ENERGOS

TRANSFER COEFFICIENTS FOR WASTE COMBUSTION PLANTS

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1. INTRODUCTION

The project "Aid in the Management and European Comparison of Municipal Solid Waste Treatment methods for a Global and Sustainable Approach" (AWAST) is a multinational project with financial support from EU. The objective of the project is to develop modelling and simulation tools for the selection, evaluation and optimisation of a complete municipal solid waste (MSW) chain including aspects related to materiel recovery, economy, energy and environmental effects. The project was started in 2001 and will be terminated at the end of 2003.

The AWAST project aims to cover the complete MSW chain including standardisation of characterisation of MSW and material flows, energetic aspects, economic aspects, collection and transport, sorting, recycling, landfill and biological and thermal treatment of MSW.

The engagement from Energos in the project has primarily been towards activities related to energetic aspects and thermal treatment of waste.

This report summarises the results from the work conducted at NTNU, SINTEF Energy Research and Energos on material balances through a MSW combustion plant and the prediction of the distribution of selected components in the different material flows expressed as transfer coefficients.

2. METHODOLOGY

In this study, the transfer coefficient is stated as a fraction or a percentage of the total input mass of the actual component in each material flow out of the system. In the AWAST project the material flows used to describe the mass balance of components are:

Input flow:
Municipal solid waste

Output flows:
Bottom ash
Boiler ash and solid flue gas cleaning products
Flue gas

It is rare to find documentation that states the content of specific components in the incoming waste. Due to the variations in composition and moisture content that normally is observed for MSW it is not feasible in practical terms to obtain continuous measurements of the components of interest in the MSW. The outgoing flows from MSW plants are generally better documented in terms of composition and flow rates and thus the ingoing flow of components can be estimated by mass balance calculations.

2.1 Selected components

For the AWAST project, components were selected both with respect to process and combustion aspects and to environmental aspects. The project aimed at establishing transfer coefficients for the following components; C, N, S, Cl, F, P, Fe, Al, Pb, Zn, Cd and Hg.

2.2 Data acquisition

In order to collect as relevant information as possible, a questionnaire was sent to numerous waste-to-energy plants in Europe. The objective was to collect information from different combustion technologies (grate, fluidised bed and rotary kiln), different flue gas cleaning systems and different fuel mixtures. The information requested included description and age of the installed technologies, characterisation of the fuel, consumption of consumables, flow rates of inlet and exit streams and characterisation of the inlet and exit streams with respect to the components listed above.

The questionnaire was distributed to plants selected by Energos and the other AWAST project partners and through contact in IEA Task 36 (Energy from Integrated Solid Waste Management Systems).

About 30 replies was received, but a study of the received documentation showed that rather few plant had reported results to the extent that it was possible to establish the necessary material balances to estimate transfer coefficients. The results from the questionnaires also showed that none of the plants reported analysis result with all the requested components. The components that were not documented were especially N, Fe and P.

The information collected from plants in operation is supplemented from data found in literature.

3. TRANSFER COEFFICIENTS

The received data that was analysed in order to establish mass balances for the different streams in and out of the plant in accordance to the main flows defined for the AWAST project. Based on the mass balances and the concentrations of the selected component transfer coefficients for the various streams was estimated.

3.1 Base case scenario

A selection of different species in MSW has been investigated to see where these species end up in a MSW combustion plant. The following species are included in this investigation: sulphur (S), chlorine (Cl), fluorine (F), phosphorous (P), iron (Fe), mercury (Hg), zinc (Zn), cadmium (Cd) and lead (Pb). A base case scenario with a given composition of these species and a given moisture content and feeding rate gives us the concentrations of these species both in the bottom ash and in the raw flue gas. Table 1 shows the input data used in this study.

Table 1. Input data for mass flow calculations.

Moisture	30 wt% (wet)	S	0.4 wt% dry
Input feed	5480 kg/h	Cl	1.0 wt% dry
		F	0.02 wt% dry
Gross flue gas	51 345 Nm^3/h wet	P	2.0 wt% dry
Moisture	15.9 vol%	Fe	1.0 wt% dry
Reference O_2	11 vol% dry	Pb	2 mg/kg dry
Dry flue gas	60 454 $Nm^3/h@11vol\%O_2$	Zn	400 mg/kg dry
		Cd	10 mg/kg dry
		Hg	2 mg/kg dry

Based on the given conditions the mass flows of the different components were calculated. The results are given in Table 2 and 3. Table 2 shows the mass flow of the different species in the bottom ash. Minimum, maximum and mean values based on an investigation from literature values and plant data as shown in Appendix are given in both tables. From table 2 it can be observed that with the exception of P and Fe the difference between minimum and maximum values are relatively large. This observation is consistent with the possible large variations in fuel composition and operational conditions of each combustion plant. A more detailed overview of the range of minimum and maximum values for the different mass flows are given in the Appendix.

