available techniques going beyond these requirements are described for the cement industry in Chapter 1.5 BAT and for the lime industry in Chapter 2.5 BAT of the Reference Document on Best Available Techniques in the Cement and Lime Manufacturing Industries of March 2000.

II.1 Special provisions for cement kilns co-incinerating waste

Daily average values (for continuous measurements): Sample periods and other measurement requirements as in Article 7.
All values in mg/m^3 (Dioxins and furans ng/m^3). Half-hourly average values shall only be needed in view of calculating the daily average values.

The results of the measurements made to verify compliance with the emission limit values shall be standardised at the following conditions: Temperature 273 K, pressure 101,3 kPa, 10 % oxygen, dry gas.

II.1.1 C - Total emission limit values

Pollutant	C
Total dust	30
HCl	10
HF	1
NO_x for existing plants	800
NO_x for new plants	500 (1)
Cd + TI	0.05
Hg	0.05
Sb + As + Pb + Cr + Co + Mn + Ni + V	0.5
Dioxins and furans	0.1

(1) For the implementation of the NO x emission limit values, cement kilns which are in operation and have a permit in accordance with existing Community legislation and which start co-incinerating waste after the date mentioned in Article 20 (3) are not to be regarded as new plants.

Until 1 January 2008,exemptions for NO_x may be authorised by the competent authorities for existing wet process cement kilns or cement kilns which burn less than three tonnes of waste per hour, provided that the permit foresees a total emission limit value for NO_x of not more than 1200 mg/m^3.

Until 1 January 2008,exemptions for dust may be authorised by the competent authority for cement kilns which burn less than three tonnes of waste per hour, provided that the permit foresees a total emission limit value of not more than
50 mg/m^3.

II.1.2 C – Total emission limit values for SO_2 and TOC

Pollutant	C
SO_2	50
TOC	10

Exemptions may be authorised by the competent authority in cases where TOC and SO_2 do not result from the incineration of waste.

II.1.3 Emission limit value for CO

Emission limit values for CO can be set by the competent authority.

Annex IV to the EU directive stipulates emission limit values for the discharge of waste water from the cleaning of exhaust gases.

5.10 Best Available Techniques for the Co-incineration in the Iron and Steel Industry

In the Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste, **minimum requirements for co-incineration plants** are laid down. **Annex II** to this EU Directive stipulates special regulation for the determination of emission limit values for the co-incineration of waste (total emissions **C** into the air). Best available techniques going beyond these requirements are described in the chapters of the Best Available Techniques Reference Document on the Production of Iron and Steel of March 2000.

Annex IV to the EU directive stipulates emission limit values for the discharge of waste water from the cleaning of exhaust gases.

5.11 Best Available Techniques for the Co-incineration in Power Plants

In the Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste, **minimum requirements for co-incineration plants** are laid down. **Annex II** to this EU Directive stipulates how the total emission limit value **C** for the co-incineration of waste in power plants (emissions into the air) is to be determined. **Annex II.2** contains special regulations with total emission limit values **C** and process-specific emission limit values $\mathbf{C_{proc}}$ for furnace facilities in which waste is co-incinerated. Best available techniques going beyond these requirements are described in the chapters of the Draft reference Document of Best Available Techniques for Large Combustion Plants of March 2001.

II.2.**Special provisions for combustion plants co-incinerating waste**

II.2.1.Daily average values

Without prejudice to Directive 88/609/EEC and in the case where, for large combustion plants, more stringent emission limit values are set according to future Community legislation, the latter shall replace, for the plants and pollutants concerned, the emission limit values as laid down in the following tables (C_{proc}). In that case, the following tables shall be adapted to these more stringent emission limit values in accordance with the procedure laid down in Article 17 without delay.

Half-hourly average values shall only be needed in view of calculating the daily average values.

C_{proc}:
C_{proc} for solid fuels expressed in mg/Nm^3 (O_2 content 6 %)

Pollutant	< 50 MWh	50 to 100 MWh	100 to 300 MWh	> 300 MWh
SO_2 general case indigenous fuels		850 or rate of desulphuris-ation = 90 %	850 to 200 (linear decrease from 100 to 300 MWh) or rate of desulphuris-ation = 92 %	200 or rate of desulphuris-ation = 95 %
NO_x		400	300	200
Dust	50	50	30	30

Until 1 January 2007 and without prejudice to relevant Community legislation, the emission limit value for NO_x does not apply to plants only co-incinerating hazardous waste.

Until 1 January 2008, exemptions for NO_x and SO_2 may be authorised by the competent authorities for existing co-incineration plants between 100 and 300 MWth using fluidised bed technology and burning solid fuels provided that the permit foresees a C_{proc} value of not more than 350 mg/Nm^3 for NO_x and not more than 850 to 400 mg/Nm^3 (linear decrease from 100 to 300 MWth) for SO_2.
C_{proc} for biomass expressed in mg/Nm^3 (O_2 content 6 %):

'Biomass 'means: products consisting of any whole or part of a vegetable matter from agriculture or forestry, which can be used for the purpose of recovering its energy content as well as wastes listed in Article 2 (2)(a)(i) to (v).

Pollutant	< 50 MWh	50 to 100 MWh	100 to 300 MWh	> 300 MWh
SO_2		200	200	200
NO_x		350	300	300
Dust	50	50	30	30

Until 1 January 2008,exemptions for NO_x may be authorised by the competent authorities for existing co-incineration plants between 100 and 300 MWth using fluidised bed technology and burning biomass provided that the permit

foresees a C_{proc} value of not more than 350 mg/Nm^3.

C_{proc} for liquid fuels expressed in mg/Nm^3 (O_2 content 3 %):

Pollutant	< 50 MWh	50 to 100 MWh	100 to 300 MWh	> 200 MWh
SO_2		850 %	850 to 200 (linear decrease from 100 to 300 MWh)	200
NO_x		400	300	200
Dust	50	50	30	30

II.2.2.C — total emission limit values
C expressed in mg/Nm^3 (O_2 content 6 %). All average values over the sample period of a minimum of 30 minutes and a maximum of 8 hours:

Pollutant	C
Cd + TI	0.05
Hg	0.05
Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V	0.5

C expressed in ng/Nm^3 (O_2 content 6 %). All average values measured over the sample period of a minimum of 6 hours and a maximum of 8 hours:

Pollutant	C
Dioxins and furans	0.1

Annex IV to the EU directive stipulates emission limit values for the discharge of waste water from the cleaning of exhaust gases.

