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TNO-report

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A study of flue gas emission reduction from cremation processes by the "Amalgator"

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Intended for
Vermeulen Product Engineering
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Summary

On 1 April 1999 a study, commissioned by Vermeulen Product Engineering, was conducted by the Department of Thermal Conversion Technology of TNO-MEP of the filter efficiency of the Amalgator at the Crematorium Nedermaas in Geleen in the Netherlands. At this crematorium a cremator of the "warm-start"type is installed. The Amalgator is a filter system developed for the reduction of mercury, dust and PCDD/PCDF emissions in the flue gasses of cremators. It consists of a dustfilter, a catalytic bed and an active carbon bed.

Measurements were done simultaneously in the flue gasses in the inlet as well as in the outlet of the Amalgator during a total of 3 consecutive processes. From these measurements the efficiency of the Amalgator as to the reduction of the flue gas emission of Hg, dust, PCDD/PCDF and NO_x was calculated. The results are listed in the table below.

Table Filter efficiency.

Component	Process 1 [%]	Process 2 [%]	Process 3 [%]	Average [%]
Hg	> 99,9	99,7	> 99,9	> 99,8
dust	> 91	> 93	> 94	> 93
NO_x	11	19	23	18
PCDD/PCDF		99		99

Treatment of flue gasses with the Amalgator causes a substantial decrease of the Hg, dust and PCDD/PCDF emission. The NO_x emission is also slightly decreased. The flue gas emission of a cremator of the "warm-start" type comply with the maximum allowed emmision levels as stated in the NeR after passing the flue gasses through the Amalgator.

Although this was no part of the study, contamination of the catalyst and/or the active carbon in the Amalgator may possibly cause a decrease in filter efficiency after a prolonged operation time. It is therefore advisable to assess the filter efficiency after approximately 1 to 2 years or 1500 to 2500 processes.

Nomenclature

s.t.p.	Standard temperature and pressure (273 K, 1013 hPa) of the dry gas
PCDD/PCDF	Polychloro-dibenzo-dioxine / polychloro-dibenzo-furan
m^3	cubic metre
h	hour
g	gram
kg	kilogram
mg	milligram
µg	microgram
η	efficiency

Contents

1. Introduction

The company Vermeulen Product Engineering has developed a flue gas cleaning system for the reduction of the dust, mercury and PCDD/PCDF emission from cremation processes. They have a patented claim that this system will be able to reduce flue gas emissions to a level that will comply with the maximum allowed emission levels as stated in the Dutch Emission Guidelines (NeR). To substantiate this claim Vermeulen Product Engineering has commissioned the Department of Thermal Conversion Technology of TNO-MEP in Apeldoorn (NL) to conduct a study by means of measurements at this flue gas cleaning system, called "Amalgator".

The measurements were done April 1, 1999 at the "Crematorium Nedermaas" in Geleen (NL).

The results of this study are described in this report. Chapter 2 gives a brief description of the Amalgator. Chapter 3 describes the methods employed in this study, and the results of the study are reported in chapter 4. In chapter 5 the conclusions derived from this study are listed.

2. Description of the "Amalgator"

The Amalgator consits of the following consecutive parts.
1. a cyclone
2. a dust filter
3. a ventilator
4. a catalytic bed
5. an active carbon bed

The Amalgator is connected to the existing chimney of the cremator. From there the flue gas flows to a cyclone to remove the relatively large dust particles. In the lower part of the cyclone an artificial leak is created to let ambient air in. This air flow mixes with the flue gas, resulting in a cooling of the flue gas from approximatley 300°C to approximately 110°. From there the cooled flue gas flows through a dust filter containing cartridges to remove most of the remaining dust particles. Via a ventilator, necessary to maintain the needed underpressure in the cremator, the flue gas is brought into contact with a TiO_2/V_2O_5 catalyst. Mercury, present in the flue gas may be removed from the flue gas by amalgamation with vanadium. Also PCDD/PCDF is oxidized on the catalyst. Since the original purpose for which this catalyst was developed was the removal of NO_x, some effect on this component may also be expected.
As last component of the Amalgator an active carbon bed is installed. This will function as a so-called "police"-filter to remove mercury and PCDD/PCDF slipped through the catalytic bed. From there the flue gas is emitted into the atmosphere.

3. Study method

The measurements were done in the flue gasses from cremator n° 2 at the crematorium Nedermaas in Geleen (NL). Crematorium Nedermaas has installed a total of 3 TABO cremators, which are generally refered to as so-called "warm-start" cremators. At an oventemperature of approximately 800°C the coffin is inserted into the oven. A natural gas burner maintains the temperature in the oven during the whole process. The flue gasses are led through a natural gas fired afterburner chamber and then emitted to the atmosphere. To maintain the neccesary draft in the cremator, ambient air is injected in the chimney.

For a total of three cremation processes the flue gasses in the inlet and the outlet of the Amalgator were sampled and monitored simultaneously. Beforehand, the principal had verified that the human remains did not contain any amalgam restorations in its teeth.
Prior to the start of each process an exact known amount of mercury amalgam was put in the coffin. This amount was approximately equal to the average amount of amalgam of a person with teeth restorations (approximately 5 grams).
Also, the coffin, including the human remains was weighed by special request of the principal.
Immediately after closing of the cremator door, the measurements as stated in table 3.1 were started. The measurements and samplings were done for a total of 3 consecutive processes and were stopped the moment the cremator door was opened to remove the ashes.