Table 2. Mass flows of the different species in bottom ash.

Element	Input [kg/h]	Bottom ash [kg/h]		
		Min.	Max.	Mean
S	15.3	2.6	7.5	5.3
Cl	38.4	1.0	5.0	3.7
F	0.8	0.2	0.7	0.5
P	76.7	63.7	67.5	66.2
Fe	38.4	37.6	38.2	37.8
Pb	0.007	0.00054	0.00481	0.00157
Zn	1.5344	0.56773	1.32504	0.89244
Cd	0.0384	0.002271	0.02404	0.00785
Hg	0.0077	0.00002	0.00067	0.00035

Table 3 shows the concentration of selected species in the raw flue gas in terms of minimum, maximum and mean values. The values indicate a large variation between minimum and maximum values for species except HCl and Hg.

Table 3. Concentrations of selected species in the raw flue gas.

Element	Raw flue gas mg/Nm3 dry flue gas@11vol.% O_2		
	Min.	Max.	Mean
SO_2	259	422	333
HCl	568	635	589
HF	2	10	5
P	152	216	175
Fe	2.6	13	8.5
Pb	0.05	0.12	0.10
Zn	3.5	16	11
Cd	0.24	0.59	0.50
Hg	0.12	0.13	0.12

Based on the transfer coefficients obtained in this study a mass balance for the investigated species were calculated and the results are given in Figure 2. This study does not separate between different types of cleaning equipment (wet or dry), but gather all under same umbrella and call it flue gas cleaning residues. This way of doing mass balances is rough and it is mainly meant to be used in order to supply data (transfer coefficients) to a life cycle analysis. These results indicate that a significant portion of S, Cl, F and Hg is released via the flue gas. The other species, however, is mainly kept either in the bottom ash or captured in the flue gas cleaning system.

Literature data on several different heavy metals and their volatility have been gathered independent of this study and is presented here only as complementary to the other results and is shown in Figure 3. As indicated in the other results there is a wide range of volatility of heavy metals such as cadmium, lead and zinc, whereas other metals such as cupper and chromium show a very stable tendency to remain in the bottom ash.

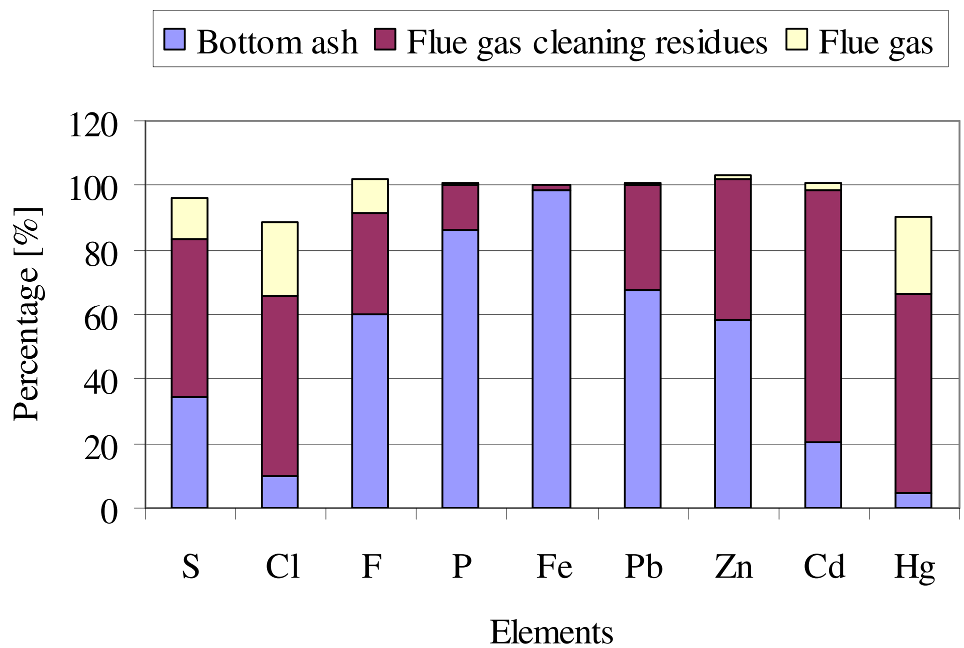

Figure 2. Partitioning of selected elements in MSW combustion plants.

