

COVANTA ENERGY CORPORATION
40 LANE ROAD, CN 2615
FAIRFIELD, NJ 07007-2615

Scott G. Mackin
President and Chief Executive Officer
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smackin@covantaenergy.com

April 3, 2002

Al Lineiro
Bureau of Air Regulation
Florida Department of the Environment
Twin Towers Office Bldg.
260 Blair Stone Road
Tallahassee, FL 32399-2400

Dear Mr. Lineiro:

I am writing to inform you about an important announcement Covanta made this week to undertake a comprehensive financial restructuring plan. This plan, which represents the completion of our comprehensive review of strategic options, will enable us to address decisively our financial challenges while ensuring the continued safe and effective operation of our energy and water facilities.

As explained in the attached press release, the Company has taken the following steps in conjunction with its financial restructuring:

- Filed for voluntary Chapter 11 bankruptcy reorganization;
- Entered into a letter of intent with the investment firm of Kohlberg Kravis Roberts and Company (KKR) for a \$225 million equity investment;
- Secured \$463 million in Debtor-in-Possession (D-I-P) financing; and
- Announced a strategic restructuring program to focus on our core energy and water market.

Our waste-to-energy and water operations are fundamentally strong – they represent the core of our business, today and for the future.

You should know that we will continue to operate our waste-to-energy and water facilities as usual, and they will continue to provide safe, reliable and environmentally sound waste management and water services. All maintenance activities will continue, unaffected by the filing. Our facilities have completed the necessary modifications to ensure compliance with the Clean Air Act, as well as other applicable state and federal

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COVANTA ENERGY CORPORATION

regulations, and we will continue to ensure compliance with all regulatory standards and disclosure schedules throughout our restructuring process. Staffing at all of our facilities is expected to remain at the same levels as it was prior to the filing and we expect that employees will be paid in the usual manner.

The decision to undertake the Company's financial restructuring was not taken lightly, and was made only after working closely with our outside financial advisers to consider the full range of available strategic options. This plan is the right one for Covanta because it recognizes the strength of our energy and water operations – they are profitable and they represent the core of our business, today and for the future.

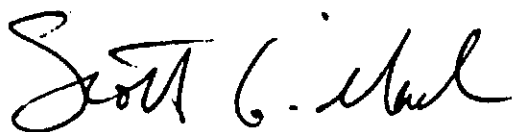
In addition, we have already arranged a substantial \$463 million in debtor-in-possession (D-I-P) financing from our lenders which, combined with the \$225 million equity investment from KKR and our current cash resources in excess of \$55 million in domestic accounts, will be used to pay all post-filing expenses and ensure the facilities' continued operation according to the highest standards.

We are convinced that our restructuring plan represents the most viable option to assure the continued performance of our energy and water facilities. Our waste-to-energy and water customers and clients can therefore continue to expect long-term, reliable, safe and environmentally sound solid waste management and water services.

For additional information please visit our website at www.covantaenergy.com, or call our automated information system at 1-866-COVANTA.

Thank you. We look forward to continuing to serve you and our respective constituents.

Sincerely,

A handwritten signature in black ink, appearing to read "Scott G. Mackin". The signature is fluid and cursive, with a large initial "S" and a distinct "G" and "M".

Scott Mackin
President and CEO



FOR IMMEDIATE RELEASE

**COVANTA ANNOUNCES FINANCIAL RESTRUCTURING
RESULTING FROM STRATEGIC REVIEW**

- Company Files Voluntary Chapter 11 Petition --**
- KKR Intends to Provide \$225 Million in Equity Financing --**
- \$463 Million Debtor-in-Possession Financing Arranged --**
- Announces Program to Focus on Core Energy and Water Operations --**

FAIRFIELD, NJ, April 1, 2002 – Covanta Energy Corporation (NYSE: COV) today announced a financial restructuring plan resulting from its comprehensive review of strategic alternatives. As the first element of that plan, the Company has filed a voluntary petition for Chapter 11 reorganization with the U.S. Bankruptcy Court in the Southern District of New York. The Company's core energy and water facilities will continue to operate in the normal course of business and will be unaffected by the filing.

Results of Strategic Review

Today's announcement represents the culmination of the strategic review conducted by the Company's Board and management, with outside financial advisers, which was announced in December 2001. As a result of that review, the Company:

- Determined that reorganization under Chapter 11 represents the most viable venue to reorganize the Company's capital structure, complete the disposition of its remaining non-core entertainment and aviation assets, and protect the value of the Energy and Water franchise;
- Entered into a non-binding Letter of Intent with the investment firm of Kohlberg Kravis Roberts & Co. (KKR) for a \$225 million equity investment under which a KKR affiliate would acquire the Company upon emergence from Chapter 11; and
- Announced a strategic restructuring program to focus on the U.S. energy and water market, expedite the disposition of non-core assets and, as a result, reduce overhead costs.

In connection with the filing, Covanta obtained a commitment for \$463 million of debtor-in-possession (D-I-P) financing from its current bank group. This financing, subject to approval by the Bankruptcy Court, will cover all of the Company's ongoing cash needs and help ensure the continuation of the Company's Letters of Credit, which are used to support the performance and payment obligations of its core energy and water facilities.

Scott G. Mackin, Covanta President and Chief Executive Officer, stated, “We have painstakingly reviewed and pursued all options outside of a Chapter 11 filing for quite some time now. Our core businesses – Waste to Energy, Independent Power Production and Water – are strong. However, the capital structure impediments left over from the non-core, former Ogden Corporation businesses, and the lack of access to the capital markets as means by which to deal with them, have foreclosed other options. The exhaustive strategic review has demonstrated that Chapter 11 represents the most viable venue for Covanta to address those capital structure issues, expedite our restructuring and preserve the value of our strong core businesses. When we emerge, we will do so with a strong balance sheet and core businesses unencumbered by the problems we inherited.

“We are gratified by the support of our bank group and KKR, which we believe will allow us to complete the Chapter 11 process expeditiously. Our bank group, particularly the Agents, has worked exceptionally hard to put together an impressive D-I-P facility that will preserve our core businesses through this process. And, the relationship we have formed with KKR over the past several months is particularly exciting. Their expertise, business acumen and financial resources will add significant value to Covanta’s prospects, and their potential investment affirms the strength of our core energy and water operations.

“We are working to obtain court approval of the substantial D-I-P package quickly, but in the meantime, interim approval affords us access to ample cash with which we will continue to operate our energy and water facilities as usual. At this time, the Company has in excess of \$55 million in its domestic accounts. We intend to pay in full our post-petition obligations, including payments to vendors. With our bank group and KKR, we look forward to working with our creditors to develop a Plan of Reorganization that is fair and feasible and positions us to realize the full potential of our core businesses,” Mr. Mackin said.

