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D21New sets of thermal treatment data and compilation of the whole data.

Acronym: AWAST

Project title: Aid in the Management and European Comparison of Municipal Solid Waste Treatment methods for a Global and Sustainable Approach:

Material, economic, energetic and environmental modelling and simulation tools for the selection, evaluation and optimisation of a complete MSW chain.

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Energy, Environment and Sustainable Development

Summary

This deliverable consists of two data sets which are attached as EXEL files;

1. Data base from a conducted survey on the 29 incineration plants where a questionnaire sent out was filled in and answered. As can be seen, the amount of information given varies.

2. On the basis of the more detailed answers given in the questionnaire and similar information found in the literature, transfer coefficients for unit operations based upon data from 7 incineration plants and 5 literature sources were established

Incineration plant findings

- ✓ Mainly community owned plants responded to the questionnaire. There was an overweight of Scandinavian plants (Commercial plants in a competitive market do not give away "secrets")
- ✓ Mostly MSW plants of 70 000 tonnes capacity or more are represented.
- ✓ Average 16 % bottom ash
- ✓ Fly ash fraction more uneven, 1-3 % of fuel

Use of the information

The questionnaire was sent out to get a better data base, wider than the 5 sources found in the literature. This proved to be difficult as only 7 of the returned questionnaires were detailed enough to have data that could be included in the background material for the transfer coefficients.

It was planned to test the transfer coefficients directly in the model. The prototype model we have so far is technically made so this is difficult without some time consuming modifications.

CONTENTS

Appendix 1 Database Plants
Appendix 2 Transfer coefficients

General information

Technology
Grate
FB=fluidized bed
Cement kiln

Type of waste
MSW=municipal solid waste
HHW=household waste
IW=industrial waste
RDF=refuse derived fuel
O=other
SS=sewage sludge
HW=hazardous waste
LHW=liquid hazardous waste
SHW=solid hazardous waste

Energy Production
el=electricity
hw=hot water

Gas cleaning methods
Dry
Semi-dry
Wet

FF=fabric filter / bag houses
ESP=electrostatic precipitators

No.	Technology	Type of waste	Capacity [ton/year]	Operating hours [hours/year]	Energy Production [GWh/year]	Gas cleaning method	Bottom ash [ton/year]	% fraction of fuel	Fly ash [ton/year]					% fraction	
									FF	ESP	Cyclone	Other	Total	ash	fly ash
1	Grate, 2 lines	HHW+IW	74 000	16 000	250	Dry	14 420	19	1 175				1175	21	2
2	Grate, 2 lines	70% HHW+30% IW	62 000	16 000	141	Wet	11 932	19	800				800	21	1
3	Grate	HHW+IW	19 523	8 217.5	42	Semi-dry	3 236	17	Yes		Yes		140	17	1
4	Grate	HHW+IW+O	89 030	7 315	29	Wet	12 841	14		Yes				14	0
5	Grate, 3 old lines	HHW+IW+O	18 135	9 291	21	Dry			546				546	3	3
5.1				4 547	7										
5.2				2 836	7										
5.3				1 908	7										
6	Grate	HHW+IW	20 000	8 100		Dry	3 400	17	296				296	18	1
7	Grate, 2 lines	HHW+IVV	58 468	12 645	147	Wet	10 097	17		Yes			813	19	1
8	Grate	HH+RDF	22 165	7 500		Dry	3255	15	557.2				557.2	17	3
9	Grate	RDF	7 184	7 500		Dry	413	6	190				190	8	3
10	Grate	HHW+RDF	26 213	7 500		Dry	3489	13	471.9				471.9	15	2
11	Grate, 2 lines	HHW+IW	155 000	16 000		Wet	24 800	16	4 000					16	0
12	Cement	See "handsorting"	168 000				3300		Yes	Yes				2	0
13	Grate	HHW+IW+O	5 500	5 500	12	Wet	1 000	18		Yes	Yes		49	19	1
14	Grate, 2 lines	0,6HHW+0,4IW	90 560	16 100	228.4	Wet	19 321	21		Yes			1 000	22	1
15	Grate	HHW+IW	19 000	7 700	28	Semi-dry	3 500	18	275		Yes		275	20	1
16	Grate	HHW+5% IW	90 000	7 500	58	Wet	16 500	18	Yes	2 017			2 017	21	2
17	Grate	HHW+IW	78 000	8 300		Wet	11 250	14	Yes	230			230	15	0
19	Grate, 2 lines	HHW+IW	200 000	16 400	585	Dry	42 000	21	Yes		Yes		4 850	23	2
21	Grate	HHW+O	68 000	3 400	152	Wet	7 221	11	Yes					11	0
22	Grate, 3 lines	HHW+IW	243 200	23 600	615	Wet	50 000	21	Yes	Yes			5 300	23	2
			56 000	8 000											0
			93 600	7 800											0
			93 600	7 800											0
24	Grate	HHW+IW	38 705	7 741	81.3	Dry	6 062	16	326				326	17	1
25	Grate	HHW+IW	50 000	8 227	121	Dry	8 600	17	1 651				1 651	21	3
26	Grate, 2 lines	HHW	268 912	16 000	540	Wet	55 567	21		5 009			5009	23	2
28	FB, 3 lines	RDF	260 000	24 600	170	Semi-dry	16 000	6	Yes		Yes		32 000	18	12
29	Grate 2 lines	HHW	243 586			Wet	55 986	23	Yes	Yes			3 768	25	2