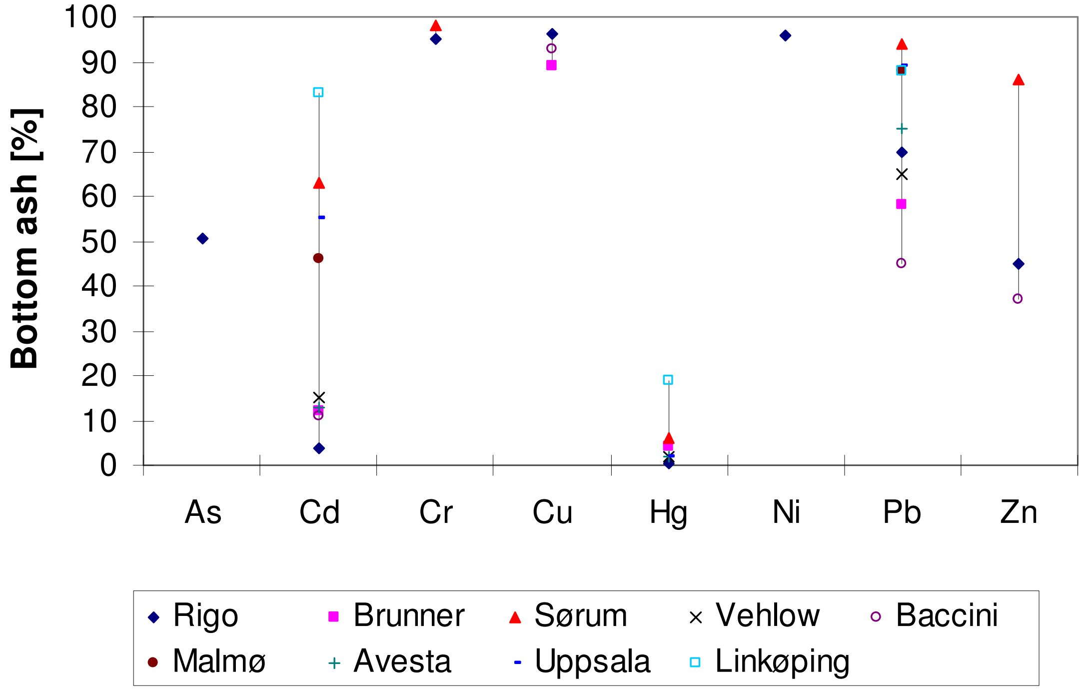

Figure 3. Percentage of different heavy metals that remain in the bottom ash in a MSW combustion plant.

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APPENDIX
TRANSFER COEFFICIENTS

Transfercoefficients (% wt of input in waste)

Referanse	Stream	C	N	S	Cl	F	P	Fe	Al	Pb	Zn	Cd	Hg	Tl	Cu	As	Sb	Cr	Co	Mn	Ni	V	Sn
	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											
Christensen				45,7	13	50,5				72,80	74,90	26,30	8,70	98,50	94,40	68,50	41,60	88,70	86,20	80,60	87,60	85,00	85,90
Plant 1								99,5835		94,45	86,36	62,67	6,47					98					
Plant 2										91,94	73,10	7,08	5,57										
Plant 3										61,99	60,66	33,79	0,47										
Plant 4										88,09	70,08	28,23											
Plant 5				34,4	8,9	80				58,3		10,2											
Plant 6				16,9	2,7	25,9				32,9		12,6	0,2										
Plant 7				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	0,2	98,5	94,4	68,5	41,6	88,7	86,2	80,6	87,6	85,0	85,9
Maximum		2		49	13	85	88	100		94	86	63	9	99	94	69	42	98	86	81	88	85	86
Mean		1		34	10	60	86	99		68	58	20	5	99	94	69	42	93	86	81	88	85	86
Median		1		34	11	65	87	99		67	51	12	4	99	94	69	42	93	86	81	88	85	86

Referanse	Stream	C	N	S	Cl	F	P	Fe	Al	Pb	Zn	Cd	Hg
	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	
Plant 1								0,42		5,3	13,5	30,3	89,1
Plant 2										8,0	26,9	92,8	91,6
Plant 3										38,0	39,3	66,2	73,9
Plant 4										11,9	29,8	71,7	
Plant 5				58,9	90,6	19,6				41,7		89,7	94,8
Plant 6				82,3	97,1	71,3				66,8		87,4	98,6
Plant 7				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 1								0		0,2412	0,0843	7,5346	5,1799
Plant 2										0,0168	0,0245	0,1284	2,8325
Plant 3										0,0046	0,0010	0,0178	25,6533
Plant 4										0,0201	0,0700	0,0258	
Plant 5				6,7	0,5	0,4				0,0113		0,0290	5,1000
Plant 6				0,8	0,2	2,8				0,3		0	1,2
Plant 7				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