\$225 Million Equity Investment by KKR

The non-binding Letter of Intent with KKR provides that the Company and the Agents for its bank group will work exclusively with KKR for up to 90 days. Upon completion of due diligence, the negotiation and execution of definitive agreements satisfactory to the Company, KKR, the bank group and other creditors, the confirmation of a Plan of Reorganization by the Court and the satisfaction of other conditions, KKR would acquire the Company upon its emergence from Chapter 11. The Agents of the bank group providing the Company’s D-I-P financing have signed the Letter of Intent and support a transaction with KKR.

The rights of Covanta’s creditors would be determined as part of the Plan of Reorganization. Existing common equity and preferred shareholders are not expected to participate in the new capital structure.

Scott Stuart, Member of KKR, said, “KKR has been working closely with Covanta's management team for several months to determine the Company's optimal course for the future. We are pleased that the Company has elected to partner with us after its lengthy strategic review process. While this is an extremely complex situation given the particular challenges of the Company's capital structure, we are attracted to Covanta's core assets and strong management team. We look forward to continuing to work closely with the Company, the bank group and other creditors to implement a Plan of Reorganization that will best meet Covanta's objectives now and over the long term.”

\$463 Million Debtor-in-Possession Financing Arranged by Existing Bank Group

The filing immediately enhanced Covanta's liquidity by enabling the Company to restructure liabilities associated with its non-core entertainment and aviation businesses. Moreover, the Company has obtained a commitment for \$463 million in debtor-in-possession (D-I-P) financing from its bank group, led by the Agents. This financing, which is subject to definitive court approval, will cover all of the Company's ongoing cash needs and helps ensure the continuation of the Company's Letters of Credit that support the performance and payment obligations of our core energy and water facilities.

Restructuring Program to Focus on Its Core Energy and Water Business

Covanta also announced a restructuring program to focus on the U.S. energy and water industry, expedite the disposition of its non-core assets and, thereby reduce overhead costs.

Further, the Company announced that it has completed the sale of its Thai energy assets for \$35 million to two consortia of co-investors. The sales included Covanta's Saha and Rojana co-generation facilities, as well as its subsidiary operating those plants.

Core Energy, Water Facilities Conducting Business in Ordinary Course

Covanta will continue to conduct business at its core energy and water facilities. The Chapter 11 filing will have no effect on their operation, and the Company intends to continue operating those facilities according to the same high standards as always.

“Continued performance to our loyal customers, client communities, partners and vendors is our paramount focus,” said Mr. Mackin. “We value those relationships and are committed to maintaining the same levels of service and performance that they have come to expect from us. In particular, we are grateful to the many clients who have gone out of their way to voice their support for us as we go through this process.

“We will become predominately a domestic energy and water business allowing us to more efficiently focus our resources on the current operations and the expansion opportunities available to us in the U.S. The Chapter 11 process along with KKR's

Energy Regulatory Commission and similar entities with regulatory oversight, including without limitation the impact of newly adopted FASB 133 relating to accounting for derivatives which is effective beginning January 1, 2001. The impact of FASB 133 will vary between accounting periods based on changes in pricing of various items bought and sold by the Company.

- Cost and other effects of legal and administrative proceedings, settlements, investigations and claims;
- Limitations on Covanta's ability to control the development or operation of projects in which Covanta has less than 100% interest;
- The lack of operating history at development projects provides only a limited basis for management to project the results of future operations.

Additional information about Covanta can be obtained via the Internet at www.covantaenergy.com, or through the Company's automated information system at 866-COVANTA (268-2682).

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Proposed Emission Factors for
Lee County Energy Recovery Facility's
Third Combustor Unit

Pollutant Name	Emission Factor Corrected to 7% Oxygen
Ammonia	50 ppm _{dv}
Arsenic (Ar)	10.74 ug/dscm
Beryllium (Be)	0.16 ug/dscm
Carbon Monoxide (CO)	100 ppm _{dv}
Cadmium (Cd)	20 ug/dscm
Hydrogen Chloride (HCl)	25 ppm _{dv} or 95% Control*
Hydrogen Fluoride (HF)	3.5 ppm _{dv}
Lead (Pb)	200 ug/dscm
Mercury (Hg)	70 ug/dscm or 85% Control*
Municipal Waste Combustor Organics (Total PCDD/PCDF)	13 ng/dscm
Nitrogen Oxides (NO _x)	180 ppm _{dv} 1 st year; 150 ppm _{dv} thereafter
Particulate Matter (PM)	0.009 grains/dscf
Sulfur Dioxide (SO ₂)	29 ppm _{dv} or 80% Control*
Sulfuric Acid Mist (SAM)	16.68 ppm _{dv}
Volatile Organic Compounds (VOC)	30 ppm _{dv}

Note: ppm_{dv} = parts per million by volume (dry basis)
 ug = micrograms
 ng = nanograms
 dscm = dry standard cubic meter
 dscf = dry standard cubic foot

*Whichever is less restrictive

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*Whichever is less restrictive

Because of these two factors – (1) continuing population growth and resulting infrastructure needs and (2) refinancing of existing issues – it has become very important for County government officials and residents to understand their overall debt position and how it changes from year to year.

The **Debt Manual** was first published in July 1991 as a source of detailed information describing each debt issue by type. This information, when combined with proposed debt issues, provides a statement of existing and proposed County obligations. This new document represents the ninth update of the July 1991 **Debt Manual**. The document is titled the **2001 Debt Manual**. Most of the data is based upon the FY 00 Comprehensive Annual Financial Report (CAFR) for the period ending September 30, 2000. In addition, any debt-related activity between September 30, 2000 and November 6, 2001 is included. During that period, the Transportation Facilities Refunding Revenue Bonds, Series 1991 and the Solid Waste System Revenue Bonds Series 1991A and 1991B were refunded.

FORTHCOMING DEBT ACTIVITY

The County intends to begin participation in the State's Revolving Fund (SRF) Program for Water and Wastewater Projects through the Florida Department of Environmental Protection. This program makes funds available for eligible water and wastewater projects. The County has received approval for \$4.6 million in planning/design/engineering funds that would be used to develop Facilities Plans for Wastewater and Water Projects as a basis to apply for \$39 million in wastewater projects and \$54.3 million in water projects. The interest rate for the pre-construction loan was 3.08% payable over a 20 year period. The top priority project is a new North Lee County Water Treatment Plant.

This program represents an alternative to traditional bond issues and is expected to save over \$800,000 in issuance costs and over \$10 million in debt service due to the lower interest rates available through the SRF program.