Chemical analysis

Grate

1	C	O	H	S	N	Cl	F	P	Fe	Al	Pb	Zn	Cd
Waste													
Bottom ash													
Filter ash													
Filter cake													
Stack gas [mg/Nm3 dry 11vol%O2]											0.01		0.002

Grate

2	CO ton/year	CO2 ton/year	H	SO2 ton/year	NOx ton/year	HCl ton/year	HF ton/year	P	Fe	Al	Pb [kg/year]	Zn	Cd+Hg [kg/yea
Waste													
Bottom ash													
Filter ash													
Filter cake													
Stack gas	4.63	69752		42	110	2.58	0.29				2.35		

Grate

4	CO			SO2	N	HCl	HF	P	Fe	Al	Pb	Zn	Cd
Waste													
Bottom ash													
Filter ash													
Filter cake													
Stack gas [mg/Nm3 dry 11vol%O2]	<10			8.2		3	<0,07				<0,009		<0,001

Grate

8	C	O	H	SO4	N	Cl	F	P	Fe	Al	Pb	Zn	Cd
Waste [mg/kg(dry)]	406000			4500		7100	200		4500	2700	140	600	<1,0
Bottom ash [mg/kg(dry)]				1700		700	400		16200	40500	1180	3480	1.2
Filter ash [mg/kg(dry)]				43000		79000	600		3950	8600	3120	4340	28
Filter cake													
Stack gas													

Grate

11	CO	O	HF	SO2	N	HCl	F	P	Fe	Al	Pb	Zn	Cd
Waste													
Bottom ash													
Slag / clinker - average [mg/kg]							<1,0		70624	36258	1141	2565	105
Filter ash [mg/kg]									6830		1280	11100	90
Filter ash [mg/kg]									6860		1190	9000	120
Waste water [mg/l]											<0,018		0.002
Stack gas [mg/Nm3]	27.5		<0,13	18.9		1.5					Pb+Cr+Cu+Mn: 0,051		0.003

Cement

12 Waste	C	O	H	S	N	Cl	F	P	Fe	Al	Pb	Zn	Cd
Waste oil [mg/kg]	0										361	607	1
Liquid waste[mg/kg]												1170	3.2
Solid waste[mg/kg]												12087	11.3
Refuse derived fuel[mg/kg]												100	4
Plastics[mg/kg]												100	4
Animal meal[mg/kg]	110000			4000		5000			554	441	27	121	3

Grate

17	C	O [mg/kg(dry)]	H	S [mg/Nm3]	NOx (NO2) [ug/Nm3]	Cl	F	P [mg/Nm3]	Fe [mg/kg(dry)]	Al [mg/kg(dry)]	Pb [mg/kg(dry)]	Zn [mg/kg(dry)]	Cd [mg/kg(dry)]
Waste													
Bottom ash													
Filter ash								5160	4300	30800	5225	26350	466
Filter cake (FF dust)								80	1550	2100	70	250	6
Stack gas		100000		3	360						0.0005		0.004