5.12 Bast Available Techniques for the Co-incineration in Other industrial Sectors

In the Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste, **minimum requirements for co-incineration plants in which waste is co-incinerated** are laid down. **Annex II** to this EU Directive stipulates how the total emission limit value **C** for the co-incineration of waste in other industrial sectors (emissions into the air) is to be determined. **Annex II.3**, in addition, contains special regulations for industrial sectors not covered by Sections II.1 and II.2 of Annex II to the EU directive with total emission values **C** for heavy metals as well as dioxins and furans.

II.3.Special provisions for industrial sectors not covered under II.1 or II.2 co-incinerating waste

II.3.1.C —total emission limit values:

C expressed in ng/Nm$^{3.}$ All average values measured over the sample period of a minimum of 6 hours and a maximum of 8 hours.

Pollutant	C
Dioxins and furans	0.1

C expressed in mg/Nm^3. .All average values over the sample period of a minimum of 30 minutes and a maximum of 8 hours:

Pollutant	C
Cd + TI	0.05
Hg	0.05

Annex IV to the EU directive stipulates emission limit values for the discharge of waste water from the cleaning of exhaust gases.

2 Future Techniques for the Co-incineration of Waste see sectoral BREF’s

6 DEVELOPING TECHNIQUES FOR THE INCINERATION AND CO-INCINERATION OF WASTES AND ALTERNATIVE PROCESSES

6.1 Thermal Waste Treatment Plant, Lauta – T.A. Lauta: A project

6.1.1 Project development

The project T.A. Lauta is a incineration plant for municipal waste at Lauta in Saxony currently under construction. Reliable values below the required emission values, minimization of operating agents and resulting residues as well as low total costs were the main objectives in the development of the project.

6.1.2 The plant concept – Tried and tested methods in a new concept

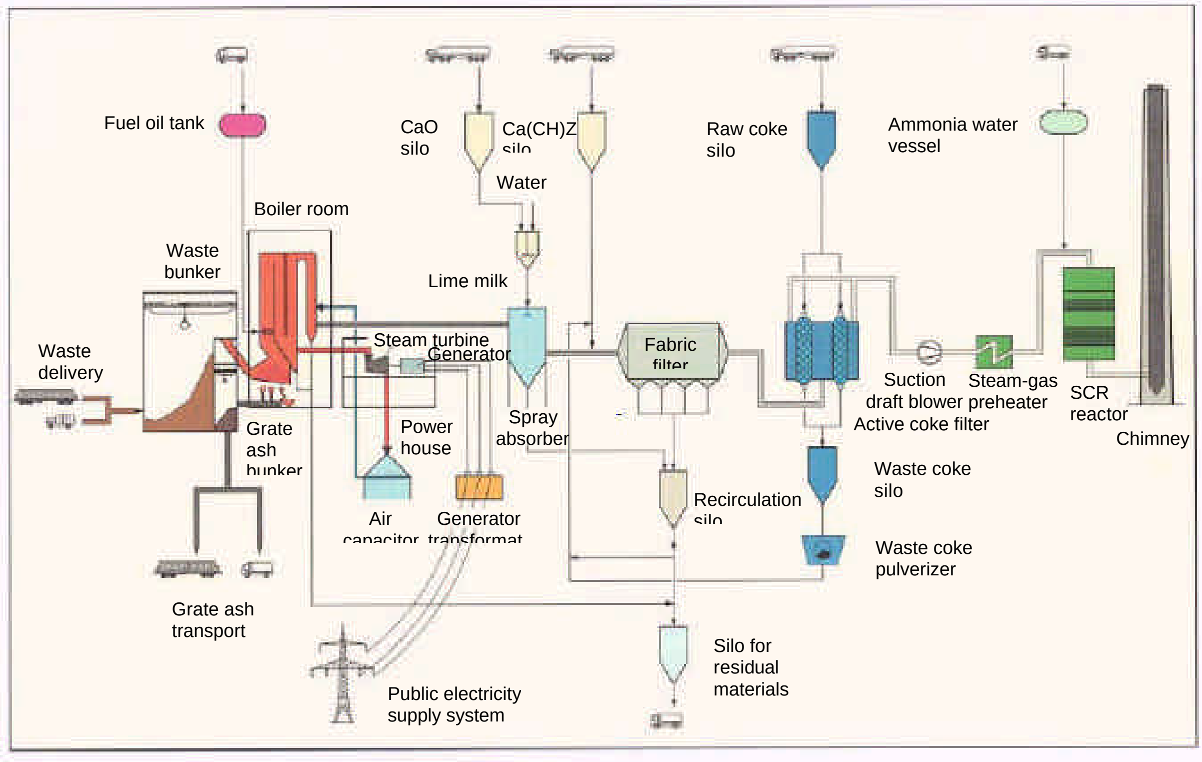


Figure 35: T.A. Lauta, concept

To meet the basic principle of the design, namely <u>disposal safety</u>, tried plant components such as feed grate, vertical boiler, spray absorber, tissue filter, activated coke filter and SCR reactor were included into the process chain of T.A. Lauta. <u>Economic efficiency</u> and <u>environmental compatibility</u> were realized through their new concept, completed by optimization of technical details. Special features of this trendsetting incineration concept are the following technologies/advantages:

- Water-cooled feed grate
- Flue gas recirculation
- Recirculation system for filter ash and residues from spray absorber
- Dry sorbens injection between spray absorber and tissue filter

- Recycling of the loaded activated coke into the flue gas flow
- Residue products can be supplied to reutilization
- Only two residue materials (slag, reaction product) from flue gas cleaning
- Observation of more rigid emission values

6.1.3 The water-cooled feed grate

The feed grate (incineration grate) is a sloping grate slanted under approximately 10° to the horizontal from the incineration material feed to the grate ash discharge. The grate links in the second and third zone are cooled with cooling water from the intercooler circuit in addition to continuous cooling with primary incineration air. The structure of incineration chamber and incineration performance control has been designed in such a way that the NO_x content of the flue gases is reduced from the onset. Incineration temperatures of at least 850°C at a residence time of 2 seconds and a minimum volume content of 6% oxygen in the flue gas after the last addition of incineration air lead to an almost complete destruction of organic components already in the incineration chamber.