Table 3.1 Overview of measurements

Component/ parameter	Inlet Amalgator	Outlet Amalgator
O_2	continuous	continuous
CO_2	-	continuous
CO	-	continuous
C_xH_y	-	continuous
NO_x	continuous	continuous
SO_2	continuous	continuous
dust	1 sample per process	1 sample per process
Hg	1 sample per process	1 sample per process
PCDD/PCDF	1 sample over 3 processes	1 sample over 3 processes
temperature	continuous	continuous
flue gas flow	-	continuous

The measurements were carried out in the horizontal inlet channel (ID 40 cm) of the Amalgator and the vertical outlet channel (ID 40 cm) of the active carbon bed.

Appendix B gives an overview of the applied measurement and sampling methods used.

4. Results

4.1 General

Table 4.1 lists the data of the coffin and the human remains being cremated during which the various readings were made. Measurements were made on 1 April 1999. The times and durations of the cremations under study are recorded in Table 4.2.

Table 4.1 Overview of cremation processes.

Cremation no.	Weight of coffin + human remains [kg]	Sex
1	96,0	F
2	106,0	M
3	105,8	F

Table 4.2 Overview of cremation process times and duration.

Cremation no.	Start and finish times	Duration [min]
1	13:07 - 14:28	81
2	15:23 - 16:57	94
3	17:20 - 19:00	100

From the data listed in table 4.1 and data from literature [1,2,3] for the average composition of coffin and the human body the calorific value and the stoichiometric flue gas flow can be estimated by calculation. These estimates are listed in table 4.3.

Table 4.3 Estimation of the calorific value and the stoichiometric flue gas flow.

Cremation no.	Calorific value [MJ/kg]	Stoichiometric flue gas flow [m^3 s.t.p /process]
1	12,7	316
2	10,6	304
3	10,6	304

Before each cremation process an exact known amout of mercury amalgam was put in the coffin. Also a sample of this mercury amalgam was analysed as to the concentration of mercury. Table 4.4 lists the amount of mercury amalgam and mercury added to the process. The laboratory analysis showed that the amalgam used contained 0,504 gram Hg per gram amalgam.

Table 4.4 Amount of mercury amalgam added to the process.

Cremation no.	Amalgam added [g]	Hg amount [g]
1	5,068	2,554
2	5,164	2,603
3	5,019	2,530

4.2 Flue gas measurements

In tables 4.5, 4.6 and 4.7 the results are listed of the various measurements per cremation process. The results of the PCDD/PCDF measurement are listed separately in table 4.8. To be able to evaluate the efficiency of the Amalgator, the concentrations of the components in the outlet channel are also refered - by calculation - to the O_2 concentration in the inlet channel.

Table 4.5 Results of process 1.

Component/parameter		Inlet	Outlet	Outlet refered to O_2 in inlet
O_2	vol%	17,4	19,0	17,4
CO_2	vol%	-	1,4	2,5
CO	mg/m³ s.t.p.	-	5	10
C_xH_y	mg/m³ s.t.p.	-	< 1	< 1
NO_x (as NO_2)	mg/m³ s.t.p.	132	64	118
SO_2	mg/m³ s.t.p.	18	36	66
Hg	µg/m³ s.t.p.	755	< 0,4	< 0,7
dust	mg/m³ s.t.p.	23	< 1	< 2
flue gas flow	m³ s.t.p./h	3210	5880	-
temperature	°C	294	118	-

Table 4.6 Results of process 2.

Component/parameter		Inlet	Outlet	Outlet refered to O_2 in inlet
O_2	vol%	18,2	19,4	18,2
CO_2	vol%	-	1,1	2,0
CO	mg/m³ s.t.p.	-	5	8
C_xH_y	mg/m³ s.t.p.	-	<1	<1
NO_x (as NO_2)	mg/m³ s.t.p.	132	60	107
SO_2	mg/m³ s.t.p.	28	26	44
Hg	µg/m³ s.t.p.	610	1,0	1,6
dust	mg/m³ s.t.p.	27	< 1	< 2
flue gas flow	m³ s.t.p./h	3250	5650	-
temperature	°C	279	110	-

Table 4.7 Results of process 3.

Component/parameter		Inlet	Outlet	Outlet refered to O_2 in inlet
O_2	vol%	18,4	19,4	18,4
CO_2	vol%	-	1,1	1,7
CO	mg/m³ s.t.p.	-	5	8
C_xH_y	mg/m³ s.t.p.	-	< 1	< 1
NO_x (as NO_2)	mg/m³ s.t.p.	117	53	91
SO_2	mg/m³ s.t.p.	21	17	28
Hg	µg/m³ s.t.p.	551	< 0,4	< 0,7
dust	mg/m³ s.t.p.	34	< 1	< 2
flue gas flow	m³ s.t.p./h	3500	5700	-
temperature	°C	277	112	-

A graphical presentation of the concentration of O_2, CO_2, CO, C_xH_y, NO_x and SO_2 as well as the flue gas temperature against time is presented in appendix A.1 - A.3.

The results for the three processes show a big decrease in the emission of Hg and dust after passing through the Amalgator. However, the average SO_2 concentration in the flue gas rises after passing through the Amalgator. From the graphics in appendix A it can be seen that the SO_2 concentration in the outlet is fairly constant and independent of the SO_2 inlet concentration. Most probably this is caused by sulfur present in the active carbon. Since this carbon was a fresh batch - flue gasses from a total of only 30 processes have passed since start-up - some sulfur present in it will be emitted as SO_2. This emission is likely to decrease gradually in time.
The NO_x emission is also slightly decreased.

Table 4.8 Results of PCDD/PCDF measurement (one integral sample for 3 processes).

PCDD/PCDF inlet channel [ng TEQ/m^3 s.t.p.]	PCDD/PCDF outlet channel [ng TEQ/m^3 s.t.p.]	PCDD/PCDF outlet refered to O_2 in inlet [ng TEQ/m^3 s.t.p.]
0,55	0,004	0,007

To test the emission from the Amalgator against the maximum allowed emission levels as stated in the NeR, the results of the emission concentration measurements have to be refered to 11% O_2 in the flue gas. Since this involves a relative high conversion factor, because of the high O_2 percentage in the flue gas from the Amalgator, a reference to 11% O_2 should be considered as less reliable. In table 4.9 the results of the emission measurements refered to 11% O_2 are listed.