Grate

19	C	O [mg/Nm3]	H	S [mg/Nm3]	N	Cl [mg/Nm3]	F [mg/Nm3]	P	Fe	Al	Pb [mg/kg]	Zn [mg/kg]	Cd [mg/kg]
Waste						5000							
Bottom ash	50000												
Filter ash											4000	12000	120
Filter cake													
Stack gas		90000		100		50	0.1						

Grate

20	C	O	H	S	N	Cl	F	P	Fe	Al	Pb	Zn	Cd
Waste													
Bottom ash [mg/kg]											2800	140000	1.4
Filter ash [mg/kg]											720	4900	41
Filter cake													
Stack gas													

Grate

21	C	O	H	S	N	Cl	F	P	Fe	Al	Pb	Zn	Cd
Waste													
Bottom ash[mg/kg(dry)]											1800	18000	2.9
Filter ash													
Filter cake													
Stack gas													

Grate

22 [ug/Nm3]	C	O	H	S	N	Cl	F	P	Fe	Al	Pb	Zn	Cd
Waste													
Bottom ash													
Filter ash													
Filter cake													
Stack gas / Flue gas [ug/Nm3]											0.39	4.6	0.38

Grate

23.1.1	C	O	H	S	N	Cl	F	P	Fe	Al	Pb	Zn	Cd
Waste [mg/kg(dry)]	470000		60000	2500	7000	5000				3000	150	250	2
Bottom ash [mg/kg(dry)]	0			0	0	0		3100	53000	89000	3800	3570	1
Filter ash [mg/kg(dry)]	50000			19000	0	59000		3500	28000	55000	103	32650	126
Filter cake [mg/kg(dry)]	0			170000	0	0		100	2000	2400	<5	3.4	52
Stack gas													

FB

23.2	C	O	H	S	N	Cl	F	P	Fe	Al	Pb	Zn	Cd
Waste [mg/kg(dry)]	570000		70000	1000	8000	0				800	48	249	0.5
Bottom ash [mg/kg(dry)]	0			0	0	0		700	20000	55000	90	2470	<5
Filter ash [mg/kg(dry)]	50000			27000	800	20000		4700	53000	44000	73	14028	22
Filter cake [mg/kg(dry)]	70000			40000	1500	0		300	3600	2600	142	1401	1.9
Stack gas													

Grate

24	C	O2	H2O	SO2	NOx	HCl	HF	P	Fe	Al	Pb	Zn	Cd
Waste													
Bottom ash [mg/kg(dry)]											359	1560	9.3
Filter ash [mg/kg(dry)]													
Filter cake [mg/kg(dry)]											3720	17100	308
Stack gas ug/m3ntg		8,5 %	13,7 %	<44000	95000	26000	<100				0.558	0.532	0.102

Grate

25	C	O	H	S	N	Cl	F	P	Fe	Al	Pb	Zn	Cd
Waste													
Bottom ash [mg/kg(dry)]											ca. 1320	ca. 3405	ca. 6
Filter ash (measured in wet gas) [mg/m3 ntg 9%CO2]										0.022	0.002	0.0159	0.0001
Filter ash (wet)											ca. 596	ca. 4850	ca. 51
Filter cake													
Stack gas [mg/m3 ntg 9%CO2 wet]										0.09	0.009	0.109	<0,001

Grate

26	C	O	H	S	N	Cl	F	P	Fe	Al	Pb	Zn	Cd
Waste [mg/kg]													
Bottom ash [mg/kg]						4670	100	5692	55587	33618	2387	3462	2
Filter ash [mg/kg]						78000	1200	4834	12634	52902	1988	12334	253
Filter cake [mg/kg]						4732	5714	934	24729	9950	1041	1865	63
Stack gas [mg/Sm3]											0.012	0.032	0.001