Item	**Measure**	**Value**
Incineration grate	Feed grate with 4 grate zones, 2 of them water-cooled and 2 air-cooled (primary air)	
Plant throughput	Mg/h	2x15
Plant availability	%	> 85
Calorific value range	MJ/kg	7 - 12
Furnace thermal output (nominal output)	MW	2 x 37.5
incineration chamber temperature	°C	max. 1100
Loss on ignition of grate ash/slag	% by weight	<3

Table 73: Technical data

6.1.4 Flue gas recirculation

A portion of the flue gases is withdrawn from the flue gas chimney flue behind eco and recirculated to the incineration chamber via a separator for solid matter and a recirculation blower. These recirculated flue gases are injected at high speed into the incineration chamber through separate jets at the front and rear panel of the incineration chamber.

6.1.5 Dry sorbens injection between spray absorber and tissue filter

Dry calcium hydroxide $Ca(OH)_2$ is injected as neutralizing agent before the tissue filters.

6.1.6 Recirculation of the operating agents

The filter ashes and reaction agents withdrawn from the spray absorbers are fed into the recirculation silos. A branch current is recycled from there into the transport air current for calcium hydroxide $Ca(OH)_2$ before the tissue filters for further use.
The active coke loaded with deposited products is fed into a grinding plant. The ground stock produced there is injected before the tissue filters as an adsorption agent. By recycling the loaded active coke into the flue gas flow, the remaining activity is utilized to an optimum.

6.1.7 Residual material

Due to the recirculation system only one residual substance is produced in the flue gas cleaning process, which can be utilized in deep mining. Grate ash/slag will accumulate from incineration and can be used in road construction.

6.1.8 Admissible emission limit values

In addition to the design principles mentioned above, the emission values attained through this innovative and future-oriented plant concept are of particular importance. These are significantly lower than the German statutory emission values, as the following table illustrates.

Component	Measure	ELV 17. BImSchV*	Admissible values* T.A.Lauta
Total dust	mg/m^3	10	5
Total carbon	mg/m^3	10	5
Hydrogen chloride	mg/m^3	10	5
Hydrogen fluoride	mg/m^3	1	0,5
Sulphur dioxide	mg/m^3	50	5
Nitrogen dioxide	mg/m^3	200	70
Carbon monoxide	mg/m^3	50	40
Sum cadmium and thallium	mg/m^3	0,05	0,025
Mercury	mg/m^3	0,05	0,025
Sum antimony, arsenic, lead, chromium, cobalt, copper, manganese, nickel, vanadin and tin	mg/m^3	0,5	0,25
Dioxins and furans indicated as toxicity equivalent (TE)	ng/m^3	0,1	0,05
Benzo(a)pyrene	$\mu g/m^3$	-	0,5
Ammonia	mg/m^3	-	10

*related to the waste gas volume in s.t.p. (273 K, 1013 mbar) after deduction of humidity in water vapour at a volumetric content of 11% oxygen by volume

Table 74: Admissible emission limit values for MVA Lauta

6.1.9 The operating company

In 1997, T.A. Lauta oHG and Regionaler Abfallverband Oberlausitz - Niederschlesien (RAVON; Regional Waste Association of Upper Lusatia – Lower Silesia) signed the operator and ground lease contracts on the financing, planning, construction and operation of T.A. Lauta. The contracts have a validity of 25 years as from the beginning of continuous operation, which has been scheduled for the middle of 2004.

6.1.10 Costs

- Investment costs: 128 Mio. Euro (planning, gruond, construction interest incl.)
- 92 Mio. Euro only for the plant investment or 410 Euro per Mg annual plant capacity
- Specific treatment costs: 95 Euro per Mg ((basic year for the price calculation 1996)

6.2 Pyrolyse processes

Pyrolyse plants for waste treatment consist of two process stages:

- Pyrolyse of wastes, where in addition to the pyrolyse gas a solid carbon-containing residue accumulates which also contains mineral and metallic portions

- Secondary treatment of pyrolyse gas and pyrolyse coke through condensation of the gases for the extraction of energetically usable oil mixtures and/or incineration of gas and coke for the destruction of the organic ingredients and simultaneous utilization of energy.