Table 4.9 Flue gas concentrations in outlet Amalgator refered to 11% O_2.

Component		Process 1	Process 2	Process 3	NeR maximum level
CO	mg/m^3 s.t.p.	29	31	34	-
C_xH_y	mg/m^3 s.t.p.	< 2	< 2	< 2	-
NO_x (as NO_2)	mg/m^3 s.t.p.	310	360	313	200 *)
SO_2	mg/m^3 s.t.p.	217	196	138	200 *)
Hg	mg/m^3 s.t.p.	< 0,0021	0,0066	< 0,0023	0,2
dust	mg/m^3 s.t.p.	< 5	< 6	< 6	10
PCDD/PCDF	ng TEQ/m^3 s.t.p		0,024		-

*) Only if mass flow of component exceeds 5,0 kg/h. If the mass flow is less, no maximum emission level is defined.

The Hg and the dust emission comply with the maximum allowed NeR values. The NO_x and SO_2 emission also comply with the NeR values, since the mass flow for each component is less than 5,0 kg/h.

4.3 Filter efficiency

The filter efficiency is calculated as the ratio of the difference between inlet and outlet concentration and the inlet concentration. For the calculation, the outlet concentration is refered to the O_2 concentration in the inlet of the Amalgator.

$$\eta filter = \frac{Cin - Cout}{Cin} * 100\%$$

In table 4.10 the filter efficiency for Hg, PCDD/PCDF, dust and NO_x are listed for each process.

Table 4.10 Filter efficiency.

Component	Process 1 [%]	Process 2 [%]	Process 3 [%]	Average [%]
Hg	> 99,9	99,7	> 99,9	> 99,8
dust	> 91	> 93	> 94	> 93
NO_x (as NO_2)	11	19	23	18
PCDD/PCDF		99		99

The reported filter efficiency is valid for the Amalgator as installed at a "warm-start" cremator, since a "cold-start" cremator produces a flue gas with a higher temperature (approximately 650 °C) and a lower O_2 percentage (approximately 12 vol%). [1)]
No conclusions can be drawn from this study to which part of the Amalgator is responsible for the reduction of the emission of a certain component. For example, it remains unclear whether the mercury present in the flue gasses is amalgamated in the catalytic bed or absorbed on the active carbon. [2)]
On the day of this study, the Amalgator had previously treated the gasses of approximately 30 cremation processes since start-up. Filter efficiency may therefore decrease in time because of contamination of the catalyst and/or the active carbon. It is therefore advisable to determine the filter efficiency after a prolonged operation time of 1 to 2 years or 1500 to 2500 processes of the Amalgator.

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1) According to Vermeulen Product Engineering, the Amalgator can be installed to treat the flue gasses of a "cold-start" cremator, by injecting ambient air into the flue gasses (approx. 875 m^3 s.t.p./h; 12 vol% O_2; 650 °C) before entering into the Amalgator. This results in a mixture of cooled flue gas (approx. 2100 m^3 s.t.p./h; 17 vol% O_2; 280 °C). In the scope of this research these data have not been verified by TNO-MEP.

2) Simultaneous with the TNO measurements, the principal performed an indicative measurement of the Hg concentration in the flue gasses between the catalytic bed and the active carbon bed using a continuous UV spectrophotometer. The results of these measurements by the principal indicated a reduction of the Hg concentration by the catalytic bed of approximately 98%.

5. Conclusions

- The Hg emission is reduced by more than 99,8 % in average after passing through the Amalgator.
- The dust emission is reduced by more than 93 % in average.
- The PCDD/PCDF emission is reduced by 99 % in average.
- The NO_x emission is reduced by 18% in average.
- The emissions of the "warm-start" cremator comply with the emission levels as stated in the NeR after passing the flue gasses through the Amalgator.
- The emission from the Amalgator should again be determined after a prolonged operation time of 1 to 2 years or 1500 to 2500 processes, to assess any decrease in filter efficiency by contamination of the catalyst and/or the active carbon.

6. References

[1] H.A. Schroeder; The biological trace elements; J. Chron. Dis. 1965, vol. 18, pp. 217-228

[2] VDI 3891; Emissionsminderung einascherungsanlagen; 1992

[3] P. Eggels, S. van Loo; Milieueffecten van de energiewinning uit (afval)hout; TNO rapport nr. 94-372; april 1995

7. Authentication

Name and address of the principal:

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Names and functions of the cooperators:

E.R. Smit - Research worker/Project leader
A.E.A. van Velde - Research worker

Names and establishments to which part of the research was put out to contract:

Analytical laboratory TNO-MEP

Date upon which, or period in which, the research took place:

1 April 1999

Signature:

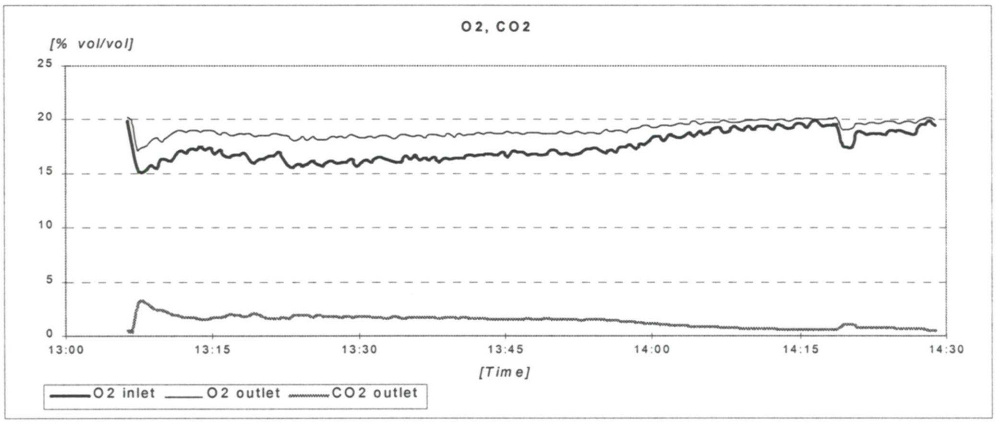
E.R. Smit, B.Sc.
Project leader

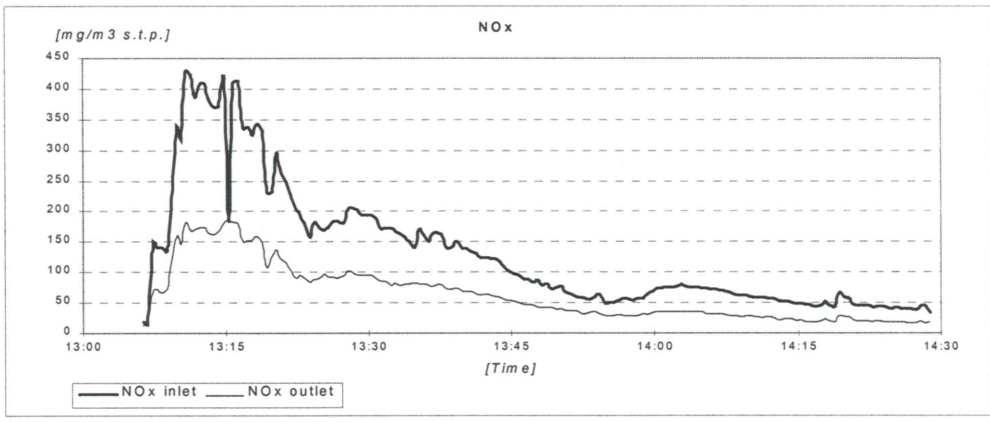
Approved by:

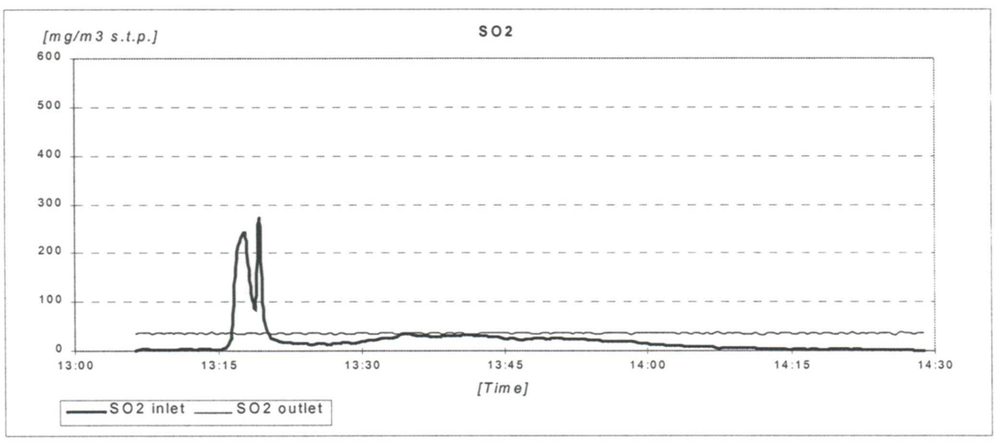
S. van Loo, B.Sc.
Head of Department

Appendix A Specification of measurement results

A.1 Curves of continuously recorded measurements, process 1







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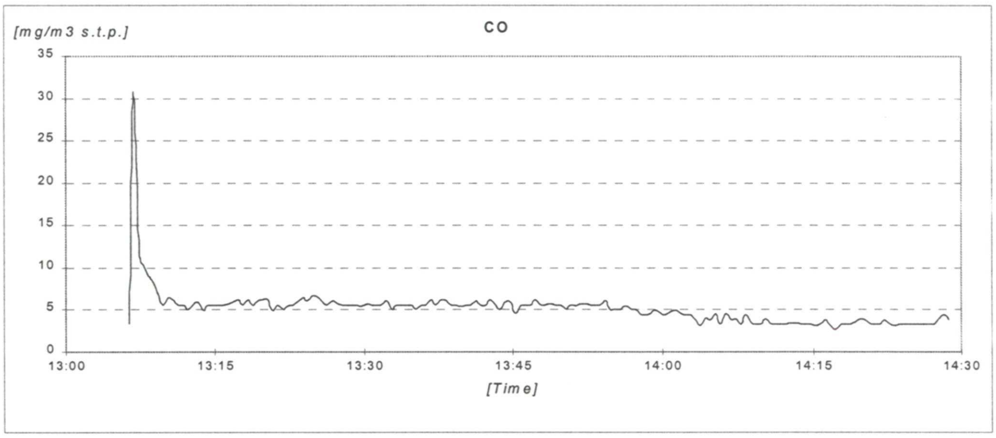