FB

28	TOC	CO	H	SO2	NOx	HCl	HF	P	Fe	Al	Pb+Cr+Cu+Mn	Zn	Cd+Hg
Waste													
Bottom ash													
Filter ash													
Filter cake													
Fly ash [mg/kg]											1.6		12200
Stack gas [mg/dNm3]	<2	9		1.7	225	14.5	<0.02				0.017		<0.002

Average over the three lines

Handsorting

Fractions	Grate 8 [weight%wet]	Grate 10 [weight%wet]	Grate 11 [weight%wet]	Grate 16 [weight%wet]	Grate/FB 23 [weight%wet]	Grate 25 [weight%wet]	Grate 26 [weight%wet]	FB 28 [weight%dry]
Wood	4.4	4.0	0.72		14.8		5.06	1.9
Paper	13.9	18.0	43.91	30.5		11.0	23.75	28.8
Glass			5.50	4.3		3.0	5.87	0.4
Fe metals			1.40	3.1		2.5		
Non Fe metals	1.8	3.0	1.00		31.7	0.5	4.79	1.9
Plastics	13.0	12.0	7.93	9		11.0	5.35	19.0
Textiles	11.2	9.0	3.50	6.9	33.9	3.0	1.92	5.6
Biowaste	0.2	5.0	28.10	41.6		40.0	31.55	1.4
Hazardouse waste			0.80	0.8			1.00	
Others	55.5	48.0	7.14	3.8	19.6	29.0	20.71	
Sum	100.0	99.0	100.00	100.0	100.0	100.0	100.00	59.1

Moisture: 41%

Cement

Fractions	12 [weight%]
Coal	53.8
Pet-coke	3.9
Coal inferiors	2.1
Light fuel oil	0.5
Waste oil	3.0
Hazardous liquid waste	6.0
Hazardous solid waste	5.9
Refuse derived fuel	15.8
Wood (sawdust)	1.7
Animal meal	7.2
Sum	99.9

Mean concentrations in the waste and in solid residues							
Sources: Municipal solid waste incinerator residues, IAWG, Elsevier,							
A rewiew of metal partitioning in Thermal treatment processes,							
Thermal Process residues; Sources, technologies and types, IEA (International Energy Agency)							
Element	**Waste**	**Bottom ash**	**Boiler ash**	**Fly ash**	**Clean gas dust**		
		(mg/kg)		**(mg/kg)**			
C		n.d - 30 000			8000 - 100 000		
S		n.d - 40 000		n.d			
Al			10000 - 100 000		20 000 - 70 000		
Cl		<1000 - 5000			10 000 - 180 000		
F		<100 - 1000		n.d			
Fe	25 000-50 000	4 100-150 000	30 000-50 000	32 000-60 000	400 000	mg/kg	Elements
Cu	200-1 000	250-8 200	300-1 500	50-5 000	300-3 000	mg/kg	Elements
Element	**Waste**	**Bottom ash**	**Boiler ash**	**Fly ash**	**Emissions**		
	(mg/kg)	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(ug/Rm3)**		
Cd	5-15	<0,5-70	50-150	20- 1 000	<10		Volatile metals
Pb	400-1 000	98-14 000	2 000-8 000	500-26 000	<50		Volatile metals
Hg	0,5-5	<0.05 - 7.8	<5	1-80	<50		Volatile metals
Zn	600-2 000	300-7 800	5 000-10 000	1 000-80 000	<5		Volatile metals

Composition of fly ash, dry/semidry and wet APC system residues from mass burn incinerators				
Source: Municipal solid waste incinerator residues, IAWG, Elsevier				
Element	**Range for fly ash**	**Range for dry/semidry APC system residues**	**Range for wet APC system residue without fly ash**	**Range for wet APC system residue/fly ash mixture**
	(mg/kg)	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
Al	49 000-90 000	12 000-83 000	21 000-39 000	71 000-81 000
C				
Cd	50-450	140-300	150-1 400	220-270
Cl	29 000-210 000	62 000-380 000	17 000-51 000	48 000-71 000
Cu	600-3 200	16-1 700	440-2 400	1 000-1 400
Fe	12 000-44 000	2 600-71 000	20 000-97 000	15 000-18 000
Hg	0,7-30	0,1-51	2,2-2 300	38-390
N			1600	
O				
P	4 800-9 600	1 700-4 600		6 000-7 400
Pb	5 300-26 000	2 500-10 000	3 300-22 000	5 900-8 300
S	11 000-45 000	1 400-25 000	2 700-6 000	11 000-26 000
Zn	9 000-70 000	7 000-20 000	8 100-53 000	20 000-23 000