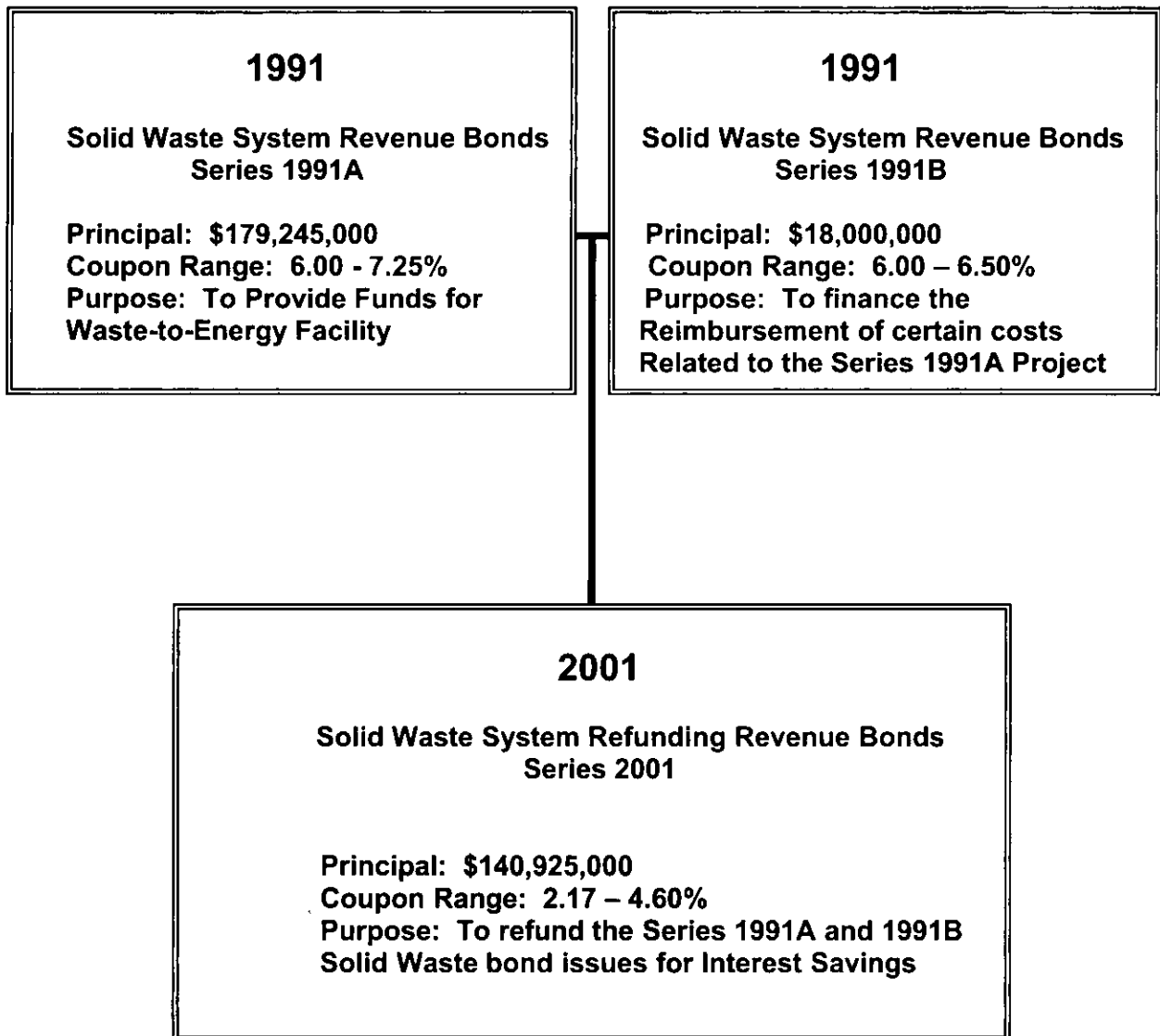
Future debt financing is anticipated for construction of a third combustion unit at the County's Waste to Energy Facility in 2002. The project is expected to cost \$79 million. However, contributions from the Solid Waste System and the release of debt service reserve funds should reduce the borrowing to less than \$37 million.

Alternatives for financing a replacement for the Sanibel Causeway continue to be evaluated. Debt financing is included as part of several options.

Refunding of the Transportation Facilities System Revenue Bonds, Series 1995 (Midpoint Bridge) has been attempted several times (most recently in April, 2001) but market conditions have not been satisfactory. That refunding remains a possibility depending upon changes in the markets.

Additional debt issues can be difficult to determine because of the changing character in the project scope of selected needs. The **Proposed Debt** listed on Page 115 represents the latest available information to be published in **Lee County's Capital Improvement Program (CIP) – FY 2002 to FY 2006**. As the actual structuring of debt issues unfolds, these projects may be combined together with complex financing arrangements.

The Solid Waste Issues



An additional bond issue is expected to be financed in 2002 for construction of a third combustion unit.



Jeb Bush
Governor

Department of Environmental Protection

Twin Towers Office Building
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

David B. Struhs
Secretary

March 21, 2002

CERTIFIED MAIL - RETURN RECEIPT REQUESTED

Mr. Lindsey Sampson, P. E., Director
Lee County Solid Waste Management
10550 Buckingham
Fort Myers, Florida 33905

Re: Lee County Energy Recovery Facility – Unit 3
Statistical Analysis of Units 1 and 2 Emissions

Dear Mr. Sampson:

We received a letter dated March 13 from RTP Associates with a report by Predictive Sciences International. The letter and report relate to statistical analyses conducted on emissions data from Units 1 and 2 and possible emission limits for Unit 3.

We agree that we discussed the need for review of existing information during our recent meeting. We mentioned that we would perform an analysis ourselves and include data from all units in Florida with particular emphasis on those operated by Ogden Martin. This would have the benefit of including more data from facilities employing the Ogden Martin design. The report we received is based only on the performance of the existing Lee County units. We still plan to obtain and review at least data from Lake, Pasco, and Hillsborough Counties in making a BACT determination.

While we did mention “6 sigmas”, it was in the context of giving an example of an approach and not a directive to use six standard deviations to provide a margin of safety. While certain power plant manufacturers strive to achieve a “6-sigma” level of reliability on components subject to failure, it does not mean that this is the basis for setting emissions limitations in permits. We did not intend for Lee County to dogmatically follow this approach. A little follow-up prior to initiation of such a detailed effort would have provided the opportunity for clarification.

One of the flaws in such an approach when applied to the present project is that it presumes that distributions of emissions data are somehow fixed (like e.g. the weather). To the contrary, there are variables that are controllable by operating personnel that affect emissions data distribution. Those variables would undoubtedly be adjusted if emissions approach regulatory limits. There are other variables related to design prior to construction and to maintenance that can affect these distributions.

“More Protection, Less Process”


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We do not agree that (roughly speaking) the average of past actual emissions plus six standard deviations can dictate a "case-by-case top/down" Best Available Control Technology (BACT) determination. Cedar Bay CoGen made a similar argument in pursuit of a permit modification. The BACT issued in December 1999 explicitly rejected their similar claim in setting an SO₂ limitation.

We appreciate that the County proposes some reductions in a few of the parameters to values less than those given in the New Source Performance Standards (40 CFR 60, Subpart Eb). We intend to perform our own review when we receive the application and will propose aggressive limits commensurate with a case-by-case BACT determination.

We look forward to receiving the application. If you have any questions regarding this matter, please call Mike Halpin at 850/921-9519.