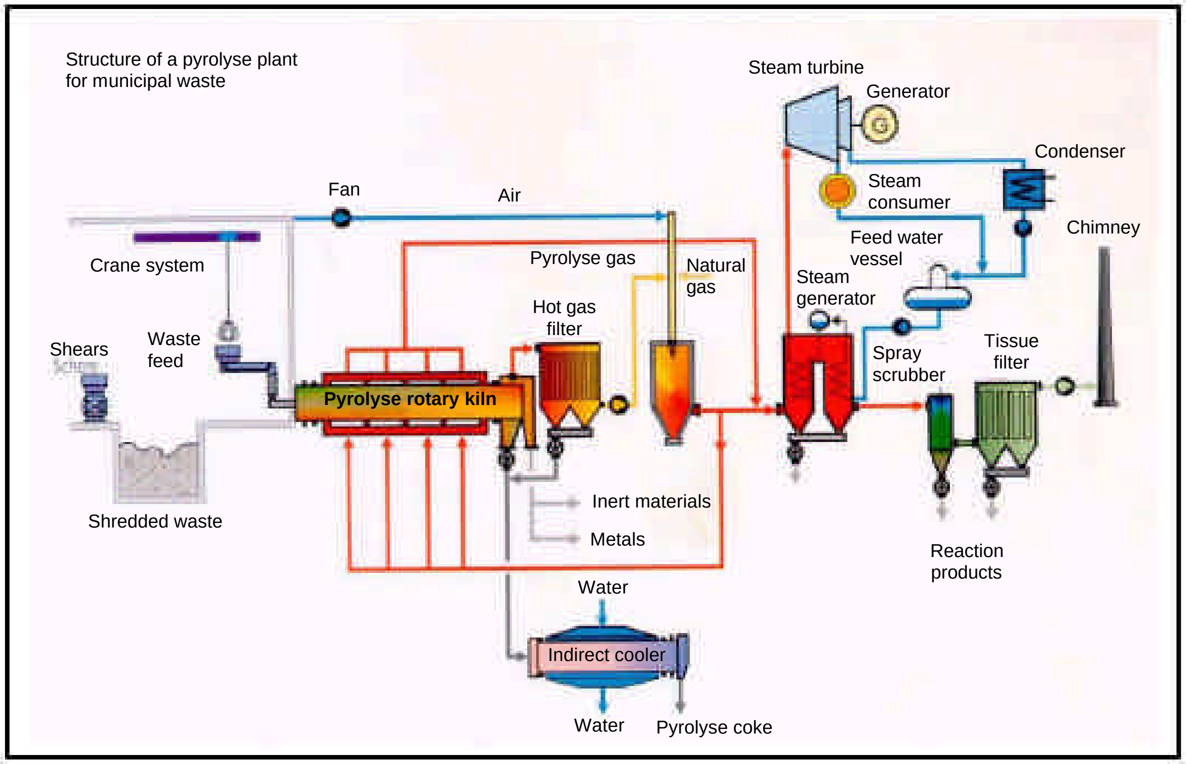


Figure 36: Structure of a pyrolyse plant anlage for municipal waste treatment

In general, the temperature of the pyrolyse stage is between 400 and 700 °C. At lower temperatures (appr. 250 °C) there are also other reactions running to some extent. Such processes are known as conversion (e.g. conversion of sewage sludge). In Germany, one plant is currently operated for the pyrolyse of municipal waste and sewage sludge at the location of Burgau, with an annual capacity of 35,000 Mg.
In additon to thermal treatment of municipal wastes and sewage sludge, pyrolyse processes are also used for:

- Decontamination of soil
- Treatment of synthetic waste and used tyres
- Treatment of cable tails as well as metal and plastic compound materials for valuable substance recovery

Pyrolyse is advantageous because in downstream incineration or gasification there is a smaller gas volume to be treated than in a corresponding incineration process.

6.3 Gasification

There are currently several different gasification processes available or being developed which are in principle suited for the treatment of municipal wastes, certain hazardous wastes and sewage sludge (dehydrated or dried, respectively). It is important for running the gasification process that the nature (size, consistency) of the wastes fed keeps within certain predefined limits which depend upon the gasifier. This requires special pretreatment for the municipal wastes to be gasified. These are the special features of the gasification process:

- smaller gas volume compared to the waste gas volume in incineration (by up to a factor of 10) by using pure oxygen,
- predominant formation of CO rather than CO_2,
- high operating pressures (in some processes),
- accumulation of solid residues as slag,
- small and compact aggregates (especially in pressure gasification),
- material and energetic utilization of the synthesis gas, as well as
- small waste water flows from synthesis gas cleaning.

The following gasification reactors are used:

- Current flow gasifier
- Cyclone gasifier
- Fluidized bed gasifier
- Packed bed gasifier