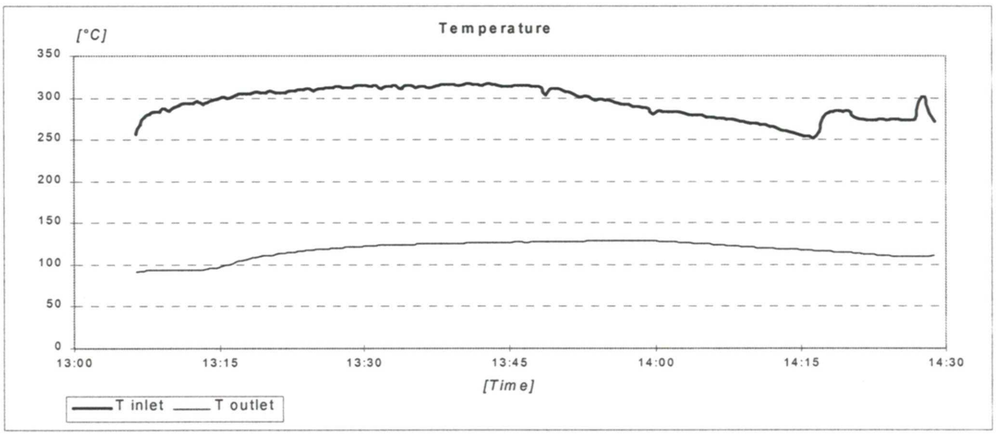

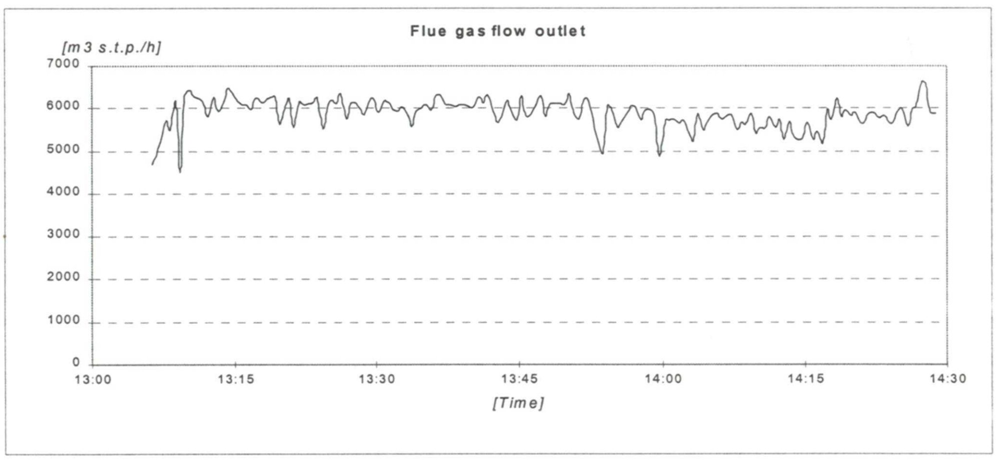

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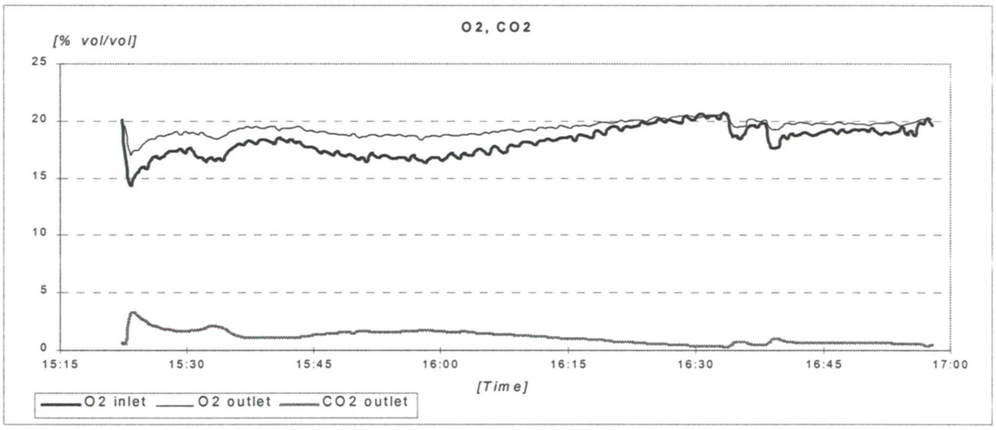