Sincerely,


for A. A. Linero, P.E. Administrator
New Source Review Section

Cc: Gregg Worley, EPA
John Bunyak, NPS
Ron Blackburn, DEP SD
Buck Oven, DEP PPSO
Don Elias, RTP Associates
David Dee, Esq.
Samuel Rosania, Malcolm Pirmie
Brian Bahor, Ogden Martin

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:

Mr. Lindsey Sampson
 Professional Engineer & Director
 Lee County Solid Waste Management
 10550 Buckingham
 Ft. Myers, FL 33905

COMPLETE THIS SECTION ON DELIVERY

A. Received by (Please Print Clearly) *DANA LONG* B. Date of Delivery *7-25-02*

C. Signature *Dana Long* Agent Addressee

D. Is delivery address different from item 1? Yes No
 If YES, enter delivery address below:

3. Service Type
 Certified Mail Express Mail
 Registered Return Receipt for Merchandise
 Insured Mail C.O.D.

4. Restricted Delivery? (Extra Fee) Yes

2. A 7001 0320 0001 3692 9144

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U S P S

Postage	\$	Postmark Here
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Restricted Delivery Fee (Endorsement Required)		
Total Postage & Fees	\$	

Sent To Lindsey Sampson
 Street, Apt. No.,
 or PO Box 10550 Buckingham
 City, State, ZIP+4
Ft. Myers, FL 33905

PS Form 3800, January 2001 See Reverse for Instructions

7001 0320 0001 3692 9144



RTP ENVIRONMENTAL ASSOCIATES INC.[®]

AIR · WATER · SOLID WASTE CONSULTANTS

239 U.S. Highway 22 East
Green Brook, New Jersey 08812-1909
(www.rtpenv.com)

(732) 968-9600
Fax: (732) 968-9603

March 13, 2002

Mr. Al Linero
Florida Department of Environmental Protection
Bureau of Air Regulation
111 South Magnolia, Suite #4
Tallahassee, FL 32301

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MAR 14 2002

BUREAU OF AIR REGULATION

Re: Lee County Energy Recovery Facility – Unit 3

Dear Mr. Linero:

As requested by the Department and discussed at our meeting on December 13, 2001 (see attached), the Lee County project team has carefully reviewed the available emissions data from the existing two units at Lee County's Energy Recovery Facility. Although we still believe that the NSPS limits are stringent and protective standards, additional analyses have been performed in order to be responsive to FDEP's concerns. These analyses included both stack test data and continuous emissions monitoring data. These data were analyzed to determine appropriate permit limits for the proposed new unit. EPA's research for the New Source Performance Standard (NSPS) was also considered.

Attached are two copies of a report from Predictive Sciences, Inc. that details the statistical analyses that were utilized to determine upper predicted limits (UPL). As discussed with the Department, a "Six Sigma" approach was used in an attempt to develop appropriate upper limits. The report represents a rigorous mathematical approach to develop UPL's based on the available data from the facility – 7 years of annual tests plus continuous emission monitoring data. The Six Sigma UPL is a value that represents the limit that would not be exceeded 3.4 times per million events (approximately 125 years of operation). It is based upon statistical reliability theory, and represents the quantitative value such that the probability of compliance during any one hour sampling period exceeds 99.999%. It is worth noting that the final permit limits are deterministic (i.e., they represent never to exceed values), consistent with the Clean Air Act's permit requirements, which are never to exceed values. Therefore, as demonstrated by current facility testing, there is a high probability that the facility will remain in compliance.

After compiling and analyzing the data, the County's consultants and legal representatives worked to define permit limits that were acceptable to the vendor (operator) as well as the County. As can be noted in Table D-1, Page 5 in the report, UPL values less than the NSPS or existing permit limits are predicted for VOCs, fluorides (HF), cadmium (Cd) and lead (Pb). However, lead and cadmium pose particular problems because emissions (and control) of these

pollutants are determined by the waste stream which is variable by nature. Further, the NSPS limits for these pollutants already are set very low. Note that there already is a 50% reduction in the emission limit for cadmium and a greater than 50% reduction in the lead limit from the existing units which are regulated under the Emission Guidelines and the NSPS for the new unit. Therefore, the county and vendor are unable to accept any reduction in the NSPS limits for these two pollutants due to the potential variability in the waste stream and the already low level required by the NSPS.

Based on the statistical study and other factors, Lee County is willing to accept permit limits for the third MWC unit that are lower than the NSPS values (or the existing permit level where no NSPS is specified) for four parameters: VOCs; HF; SO₂; and particulate matter. The attached table identifies the County's proposed emission factors for all pollutants. There are no NSPS limits for fluorides or VOCs because these are regulated as MWC acid gases and MWC organics. However, there are current permit limits for HF and VOCs in the Title V permit for the existing MWC units. The County is proposing an approximate 30% reduction in the limit for HF; an approximate 20% reduction in the VOC level; a 10% reduction in the PM level; and a 3% reduction in the SO₂ limit for the proposed new unit.

Considerable effort and expense was expended by the County, its consultants and the vendor in developing these proposed emission limits. This included a review of the Reference Methods, Accuracy And Precision (REMAP) studies performed by ASME concerning USEPA Methods 5, 23, 26 and 29, as well as a review of data from other Florida facilities. We feel that the proposed levels represent stringent yet achievable standards based on the performance of the existing units, and the extensive database compiled by USEPA in developing the New Source Performance Standards. The database of facility and emission control technologies that were utilized by USEPA to develop the New Source Performance Standards is still current. There has been no advancement in Best Available Control Technology that would allow the vendor and County to propose lower limits.

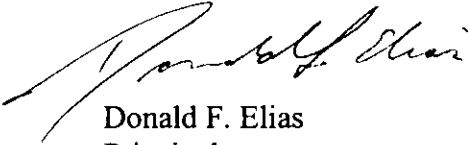
We would like to point out that while the statistical effort was rigorous and extensive, statistics by themselves are not adequate to determine an achievable emission limit. As noted above, professional judgement accrued through experience is necessary to determine whether an emission limit is achievable and is therefore appropriate for being enforceable. Achievable in the federal context of emission standards requires that the limit must be continuously achievable for known or expected variations in a process.

It should also be noted that the limit selected will have little effect on the design or operation of the facility. The facility will be designed to meet BACT requirements and the Maximum Achievable Control Technology requirements. Further, CEM data and test reports document that long term emissions are considerably less than the short term emissions factors that are monitored and regulated by continuous emission systems or short term stack tests.

We appreciate your consideration of these materials. Should you have any questions concerning the report or the proposed limits, please feel free to contact either Lindsey Sampson at 941-338-3302 or myself at the above number.