Concentrations of heavy metals in residues, flue gas and waste

Source: Ch.4 Lars Soerum, Environmental Aspects of Municipal Solid Waste Combustion

Concentration in residues, flue gas and waste

		Cd	Fe	Hg	Pb	Zn
Flue gas	[mg/Nm3 dry]@11%O2	0,057	0	0,013	0,162	0,159
Bottom ash	[mg/kg dry]	19	53 250	0,62	2 513	5 464
Filter ash	[mg/kg dry]	323	9 833	8	5 833	37 667
Filter cake	[mg/kg dry]	1 331	2 600	5 805	7 027	8 567
Drain water	[Tg/kg dry]	1,3	0	3,6	48,1	100
Input MSW	[mg/kg dry]	5	8 823	1,6	439	1 044

Heavy metal balance for the combustion plant

		Cd	Fe	Hg	Pb	Zn
Flue gas	[kg/year]	32,7	0	7,2	91,8	76,3
Bottom ash	[kg/year]	272	761 768	9	35 950	78 165
Filter ash	[kg/year]	104	3 154	3	1 871	12 083
Filter cake	[kg/year]	27,7	54,1	120,8	146,2	178,3
Drain water	[kg/year]	0,02	0	0,06	0,83	1,7
Input MSW	[kg/year]	434	764 954	139	38 061	90 515

Concentrations of major elements (>10 000mg/kg) measured in APC residues from mass burn incinerators

Source: Municipal solid waste incinerator residues, IAWG, Elsevier

Residue	Element	Mean [mg/kg]	Median [mg/kg]	25-75 percentile range [mg/kg]	Number of residues analysed
Fly ash:					
	Cl	74 000	50 000	40 000-102 000	24
	Fe	25 000	23 000	18 000-33 000	20
	Al	71 000	73 000	59 000-81 000	18
	Zn	28 000	22 000	16 000-35 000	26
	S	26 000	27 000	21 000-33 000	20
	Pb	11 000	7 800	6 300-15 000	25
Semi-dry/dry APC process products with fly ash:					
	Cl	180 000	160 000	91 000-220 000	23
	Fe	12 000	9 100	63 000-11 000?	19
	Al	26 000	19 000	15 000-29 000	27
	Zn	15 000	16 000	12 000-18 000	28
	S	15 000	17 000	8 200-21 000	18
	Pb	5 400	5 600	4 100-63 000	27

Wet sludge without fly ash:						
	Cl	36 000	38 000	26 000-47 000	4	
	Fe	54 000	45 000	20 000-97 000	3	
	Al	28 000	25 000	21 000-39 000	3	
	Zn	31 000	29 000	15 000-45 000	12	
	S	4 400		2 700-6 000	2	
	Pb	11 000	9 700	4 400-19 000	12	

Concentrations of minor elements (1 000-10 000mg/kg) measured in APC residues from mass burn incinerators

Source: Municipal solid waste incinerator residues, IAWG, Elsevier

Residue	**Element**	**Mean [mg/kg]**	**Median [mg/kg]**	**25-75 percentile range [mg/kg]**	**Number of residues analysed**
Fly ash:					
	Cu	1 200	1 100	930-1 300	25
Semi-dry/dry APC process products with fly ash:					
	Cu	710	630	490-860	25
Wet scrubber products without fly ash:					
	Cu	1 200	900	760-1 700	12

Concentrations of trace elements (<1 000mg/kg) measured in APC residues from mass burn incinerators

Source: Municipal solid waste incinerator residues, IAWG, Elsevier

Residue	**Element**	**Mean [mg/kg]**	**Median [mg/kg]**	**25-75 percentile range [mg/kg]**	**Number of residues analysed**
Fly ash:					
	Hg	8	6	2,3-10	17
	Cd	390	290	240-480	26
Semi-dry/dry APC process products with fly ash:					
	Hg	15	12	8,4-18	28
	Cd	300	260	190-360	28
Wet scrubber products without fly ash:					
	Hg	650	660	240-790	12
	Cd	630	660	290-880	12