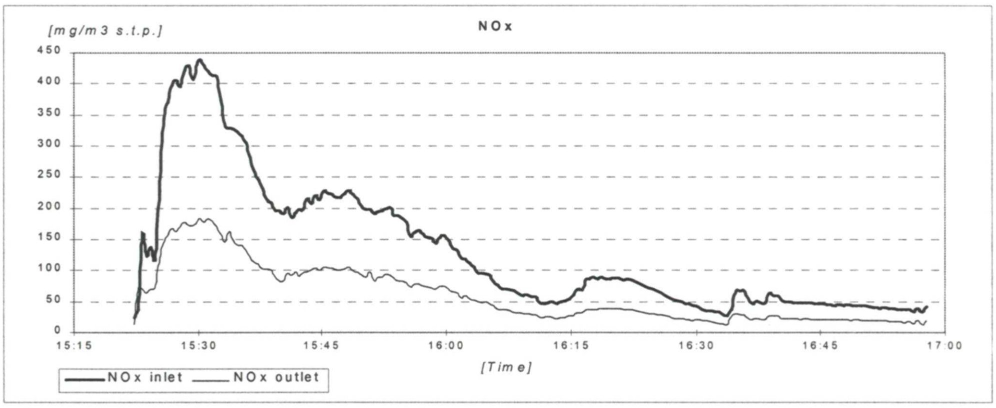

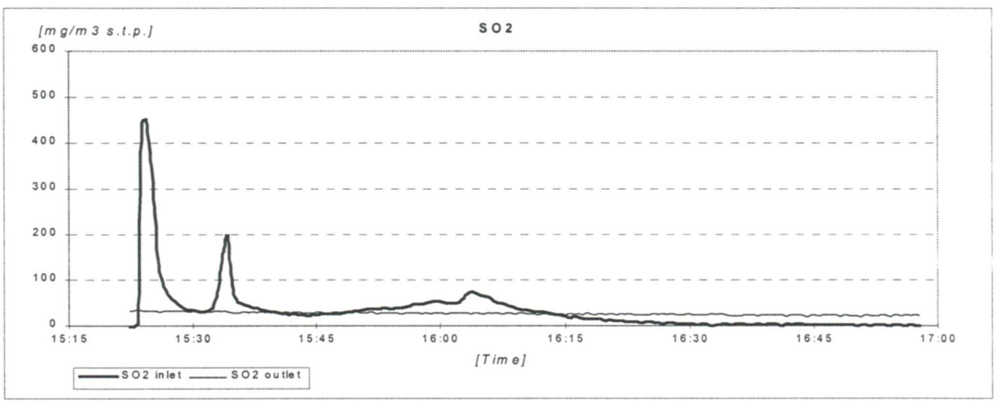

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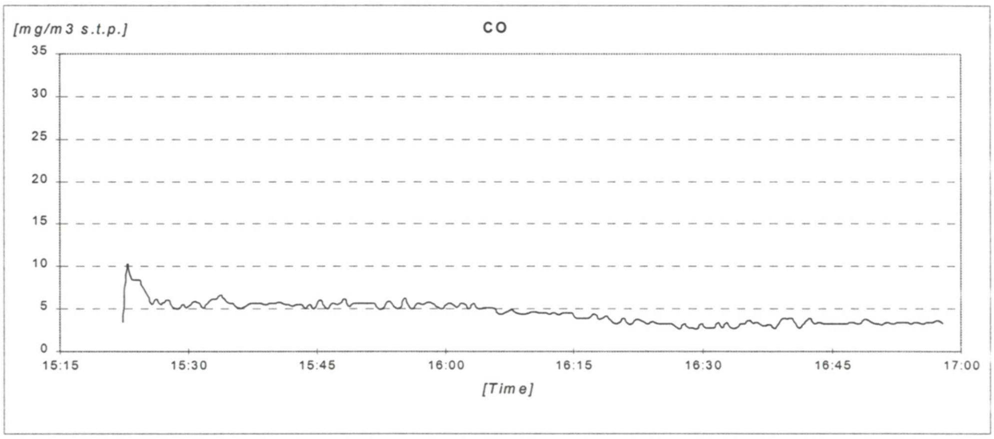