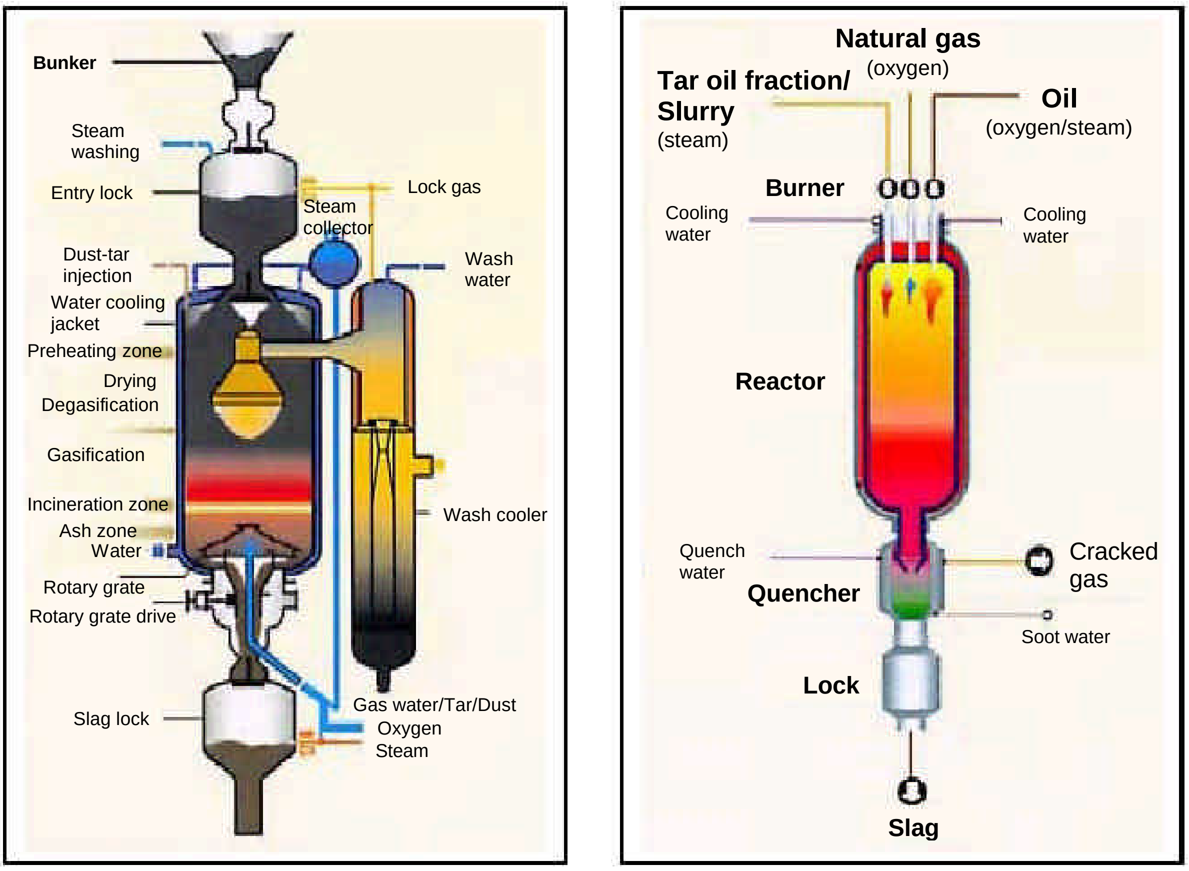


Figure 37: Representation of a packed bed and current flow gasifier

For utilization in current flow, fluidized bed or cyclone gasifiers, the feeding material must be finely granulated. Therefore expensive pretreatment is necessary especially for municipal wastes. Hazardous wastes, on the other hand, may be gasified directly in these aggregates if they are liquid, pasty or finely granulated. In Germany, a current flow gasifier is at present in use for the gasification of fluid hazardous wastes at Sekundärrohstoffverwertungszentrum (SVZ; Centre for Secondary Raw Materials Utilization) at Schwarze Pumpe. The fluid wastes are entered into the reactor via the burner system (cf. Figure 38) and transformed into synthesis gas at temperatures of 160–1800°C. Since 1995, appr. 31,000 Mg of waste oil have been disposed of in this plant.

Lumpy charging material is required as charge for the packed bed gasifier (cf. Figure 38), but drying is sufficient as a pretreatment process. SVZ Schwarze Pumpe GmbH runs six packed bed gasifiers altogether for gasification of coal-waste-mixtures. The inline induction rate for waste is admissible up to 85%. In the reactors with a throughput of 8–14 Mg each, mainly compacted waste plastics, dehydrated sewage sludge and contaminated soils are treated. The waste entered into the reactor through the entry lock is transformed into synthesis gas at appr. 800–1300 °C and 25 bar with the help of vapour and oxygen (gasification agent). An advancement from these packed bed gasifiers is the so-called slag bed gasifier (cf. Figure 39), also known as BGL gasifier (British Gas Lurgi), one plant of which SVZ Schwarze Pumpe GmbH is currently operating in a trial run (inline induction rate for waste up to 70%). Gasification in this case runs at a tempeature of appr. 1600 °C and the slag is discharged in liquid state, in contrast to the other packed bed gasifiers . The plant has a throughput of 30 Mg/h.

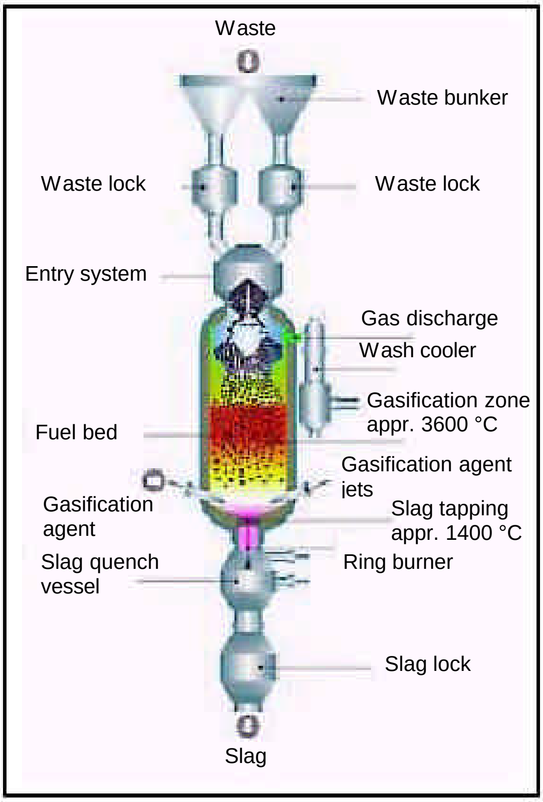


Figure 38: Slag bath gasifier

For the gasification of municipal waste, dehydrated sewage sludge and suitable hazardous waste, the company Lurgi offers the Wikonex process and the Eco-gas process. The pretreated wastes are gasified in the circulating fluidized bed. Subsequently, the crude synthesis gas is – depending upon the process – either combusted and utilized energetically or upgraded to a high-quality synthesis gas and reutilized accordingly. A plant for the treatment of municipal wastes following the Eco-gas process has been planned for Flensburg.

6.4 Combination processes

This term is used for processes consisting of a series arrangement of different thermal processes (pyrolyse, incineration, gasification) in separate aggregates for each.

6.4.1 Pyrolyse – incineration

At present there are three different ways being followed in the treatment of municipal waste:

1. Smolder-burn-process pyrolyse in the drum-type kiln with subsequent high temperature incineration of pyrolyse gas and pyrolyse coke. In Germany, the commissioning of a plant this type failed.

2. PyroMelt-process pyrolyse in the drum-type kiln, condensation of the gaseous tars and oils, subsequent high-temperature incineration of pyrolyse gas, pyrolyse oil and pyrolyse coke;

3. Duotherm-process pyrolyse on the grate with high-temperature incineration directly connected.

The solid residues from theses processes accumulate as melt granulate, which is advantageous for later reutilization or disposal. Moreover, sewage sludge (dehydrated or dried) may be co-treated.

The PyroMelt process corresponds with the Smolder-burn process in principle, but differs in two vital points: The pyrolyse gases are cooled on leaving the drum-type kiln, to deposit oil, dust and water. This is followed by oxidative high-temperature treatment in a special aggregate called Kubota-Surface-Melting-Furnance (KSMF). This is where the pyrolyse products oil-water-dust mixture and pyrolyse coke and pyrolyse gas are combusted and the solid residues are transformed into a liquid melt.