Composition of clinker and litosphere, based on total analysis

Source: Affaldsteknologi, Thomas H. Christensen, Teknisk forlag

Element		Clinker from 7 danish incineration plants 1991		Clinker from several other countries	Composition of the litosphere
		Average	*Range*	*Range*	*Average*
O	[g/kg]			400-500	465
Fe	[g/kg]	68	54-88	4,1-150	51
Al	[g/kg]	50	42-61	22-73	81
C	[g/kg]			10-60	,95
S	[mg/kg]	5 700	4 000-7 300	1 000-5 000	600
P	[mg/kg]	3 000	1 800-5 100	1 400-6 400	1 200
Cu	[mg/kg]	2 800	1 800-3 600	190-8 200	70
Zn	[mg/kg]	2 300	1 900-3 000	610-7 800	80
Cl	[mg/kg]	2 100	1 400-4 000	800-4 200	500
Pb	[mg/kg]	1 600	870-2 200	98-14 000	16
Cd	[mg/kg]	1,4	0,75-2,2	0,3-71	0,2
F	[mg/kg]			200-1 100	625
Hg	[mg/kg]	<0,08	<0,08	0,02-7,8	0,1
N	[mg/kg]	480	250-840	110-900	
Source:			Hjelmar et al (1996)	IAWG (1997)	Lindsay (1979)

Source:Auswirkung unterschiedlicher Szenarien der termischen Verwertung von Abfällen in Österreich,TU Wien

Cementplants

Transfer coefficients for clean gas

Upper limit:

Element	Minimum	Average	Maximum
C	0,91	0,91	0,94
N in NOx	0,45	0,55	0,62
S	0,068	0,10	0,14
Cl	0,026	0,046	0,17
Cd	0,014	0,074	0,98*
Hg	0,10	0,55	11*
Pb	0,00083	0,0041	0,047
Zn	0,00075	0,0016	0,0054

* Not realistic values, average values should be used.

Lower limit:

	Average

Cl	0,0184
Cd	0,0232
Hg	0,1215
Pb	0,0012
Zn	0,0010

Source:Auswirkung unterschiedlicher Szenarien der termischen Verwertung von Abfällen in Österreich,TU Wien

Transfer coefficients for fly ash and bottom ash

Element	Fly ash	Bottom ash
C	0,01	0
N	0,01	0,01
S	0,6-0,8	0,1
Cl	0,8-0,88	0,1
Cd	0,91-0,98	0,02
Hg	0,7-0,9	0
Pb	0,97	0,03
Zn	0,91-0,93	0,07

Mass balance of goods and elements in a MSW incinerator

Source: Metabolism of the Anthroposphere, Baccini & Brunner

Goods	Mass flux	Mass fraction	Element flux [mg/kg MSW]									
	[kg/h]	[g/kg]	C	S	F	Cl	Fe	Cu	Zn	Cd	Hg	Pb
Bottom ash												
Mean	675	205	4 200	900	4	900	66 000	240	1 000	1,1	0,029	250
SD	135	41	1 600	200	1	300	35 000	60	6000	0,5	0,018	110
Filter dust												
Mean	83	25	1 100	700	3	1 400	800	27	900	6,6	0,2	160
SD	8	2	200	140	1	300	100	8	700	1	0,11	30
Flue gas												
Mean	2550	770	270 000	1 100	37	4 600	0,02	3	70	1	0,6	20
SD	500	150	50 000	150	21	1 300	0,02	2	40	0,6	0,7	10
MSW (sum)												
Mean	3310	1000	275 000	2 700	44	6 900	67 000	270	2 000	8,7	0,83	430
SD	630		55 000	500	22	1 700	35 000	70	1 500	1,9	0,81	130

Transfer coefficients of mass and selected elements for MSW incineration
(typical for incinerators equipped with electrostatic precipitators and fly ash
concentrations of 100 mg/Nm3).
Based on the table above.