Sincerely,

RTP ENVIRONMENTAL ASSOCIATES, INC.®



Donald F. Elias
Principal

DFE/lm

Att.

cc: Howard Rhodes B. Bahor
 Mike Halpin J. Treshler
 L. Sampson W. Corbin
 D. Dee M. Hober
 S. Rosania S. Heath
 J. Hahn Project File: MPLC

**Appropriate Permit Limits for Proposed Lee County Energy Recovery Facility
(Unit 3)
December 13, 2001 (Revised)**

At the request of the FDEP, the Lee County project team has reviewed the current plant operational data as well as test data from other facilities. The purpose of this effort is to determine appropriate permit limits for the proposed new unit for the Lee County Energy Recovery Facility. The starting point for the permit limits begins with the 1995 New Source Performance Standards. USEPA based the performance limits in the NSPS on the most recent available data. This included 12 units with spray dry absorbers, fabric filters and selective non-catalytic reduction systems operating in 1994, as well as earlier data. Overall, EPA used performance test data from over 60 municipal waste combustor plants (60 FR 65391, 19 December 1995 and 60 FR 65396, 19 December 1995). As required by Congress, the NSPS "MACT Floor" is set at the level achieved by the best performing plant. Although EPA did not include European test data, it did indicate that the European data would not have changed the limits (59 FR 48254, 20 September 1994, Section VII - *Comparison of the Proposal and European Emission Limits*).

Due to the United States Supreme Court "Carbone" ruling on May 16, 1994, (1994 WL 183594 (U.S.N.Y.)), little development of new MWCs has occurred in the United States after 1994. Hence, the conclusions reached by USEPA at that time should still be valid. There has been some additional experience gained in the operation of facilities equipped with modern pollution control trains, including spray dry absorbers, fabric filters, selective non-catalytic reduction systems and activated carbon injection systems. Enhanced combustion controls have also improved overall municipal waste combustor performance (good combustion practice). The only potential modifications to these designs for a new facility could be the use of a selective catalytic reduction (SCR) system for NO_x control. These systems began being applied to municipal waste combustors in Europe and Asia in the early 90's and were reviewed by USEPA in setting the NSPS. They will be reviewed further, based on current costs, in the BACT review for this project.

Therefore, based on the BACT considerations, this facility will be designed and operated in accordance with the NSPS standards. Regardless of the permit limits, there will be no change in the basic design or operation of the proposed facility, unless SCR is added for NO_x control. The operation of the combustor, as well as the pollution control train, is continuously monitored and strictly regulated. The steam load is tied to the most recent dioxin stack tests demonstrating compliance with the applicable limit. The municipal waste combustor load cannot exceed more than 110% of the rate achieved during the last approved stack test. This effectively limits the load to the combustor. Additionally, the inlet temperature to the bag house is monitored to ensure that condensed metals are collected and dioxins are not formed on the particulate in the bag house. The maximum temperature cannot be more than 17°C (30.6°F) above the temperature measured during the last approved dioxin stack tests. In addition, there are continuous emission monitors for SO₂, at the inlet of the spray dry absorber and at the stack. SO₂ is one of the more

difficult acid gas species to remove and control of SO₂ to the NSPS limits indicates sufficient control of HF and HCl. The combustion related conditions are monitored continuously through CO and NO_x continuous emission monitors, along with the automatic combustion control system, to ensure proper combustion control. There are also opacity and pressure drop monitors that ensure proper performance of the bag house. These instruments are monitored by control room personnel to ensure the proper operation of the facility. There is a monitoring requirement for the carbon feed rate to ensure adequate control for mercury and other volatile metals. The accuracy of the pollution monitors are verified by quarterly performance specification tests. Those regulated pollutants not monitored by continuous emission monitors are typically subject to periodic stack tests. The overall effect of the design, control, and monitoring systems is to ensure that the operation of the plant is subject to continuous agency oversight and hence fully protective of the public and the environment.

As noted above, regardless of the emission limit set in the permits, there will be no difference in the design or operation of the facility, unless SCR is required. Overly stringent permit limits merely increase the risk of spurious "exceedences" of an overly-restrictive standard. (Note: Economic analysis of the inclusion of an SCR DeNO_x system for the proposed unit indicates the project can not be recommended by the County's Solid Waste Division)

It should be noted that the metals emissions are not guaranteed by the vendor and are the responsibility of the County. The County has maintained an aggressive materials separation/recycling program as outlined in the Materials Separation Plan for this project. There is a limited ability to predict what the variability of the waste stream will be over the life of the facility and life of the permit. The permit limits must be set to accommodate the full range of variability that may occur in the waste stream over this time. In order to provide reasonable assurance that a lower limit could be met for the NSPS metals (cadmium, lead, mercury) additional control equipment would be required, likely including a wet ESP. Costs for such additional control would be prohibitive, both on a cost per ton removed and the effect it would have on the tipping fee for the facility.

Due to the limited amount of test data available for the stack test pollutants (21 data points), there is some difficulty in determining what, if any, reductions can be achieved in practice to allow lower permit emission limits than the NSPS. Since the permit limits are deterministic, pass/fail limits that can never be exceeded, it is appropriate that they accommodate the full range of normal operation. Therefore, historical operating data supports the use of the NSPS limits as aggressive, appropriate permit limits.



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BUREAU OF AIR REGULATION

To: Al Linero
Florida Department of
Environmental Protection
Bureau of Air Regulation
111 South Magnolia, Suite #4
Tallahassee, FL 32301

Date: March 13, 2002
Project: MPLC
From: Donald F. Elias

We Are Sending You: Attached Under Separate Cover
Via: 1st Class Mail Federal Express Hand Delivery
 United Parcel Service Other _____

Copies	Date	No.	Description
1	03/13/02		<u>Letter</u> Re: Lee County Energy Recovery Facility – Unit 3
1	12/13/01		Appropriate Permit Limits for Proposed Lee County Energy Recovery Facility (Unit 3)
2			Statistical Determination of Upper Prediction Limits for Constituent Distributions – REPORT From: Predictive Sciences Made For: RTP Environmental Assoc., Inc.

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BUREAU OF AIR REGULATION

**Statistical Determination of Upper Prediction Limits
for Constituent Distributions**

A project study for RTP Environmental Associates, Inc.

Statistical Determination of Upper Prediction Limits for Constituent Distributions