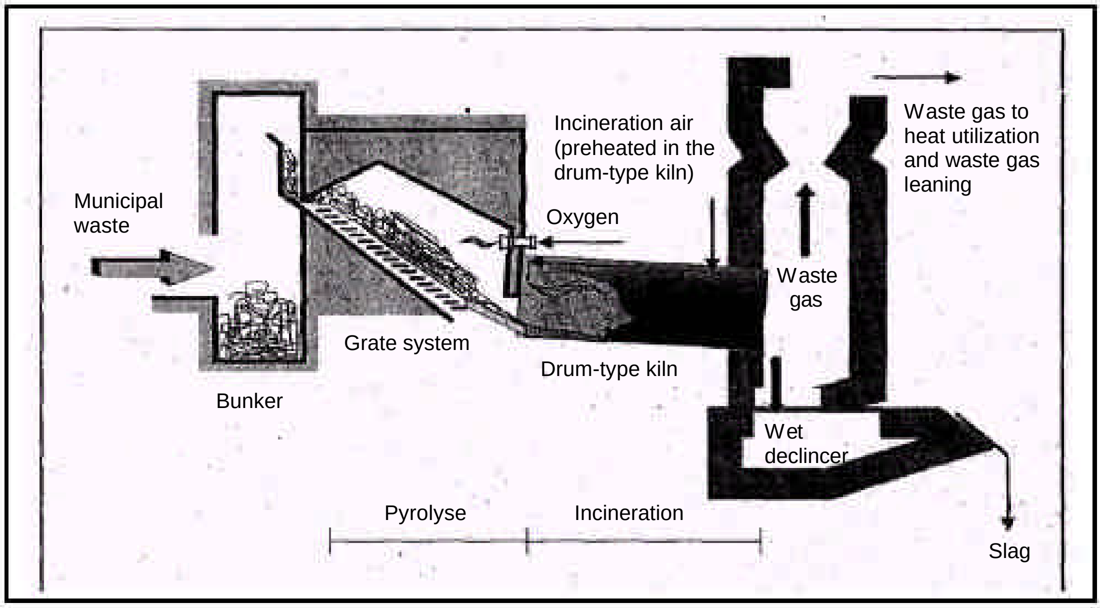


Figure 39: Duotherm process

In the Duotherm process (cf. Figure 40), which has been developed from conventional grate incineration with the objective to produce a liquid melt, the wastes are first pyrolysed on a grate by direct heating. The heat originates from a partial incineration of the pyrolyse gases with pure oxygen. In a second step, the products pyrolyse gas, coke and inerts are combusted or melted, respectively, at high temperatures in a directly connected drum-type kiln. The accumulating melt residue contains glass, stones, metals and other inert materials and is clearly different from the corresponding product of the Smolder-burn process.

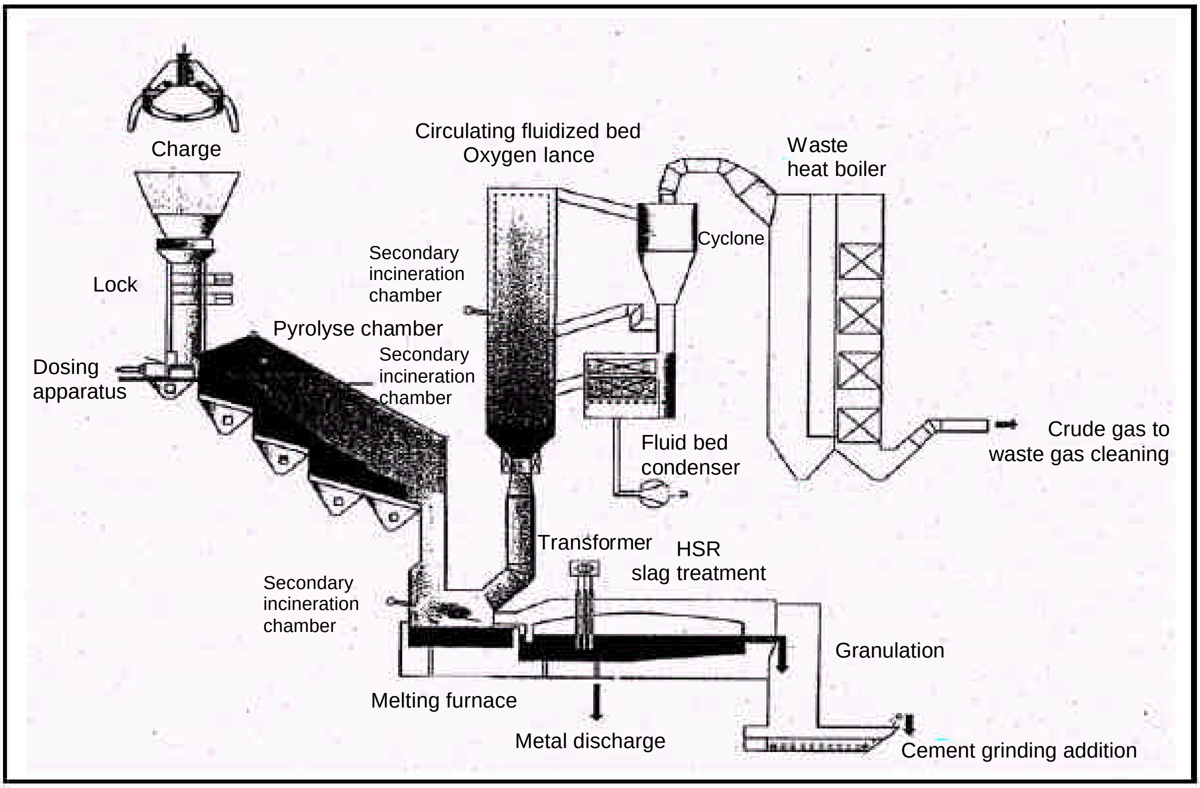


Figure 41: RCP process

The RCP process (cf. Figure 41) must be seen as an advancement of the Duotherm process, where the molten slag is to be depleted of metallic components and upgraded to a cement grinding addition in a special HSR (Holderbank-melt-redox process) secondary treatment stage. In Germany, the RCP process concept is being realized for the first time on an industrial scale at a plant with a throughput of 90,000 Mg/a (investment costs appr. 175m DM) in connection with an existing incineration plant for municipal wastes at Bremerhaven.