Transfer coefficients of	Mass	Elements C	S	F	Cl	Fe	Cu	Zn	Cd	Hg	Pb
Bottom ash											
Mean	0,2	0,009	0,33	0,09	0,13	0,99	0,89	0,52	0,13	0,035	0,58
SD	0,04	0,003	0,08	0,03	0,04	0,01	0,03	0,06	0,04	0,038	0,09
Filter dust											
Mean	0,03	0,004	0,26	0,08	0,20	0,012	0,10	0,45	0,76	0,24	0,37
SD	0,002	0,006	0,05	0,02	0,04	0,005	0,03	0,06	0,07	0,26	0,09
Flue gas											
Mean	0,77	0,987	0,41	0,83	0,67	0,0002	0,008	0,035	0,115	0,72	0,047
SD	0,15	0,090	0,08	0,42	0,16	0,0004	0,008	0,025	0,054	0,29	0,020

Distribution of elements

A Review of metal partitioning in Thermal treatment Processes

Grate %	C	O	H	S	N	Cl	F	P	Fe	Al	Pb	Zn	Cd	Hg	Cu
Bottom ash									98.0		58	50.5	15	1	89
Filter ash									1.5		37	45.5	83	89	10
Filter cake															
Stack gas									0.5		5	4.0	2	10	1
Sum									100		100	100	100	100	100

Fate of metals in waste combustion systems

Rotary kiln %	C	O	H	S	N	Cl	F	P	Fe	Al	Pb	Zn	Cd	Hg	Cu
Residual ash											58		12	4	89
Captured ash											37		76	24	10
Emitted ash											5		12	72	1
Stack gas															
Sum											100		100	100	100

The flux of metals througt MSW-incineration

Grate %	C	O	H	S	N	Cl	F	P	Fe	Al	Pb	Zn	Cd	Hg	Cu
Bottom ash	1.6			34		13	34		99.00		58	51	12	4	89
Filter ash	0.4			26		20	39		1.00		37	45	76	24	10
Filter cake															

Stack gas	98.0			40		67	27		0.02		5	4.0	12	72	1	
Sum	100			100		100	100		100		100	100	100	100	100	
Heavy metal partitioning in a MSW-incineration																
Grate	**C**	**O**	**H**	**S**	**N**	**Cl**	**F**	**P**	**Fe**	**Al**	**Pb**	**Zn**	**Cd**	**Hg**	**Cu**	**Wt%**
%																
Bottom ash									99.581		94.4	86.3	62.3	6.4		16.5
Filter ash									0.412		4.9	13.4	23.8	2.1		0.37
Filter cake									0.007		0.4	0.2	6.4	86.2		0.02
Stack gas									0.000		0.2	0.1	7.5	5.1		83.11
Sum									100		97	98	99	100		100

Approximate quantities of residues and wastewater produced per tonne of refuse				
Source: Municipal solid waste incinerator residues, IAWG, Elsevier				
		APC process		
Waste stream/Residue	**Unit**	**Dry**	**Semi-dry**	**Wet**
Fly ash	kg dry matter	(10-30)	(10-30)	10-30
Dry residue, including fly ash	kg dry matter	20-50	15-40	
Sludge from wastewater treatment	kg dry matter			1-3
Treated wastewater	m3			0,3-0,5
Chloride content in treated wastewater	kg dry matter			3,5-10
Thermal process residues, sources, technology and types, IEA				
Distribution	**Massburn**	**FBC**		
Bottom ash	300	20		
Filter ash	20	25		
Filter cake	12	15		
Stack gas				
Input	1000 kg	1000 kg		

Appendix 2. Transfer coefficients

Transfercoefficients (% wt of input in waste)