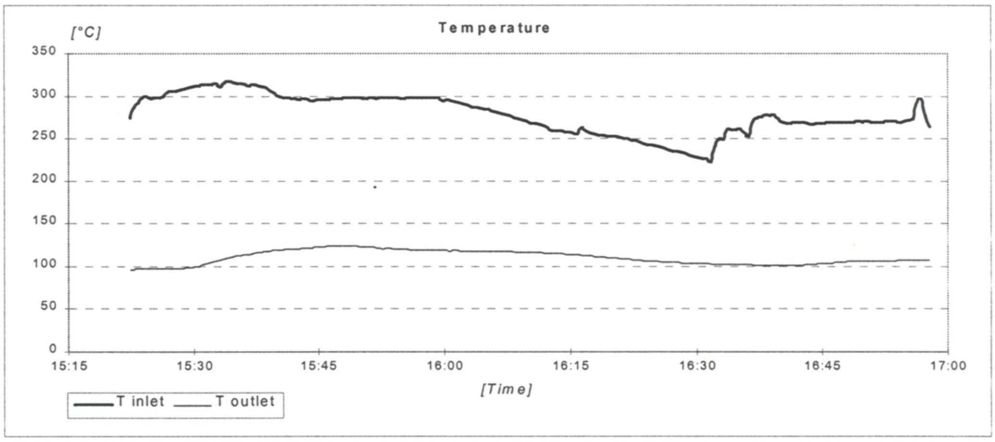

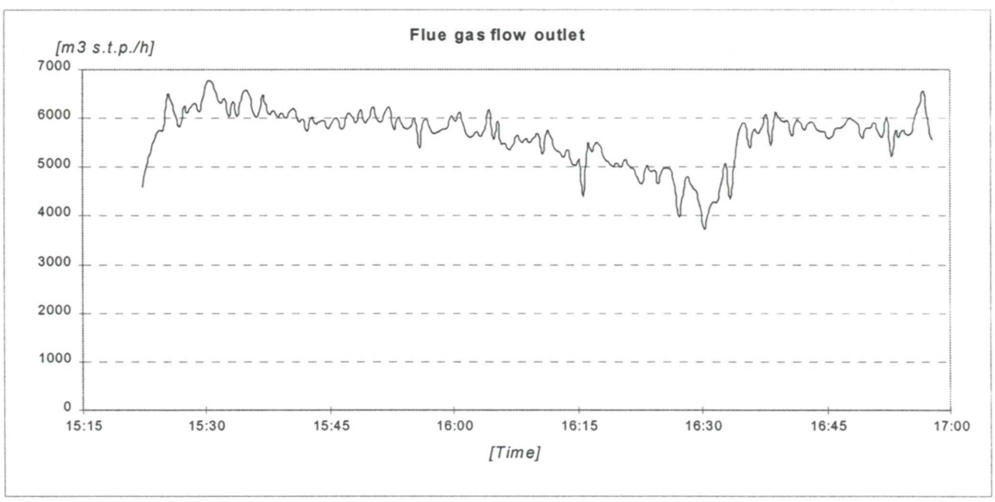

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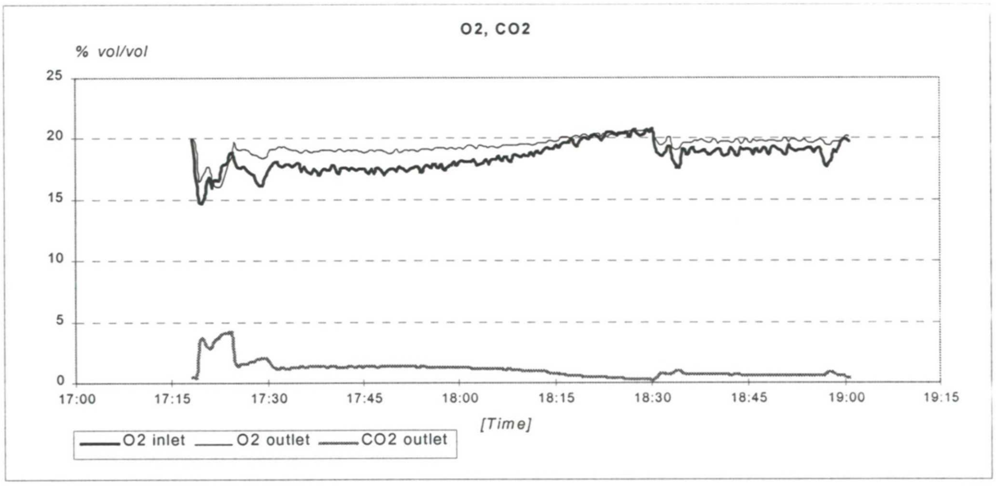

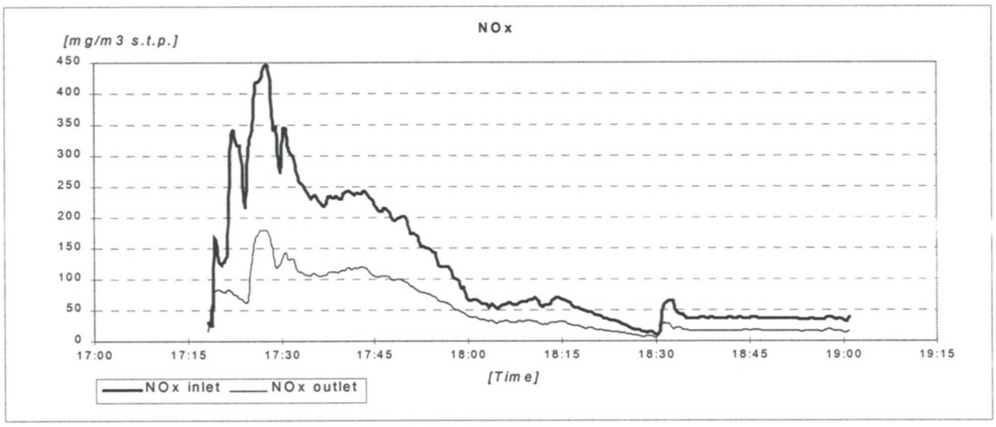

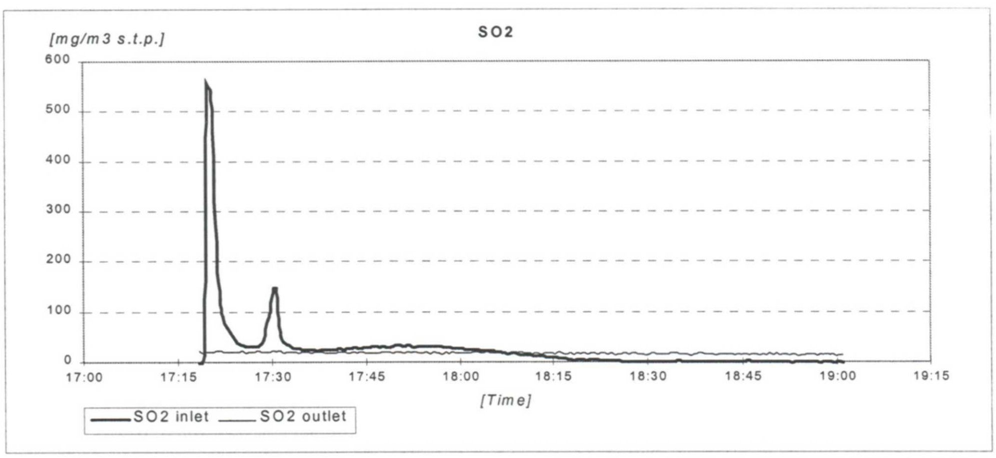

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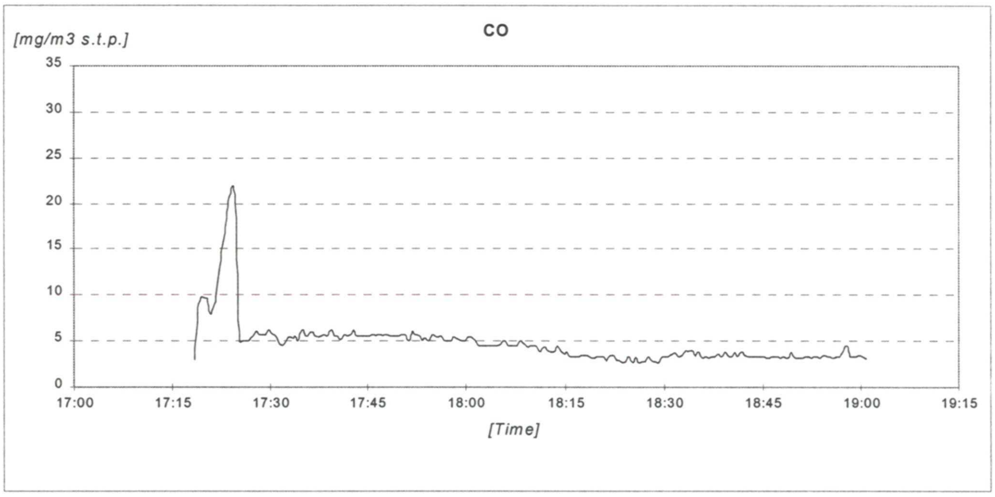