The methods for waste gas cleaning for the three pyrolyse combination processes named as examples do not, in principle, differ from the systems used in municipal waste incineration. The same residues and reaction products will accumulate. Their type and composition mainly depend upon the system of waste gas cleaning selected. In contrast to municipal waste incineration, however, filter dusts are recycled into the melting chamber.

6.4.2 Pyrolyse – gasification

Two different types of gasification processes must be distinguished: disconnected (pyrolyse with subsequent gasification = conversion process) and directly connected processes (e.g. Thermoselect).

With conversion processes, metals and, if required, inert material may be transferred outward after the pyrolyse. Pyrolyse gas and pyrolyse coke need to be reheated in the gasification process. Therefore technical and energetical expenditure is obviously higher than with connected processes. The condensated exhaust vapour is treated as waste water and discharged.

With direct connection as in Thermoselect, there is a better utilization of energy, but metals together with inert material go into a melt for which no way of utilization has been found so far.

In the **Thermoselect process** (cf. Figure 42) the unshredded wastes are dried in a push furnace and partially pyrolysed. From this furnace they are transferred directly and without interruption into a standing packed-bed gasifier, where they are gasified in its lower part at temperatures of up to 2000 °C through addition of oxygen. Pure oxygen is also added in the upper part of the gasification reactor to achieve disintegration of the remaining organic components in the generated synthesis gas through oxidation, gasification and cracking reactions. The gas is subjected to a gas cleaning process and then utilized energetically. The residues, originally solid, leave the reactor as melt. During test operation, appr. 220 kg of slag with appr. 30 kg metal accumulated per 1 g of waste.

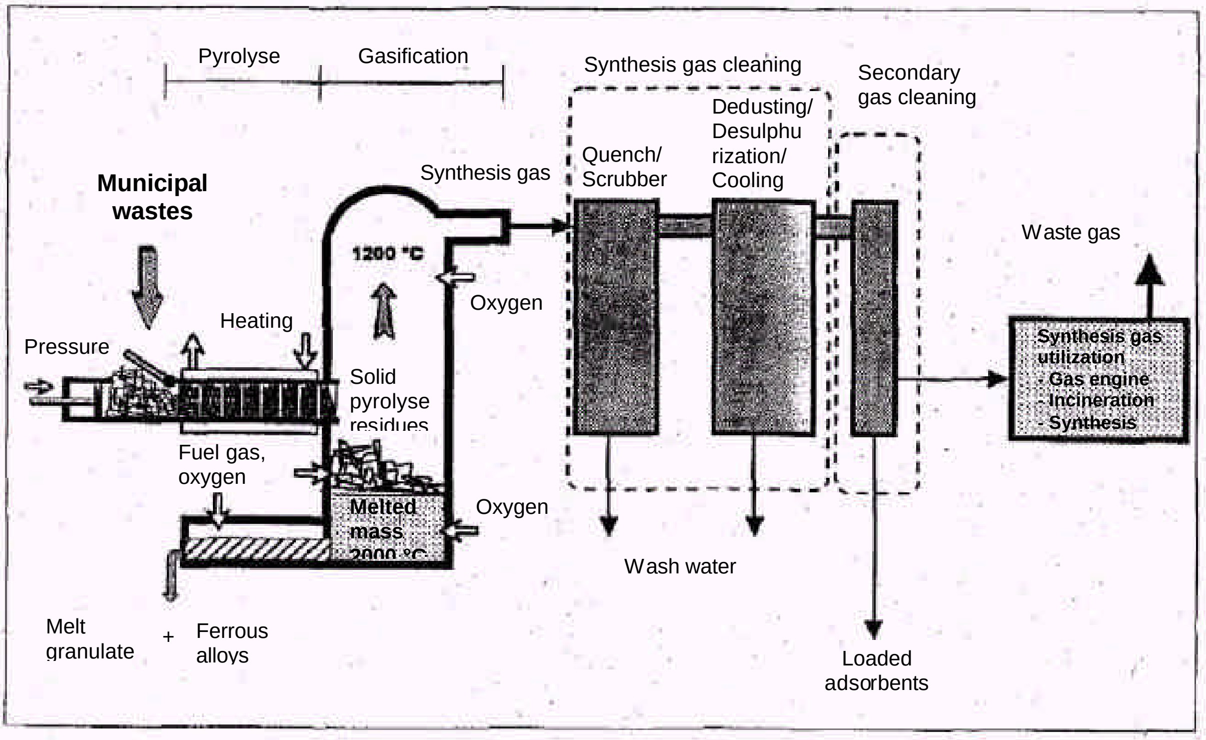


Figure 42: Thermoselect process

A Thermoselect plant with a municipal waste throughput of 108,000 Mg/a is currently under construction at Ansbach. Another plant with a throughput of 225,000 Mg/a has been built at Karlsruhe, but has not arrived at the designated continuous operation so far.

In the conversion process the waste needs to be shredded and dried before it may be supplied to the first thermal stage. This stage more or less corresponds with that of the Smolder-burn process after the following pattern:

> Pyrolyse in the drum-type → withdrawal of solid residues → Separation of the fine fraction enriched with carbon → Sorting of the metal and inert fraction

The pyrolyse gas is cooled to condense exhaust vapour and pyrolyse oil. It is then supplied, together with the pyrolyse oil and the fine fraction, to the second thermal stage, the current flow gasifying reactor. Oil and he fine fraction are gasified in the current flow at high pressure and a temperature of 1300 °C. The resulting synthesis gas is cleaned and then utilized energetically. The solid residues are withdrawn as melt granulate through a water bath. They should correspond in type and quantity with those from the Smolder-burn process.

A conversion plant for the treatment of 100,000 mg/a of municipal wastes and 16,000 Mg/a of dehydrated sewage sludge was approved at Northeim, Lower Saxony.