Executive Summary

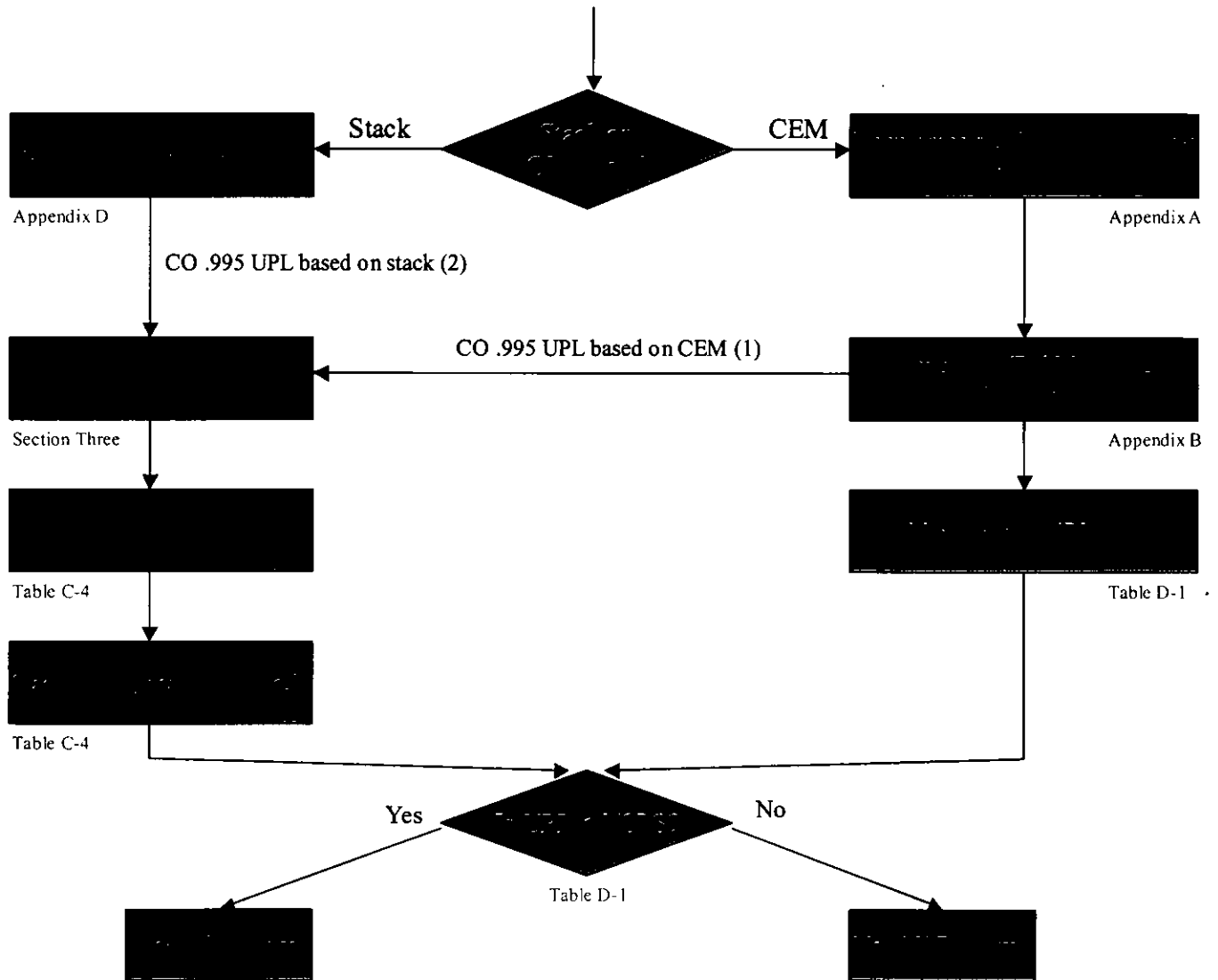
The objective of this project is to statistically derive **Upper Prediction Limits** (UPL's, as discussed in Appendix D) relative to sampling distributions of 12 constituent variables. The data are associated with a Prevention of Significant Deterioration (PSD) permitting process for the Lee County Energy Recovery Facility in the southeastern United States. Knowledge of the applicable UPL's from existing operations is beneficial in the determination of appropriate values for permit levels in future operations.

While the statistical effort was rigorous and extensive, statistics by themselves are not adequate to determine an achievable emission limit. Professional judgment accrued through experience is necessary to determine whether an emission limit is achievable, and is therefore appropriate for being enforceable. Achievable in the federal context of emission standards requires that the limit must be continuously achievable for known or expected variations in a process.

Historical operations data exists in two forms. *Stack* data is measured once per year as 3 repeated measures, and is available across 7 years for all 12 variables. *CEM* data (continuous emission monitoring) is reported as either a 4-hour average (for CO) or a 24-hour average (for SO₂ and NO_x); CEM data is available for 3 variables continuously across 19 months. It is desired to set the UPL such that it represents a 3.4 parts per million level, the *Six Sigma* value. Six Sigma quality and reliability theory has been widely studied and applied throughout industry to provide high reliability tolerancing for a variety of complex systems.

Executive Summary (cont).

This Six Sigma (6σ) Upper Prediction Limit requires careful statistical estimation. An overview of the modeling and analysis strategy follows as Flowchart A. Each major segment of the analysis sequence is detailed in its referenced appendix. Final Results are shown on Table D-1 following Flowchart A, and are presented in detail in Appendix D. The Six Sigma UPL is a quantitative level such that, for any hour of operation, the probability that the facility emissions are above the UPL is 3.4 in a million. The Six Sigma UPL is an estimated numerical value based on an analysis of site data. The UPL is not a known value that emanates directly from actual facility operations. Compliance test results and compliance reports should be researched for actual operating data at the facility and for a comparison with facility permit limits.



FLOWCHART A: Analysis and Modeling Strategy

STACK				
Constituent	units	Six Sigma UPL	NSPS limit	Appl Lim
VOC/NMHC (1)	ppmdv@7%O ₂	30.43	37.00	Six Sigma UPL
HF (1)	ppmdv@7%O ₂	1.053	5.000	Six Sigma UPL
Be(1)	mcg/dscm@7%O ₂	0.0007873	0.0001590	NSPS limit
Cd	mg/dscm@7%O ₂	0.01249	0.02000	Six Sigma UPL
Pb	mcg/dscm@7%O ₂	0.1135	0.2000	Six Sigma UPL
PM	gr/dscf@7%O ₂	0.01802	0.01000	NSPS limit
Hg	mcg/dscm@7%O ₂	289.4	70.00	NSPS limit
HCl	ppmdv@7%O ₂	190.5	25.00	NSPS limit
Total PCDD/F	ng/dscm@7%O ₂	177.7	13.00	NSPS limit
Constituent	units	Six Sigma UPL	NSPS limit	Appl Lim
NOx	ppmdv@7%O ₂	262.4	150.0	NSPS limit
SO ₂	ppmdv@7%O ₂	31.68	29.00	NSPS limit
CO	ppmdv@7%O ₂	150.8	100.0	NSPS limit

(1) VOC, HF, Be: No NSPS standard, PSD limit from existing Units 1 & 2
 Permit limit for NH₃ not addressed as no operational history for 150 ppmdv NO_x limit
 Note: The emission limits presented above do not include the removal efficiency standard provided by 40 CFR Part 60, subpart Eb or the time-weighted averages for pollutants requiring continuous monitoring. The removal efficiency is 85% for Hg, 80% for SO₂, and 95% for HCl.

TABLE D-1: Six Sigma UPL v. NSPS Limits.

Section One: Overview

As discussed in the Executive Summary, the project objective is determination of Upper Prediction Limits (UPL's) on 12 variables. All 12 variables have stack test data across 7 years (3 repeated measurements per year), while 3 of the 12 variables additionally have CEM (continuous emission monitoring) data comprised of 4-hour or 24-hour averages reported continuously across a 19-month period.

The CEM data (representing CO, SO₂, and NO_x) support statistical estimation of the Six Sigma UPL through a two-stage nonlinear modeling process (Appendices B and C). In contrast, the statistical *sparsity* of the stack data precludes direct parametric estimation of the Six Sigma UPL. Subsequently, acceleration factors are estimated through parametric modeling of the upper tail probability density function (Section Three). These models permit the observable stack parameters to be mapped into predicted CEM parameters, which in turn support estimation of the Six Sigma UPL's for the stack variables.