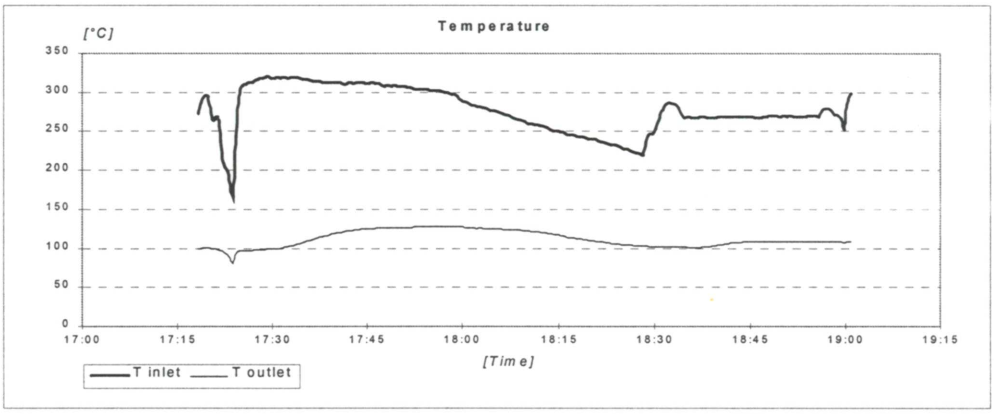

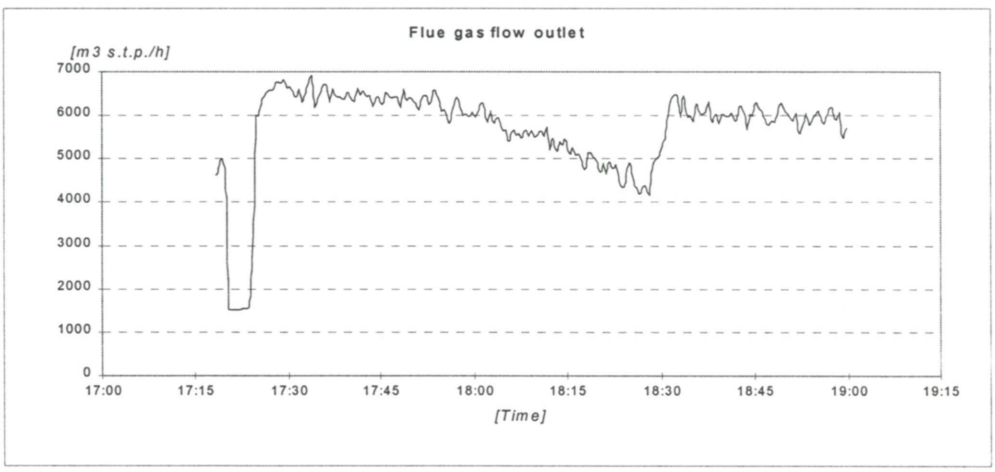

Appendix B Measurement and sampling methods

Table 1 Sampling/analysis methods used, measuring standards and uncertainties.

No.	Component	TNO Procedure Standard	Uncertainties 1)
1*	Determination of the particulate concentration (Gravimetric)	SA-015, SA-016 (based on ISO 9096)	< 10% of measuring value above 5 mg/m^3, under ideal circumstances
2*	Determination of the O_2 concentration (Paramagnetic)	SA-003, SA-004, SA-005 (based on CAN/CSA Z223.2 m86)	< 3% of 0,1 vol.%.
3*	Determination of the CO_2 concentration (non dispersive infrared)	SA-006, SA-007 (based on CAN/CSA Z223.2 m86)	< 3%.
4*	Determination of the CO concentration (non dispersive infrared)	SA-006, SA-008, SA-009, SA-013 (VDI 2459 Blatt 6)	< 3%.
5*	Determination of the C_xH_y concentration (equivalents of C_3H_8) (FID)	SA-010 (based on VDI 3481 Blatt 3)	< 5%.
6*	Determination of the NO_x concentration (equivalents of NO_2) (Chemiluminescent)	SA-011, SA-012 (based on ISO/DIS 10849, NPR 2046)	< 4%.
7*	Determination of the SO_2 concentration (UV)	SA-013 (based on ISO 7935)	< -4%, < +8%.
12*	Determination of the gas velocity (pitot, anemometer, calculated)	SA-024 (based on ISO 9096)	pitot tube: < 5% of measured value between 5-10 m/s, at higher levels < 4%.
13*	Determination of the gas temperature (Thermocouple)	SA-025 (based on ISO/DP 8756, VDE/VDI 3511, VDE/VDI 3512 Blatt 2)	<0,75% of measured value or 1,5 /C (largest value)
14*	Determination of the total concentration of-PCDD/F (diluting method VDI-3499 Blatt 1 + RIVM-TNO procedure. HR-GC-MS analyses	SA-014	PCDD/PCDF: < 25% of measured value between 0,1 - 1 ng/m^3 TEQ, at higher levels < 15%
16*	Determination of the concentration of Hg	SA-022 (based on draft NPR 2817)	< 10% of measured value

1) The stated uncertainties refer to the 95% confidence interval (2 sigma). The stated percentages are related to the actual measuring range of the instrument, unless mentioned otherwise.

BLA Besluit Luchtemissies Afvalverbranding (Decree Air Emissions Waste Combustion).

Table 2 *Analytical methods and standards in use by the TNO Analytical Laboratory (AC).*

Uncertainties of the analyses meet to or are better than the mentioned standards.

No.	Component	TNO Procedure	Method	Standard
	Hg		F.AAS	NEN 6449
*		IMWA/SI/027	Cold vapour	NEN 6449
*	PCDD/F	IMWA/SG/020	see table 1 (14)	