6.4.3 Pyrolyse in combination with a power plant

At present (3rd quarter of 2001) work is under way to put into operation the ConTherm plant of RWE power AG located at Hamm/Uentrop. The plant is designed as a topping plant of block C of the power plant Westfalen and consists of two lines of drum-type kilns with a scheduled annual municipal waste throughput of 50,000 Mg each. Thus, the boiler unit will be supplied at full load with up to 10% of the furnace thermal output from pyrolysed substitute fuels.

6.4.3.1 Specification of the ConTherm plant

The substitute fuels are heated, with oxygen precluded, to appr. 500 °C in the indirectly heated drum-type kiln plant, and thus decomposed thermally. The organic components are split up into gaseous carbohydrates. Coke, pyrolyse gas, metals and inerts accumulate as products from the ConTherm plant. The metals entered with the substitute fuels, now present in their metal form and not substance-bound, are withdrawn in a state of high purity. For this purpose there is a reutilization plant at the end of the drum-type kilns where the solid residue of the ConTherm plant is separated into individual fractions. The residue is separated into a coarse fraction (metals, inerts) and a fine fration. 99% of the carbon is contained as coke in the fine fraction. After sifting, the coarse fraction is supplied to a wet ash remover, cooled down and separated into ferrous and non-ferrous metals in a reprocessing plant.

The thermal energy is emitted through the furnace shell by radiation and to a lower degree by convection to the waste within the drum-type kiln. The pyrolyse drum-type kiln is designed for the waste to be heated to appr. 450 to 550 °C and gasified all within one hour. The resulting pyrolyse gas consists, apart from vapourized water, mainly of carbon monoxide, hydrogen and methane as well as high-order carbohydrates. A cyclone ensures dedusting of the pyrolyse gas to a great extent. The deposited dusts and carbon particles are added to the pyrolyse coke.

6.4.3.2 Integration of the ConTherm plant into block C of the power plant

Block C of the power plant is licenced for a maximum furnace thermal output of 790 MW. In addition to the regular fuels coal, coke and petroleum coke, pyrolyse coke and pyrolyse gas will be used as fuels in the future. The coke is first fed into the coal bunkers, ground together with the coal and then blown into the boiler with dust burners. The incineration of the pyrolyse product runs at temperatures of appr. 1600 °C. During this, the organic toxic agents are transformed almost totally into CO_2 and water. Due to the high ratio that sulphur bears to chlorine in the crude gas, and its fast cooling down to appr. 120 °C, any new formation of dioxins is prevented. All toxic agents that have not changed into their gaseous phase are bound into the melting chamber granulate together with the recycled airborne dust and the ground inert material.

6.4.3.3 Energy balance and weight assessment

Energy balance and weight assessment of the ConTherm plant are illustrated in the following diagrammic view (cf. Figure 43).

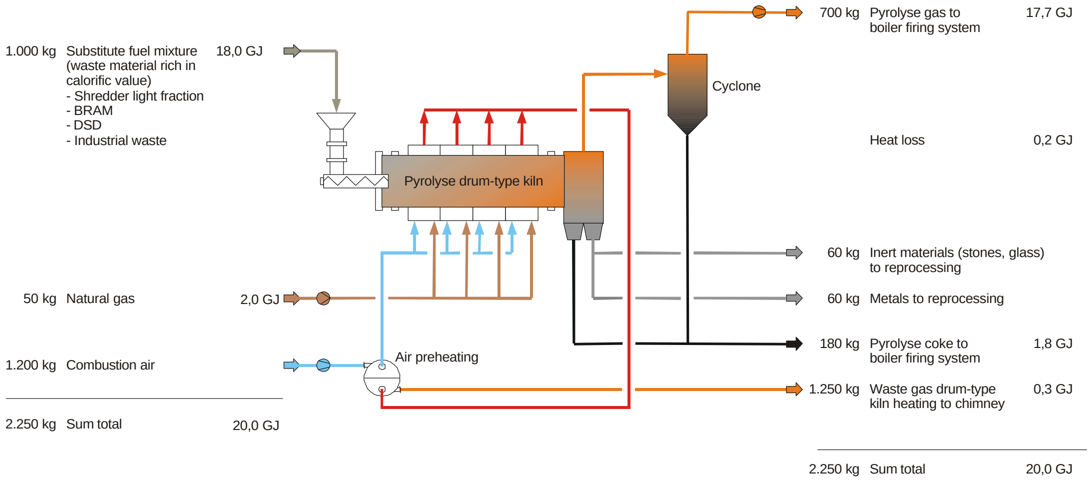


Figure 43: Energy balance and weight assessment of the ConTherm plant

6.4.3.4 Emissions of air pollutants

Block C of the power plant Westfalen is subject to the Federal Emission Protection Regulation No. 13 if only coal is combusted. If a portion of the coal is substituted by substitute fuels, more rigid emission limits will apply, as the limit values of the Federal Emission Protection Regulation No. 17 must be observed for this partial flow. The maximum admissible values for the intended compound incineration follow from the compound limit values according to § 5 Para. 3 of the Federal Emission Protection Regulation No. 17 which have to be calculated from the proportions of the fuels used. In total, the result is a reduction in the contents of toxic agents in the waste gas at the chimney as compared to all-coal incineration.

6.4.3.5 Costs

Due to the connection of the pyrolyse plant to a coal-fired power station and the utilization of the pyrolyse products in the power station, new installations are limited to waste reception and storage (bunker), the drum-type kiln system with the required heating installations, and the reprocessing system for valuable substances. The power plant co-uses the incineration unit, waste heat utilization system, flue gas cleaning system and the chimney.

The utilization of process equipment and machinery of the power plant results in low investments and reduced interest payments for thermal disposal. Moreover, the expenses for staff, operation and maintenance for topping pyrolyse plants are lower than with conventional thermal waste treatment plants, leading to comparatively lower operating expenses. Co-use of the existing infrastructure of the power plant is another cost reducing factor. Thus, disposal costs per ton of waste are well below those of single waste incineration plants.

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