Section Two: CEM Exploratory Data Analysis and UPL Calculation

The following pages describe observed histograms of the 3 CEM variables (Graph A-1), along with many important distributional indices. The SO₂ and NO_x constituents are based upon 24-hour averaging, which results in distributions with pronounced central tendencies. The SO₂ and NO_x skewness statistics (-0.0158 and -0.393 respectively) are both relatively close to zero, indicating that the distributions are symmetric (skewness is defined as the third moment about the mean). The kurtosis statistics however strongly suggest that these 2 distributions are *composite* distributions that likely emanate from an unknown set of *multimodal* processes: This assumption is consistent with our knowledge of RRF operations, in which feed stock, environmental, facility, and numerous other perturbing factors affect daily operations.

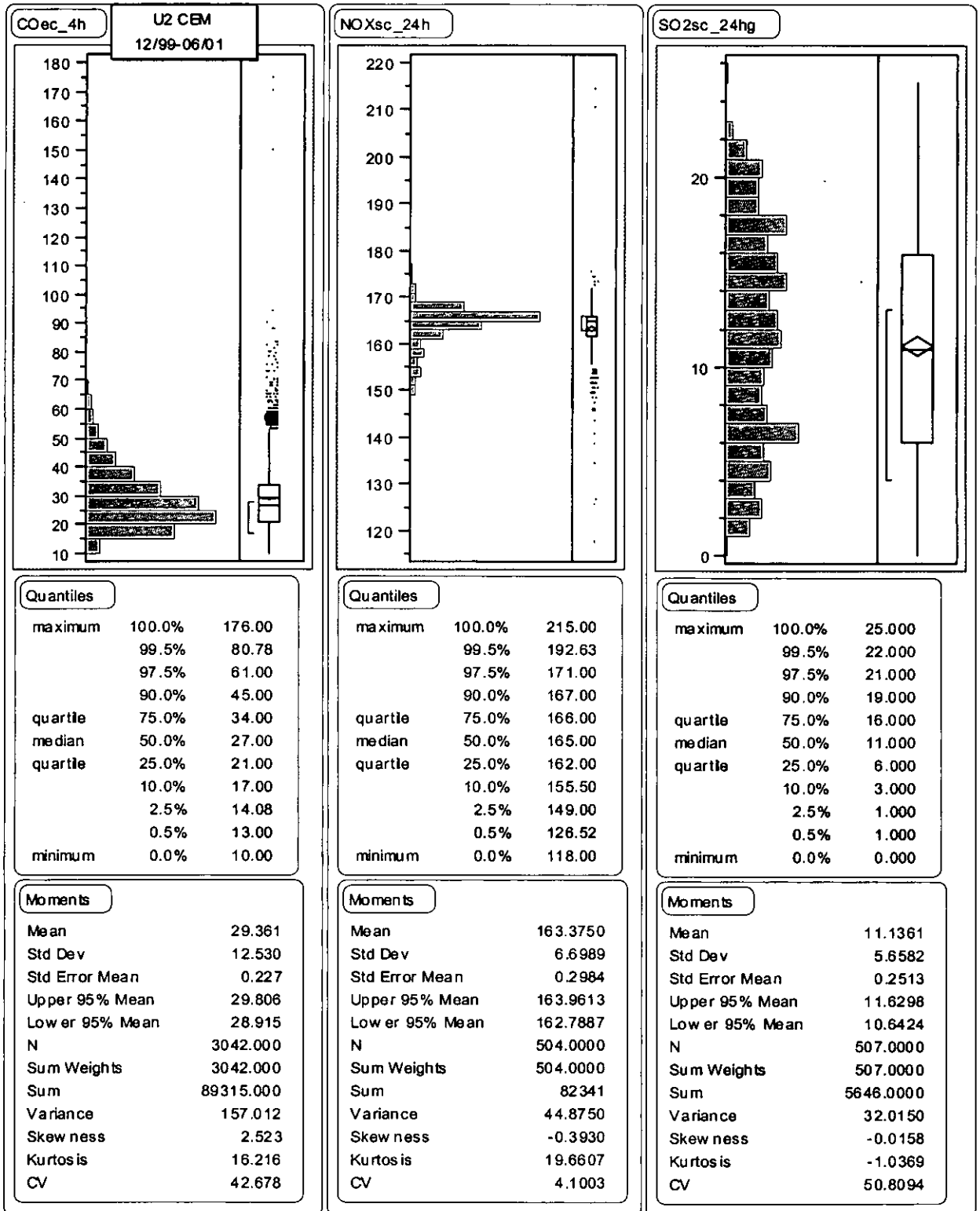
Graph A-1 displays several Exploratory Data Analysis tools, which we will describe briefly.

“Histogram: Each bar shows the frequency of occurrence of the value or range of values represented on the axis. If the variable is continuous, the axis is broken into intervals. If the variable is nominal, each discrete value is represented by a bar. The Y-axis represents the variable value (for CEM data, it is ppm_{dv}@7%O₂), and the x-axis represents relative frequency.

The Box and Whiskers Plot is a schematic that lets you see the sample. The ends of the box are the 25th and 75th quantiles, also called the quartiles. The difference between the quartiles is the interquartile range. The line across the middle identifies the median sample value. The ends of the whiskers are the outer-most data points from their respective quartiles that fall within the distance computed as $1.5 \times (\text{interquartile range})$. The bracket along the edge of the box identifies the shortest half, which is the most dense 50% of the observations. Quantiles are values that divide a distribution into two groups where the Pth quantile is larger than P% of the values. For example, half the data are below and half the data are above or equal to the 50th quantile, also called the median.”

The distribution of the CO constituent is markedly different from the distributions of the other 2 CEM variables. It is noted that CO is recorded as a 4-hour average value (versus a 24-hour average value), and accordingly has a gauging frequency 6 times greater than either SO₂ or NO_x.

The CO constituent distribution is positively skewed; its skewness coefficient of 2.523 is indicative of an asymmetric distribution. The once per year stack test (3 sequential measurements taken in the same day) is roughly equivalent gauging frequency to the CO CEM 4-hour average sampling plan, and accordingly the CO CEM data is used in the determination of the acceleration factors required for stack Six Sigma UPL estimation (Section Three).



GRAPH A-1: CEM Variables Distributional Analysis

Focus will now be directed upon the Six Sigma UPL calculation for the 3 CEM variables. Given that the 3 variables all appear to emanate from multimodal distributions (as evidenced by the skewness and kurtosis statistics), it is logical to turn to *nonparametric* approaches; i.e., approaches that do not rely upon distributional assumptions. One such technique is quantile analysis, in which a dataset is rank ordered and quantiles estimated. For example, consider the 90.0% quantile listed for each variable on Graph A-1. This value is such that only 10% of the observed values in the sample distribution were greater in value; in other words, it represents the 10% upper tail of the distribution (regardless of the true, unknown distributional form)

Robust estimation of the upper tail areas of each variable's distribution is important. Many things are happening in the parent distribution, but we are only concerned about those phenomenological events that generate the most extreme realizations; these events are represented by the upper tail areas uniquely. Our strategy will be to identify in a nonparametric fashion the upper 10th percentile of each distribution (as shown in Graph B-1). Given that these upper tails are smooth monotonic functions that sufficiently represent the phenomena of interest, it is then proposed that we model these curves using the exponential function to provide extrapolation estimates of the Six Sigma UPL's.