Referanse	Stream	C	N	S	Cl	F	P	Fe	Al	Pb	Zn	Cd	Hg
	Bottom ash												
Baccini and Brunner		1.6		34	13	34		99		58	51	12	4
Schachermayer et al		1.5		47	11	84	83	98		72	46	9	5
Schachermayer et al		1.4		49	10	85	87	99		75	43	8	4
Brunner and Mönch A		1.6		34				99		60	50	10	4
Brunner and Mönch B										80	70	40	
Schmickl				48						48	49	23	4
Belevi et al. 1		1.4		24			87	98		59	45	10	
Belevi et al. 2		1.1		20			88	98		45	37	11	
TEV (14)								99.584		94.45	86.36	62.67	6.47
Spitterlau (26)										91.94	73.10	7.08	5.57
VMR (24)										61.99	60.66	33.79	0.47
Karlstad (25)										88.09	70.08	28.23	
Averøy				34.4	8.9	80				58.3		10.2	0
Ranheim				16.9	2.7	25.9				32.9		12.6	0.2
Hurum				26.2						83.5		23.5	7.1
Minimum		1.1		16.9	2.7	25.9	83.0	98.0		32.9	37.0	7.1	-
Maximum		2		49	13	85	88	100		94	86	63	7
Mean		1		33	9	62	86	99		67	57	20	4
Median		1		34	10	80	87	99		62	51	12	4
	Filterdust + filter cake												
Bacini and Brunner		0.4		26	20	39		1		37	45	76	24
Schachermayer et al				39	35	15	17			28	54	90	30
Schachermayer et al				35	37	14	13			25	57	92	51
Brunner and Mönch A		0.4		26				1		40	50	80	24
Brunner and Mönch B										20	40	60	
Schmickl				28						51	51	77	40
Belevi et al. 1		1		61			13	2		41	55	90	
Belevi et al. 2		1		68			12	2		55	63	89	
TEV (14)								0.42		5.3	13.5	30.3	89.1
Spitterlau (26)										8.0	26.9	92.8	91.6
VMR (24)										38.0	39.3	66.2	73.9
Karlstad (25)										11.9	29.8	71.7	
Averøy				58.9	90.6	19.6				41.7		89.7	94.8
Ranheim				82.3	97.1	71.3				66.8		87.4	98.6
Hurum				65.9						16.5		76.5	65.4
Minimum		0.4		26.0	20.0	14.0	12.0	0.4		5.3	13.5	30.3	24.0
Maximum		1		82	97	71	17	2		67	63	93	99
Mean		1		49	56	32	14	1		32	44	78	62
Median		1		49	37	20	13	1		37	48	80	65

Flue gas										
Baccini and Brunner	98	40	67	27		0.02	5	4	12	72
Schachermayer et al	99	1								
Schachermayer et al	99	1								
Brunner and Mönch A	98	40				0.02	5	4	10	72
Brunner and Mönch B							1	1	2	
Schmickl		4					1	1	1	1
Belevi et al. 1	98.5	15			1	1	1	1	1	
Belevi et al. 2	98.8	12			1	1	1	1	1	
Plant 14						0	0.2412	0.0843	7.5346	5.1799
Plant 26							0.0168	0.0245	0.1284	2.8325
Plant 24							0.0046	0.0010	0.0178	25.6533
Plant 25							0.0201	0.0700	0.0258	
Plant 8		6.7	0.5	0.4			0.0113		0.0290	5.1000
Plant 9		0.8	0.2	2.8			0.30		00	1.2
Plant 10		7.9					0		0	27.5
Minimum	98.0	0.8	0.2	0.4	1.0	-	-	0.0	-	1.0
Maximum	99	40	67	27	1	1	5	4	12	72
Mean	99	13	23	10	1	0	1	1	3	24
Median	99	7	1	3	1	0	0	1	1	5

References:

Baccini and Brunner: Metabolism of the Anthroposphere, 1991, Springer-Verlag

Schachermayer Elisabeth, Bauer Gerd, Ritter Eva, Brunner Paul H.: Messung der Güter- und Stoffbilanz einer Müllverbrennungsanlage, Endbericht. TU Wien, Inst. Für Wassergüte und Abfallwirtschaft, 1994
Scmickl, H. Dissertation, Technische Universität Wien, 1993 (unveröffentlicht), Data presentert i Schachermayer et al.

Belevi, H., Langmeier, M., Moench. EAWAG Dübendorf, Schweiz, in Vorbereitnung, 1994, Data presentert i Schachermayer et al.