The exponential function is represented as:

$$y_i = \beta_1 e^{\beta_2 x_i}$$

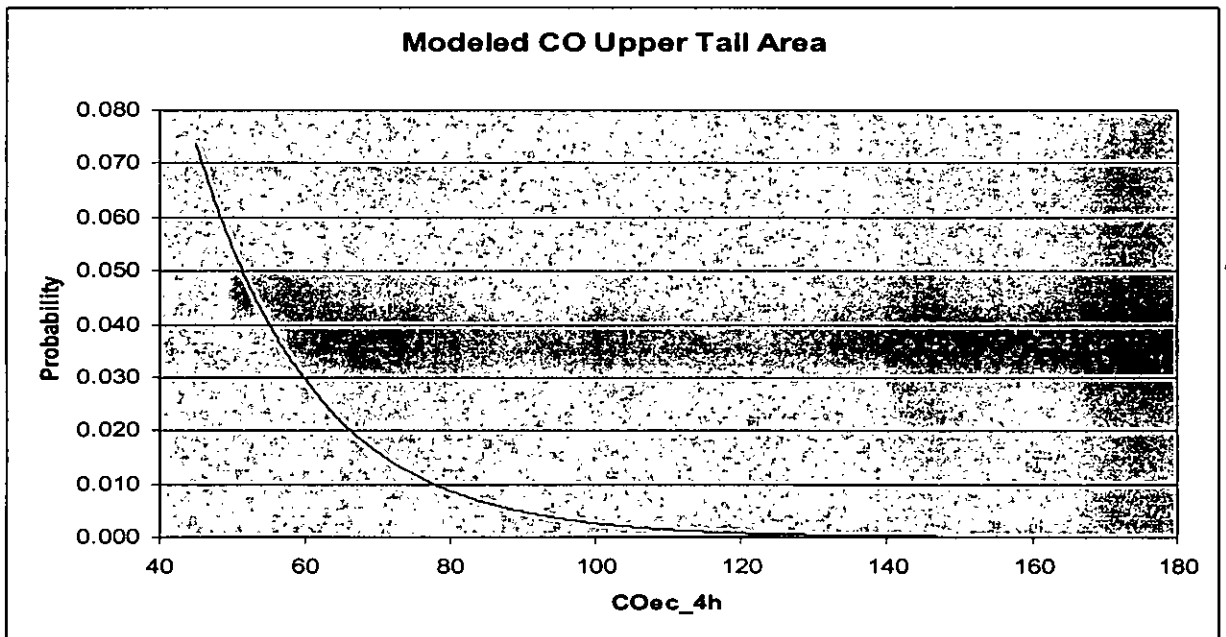
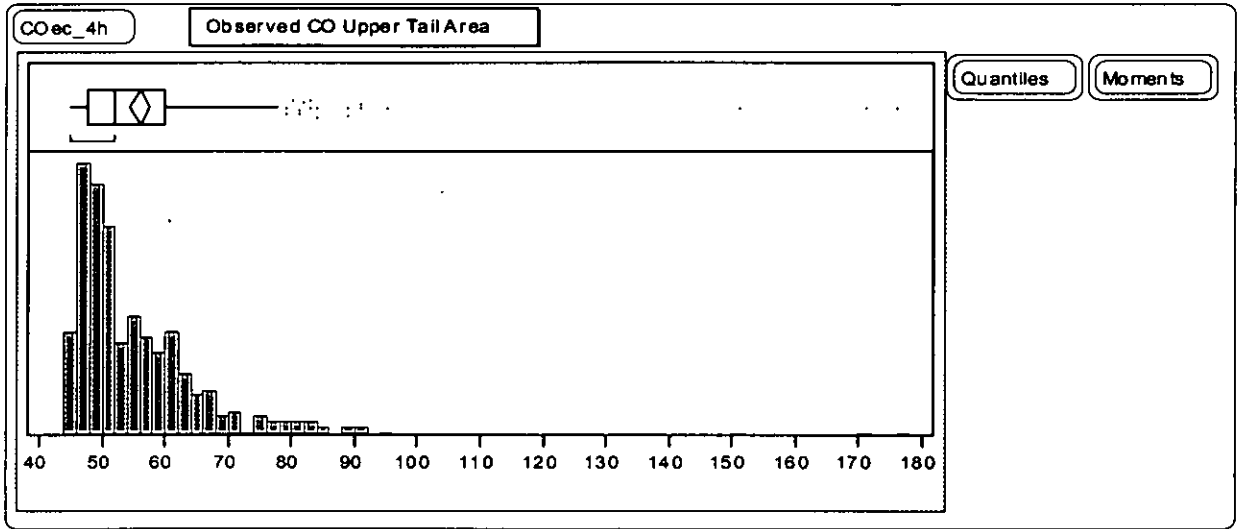
Through different values of β_1 and β_2 , the exponential curve can demonstrate significant flexibility in modeling nonlinear, monotonic, asymptotic functions (as demonstrated in Graph B-2). Exponential decay is a very popular model in engineering and physical sciences, and has been used successfully in many modeling projects. The exponential function is *parsimonious*, meaning that only two parameters require statistical estimation. Parsimony is a highly desirable property in statistical modeling, as it minimizes the potential for in-sample overfit and resulting reduction in out-of-sample predictive capability. Lastly, the exponential distribution is the least restrictive of all statistical distributions; as some distributional

assumptions must be made to generate probability estimates in the extreme tail areas, it seems logical to utilize the least restrictive assumption set as possible.

The exponential function has the additional benefit of being *intrinsically linear*; i.e., that through a transcendental transformation (natural log in this case), the strictly nonlinear exponential function may be linearized to facilitate computational solution, as follows:

$$\ln y_t = \ln(\beta_1 e^{\beta_2 x_t})$$
$$\ln y_t = \ln(\beta_1) + \beta_2 x_t.$$

This transformation permits β_1 and β_2 to be estimated with Ordinary Least Squares (OLS) linear regression. A separate exponential model was fit to the upper tail area of each CEM variable, with full details reported in Appendix B. Once the upper tail models are parameterized (as summarized in Tables B-3, 4, & 5), it is straightforward to estimate the Six Sigma UPL (this would be equivalent to 3.4 ppm = .0000034). This probability point is substituted for y_t in the applicable exponential model, and the corresponding constituent value x_t (the Six Sigma UPL) can be solved for directly (results presented in Table D-1). The following page shows results for CO; see Appendix B for complete results.



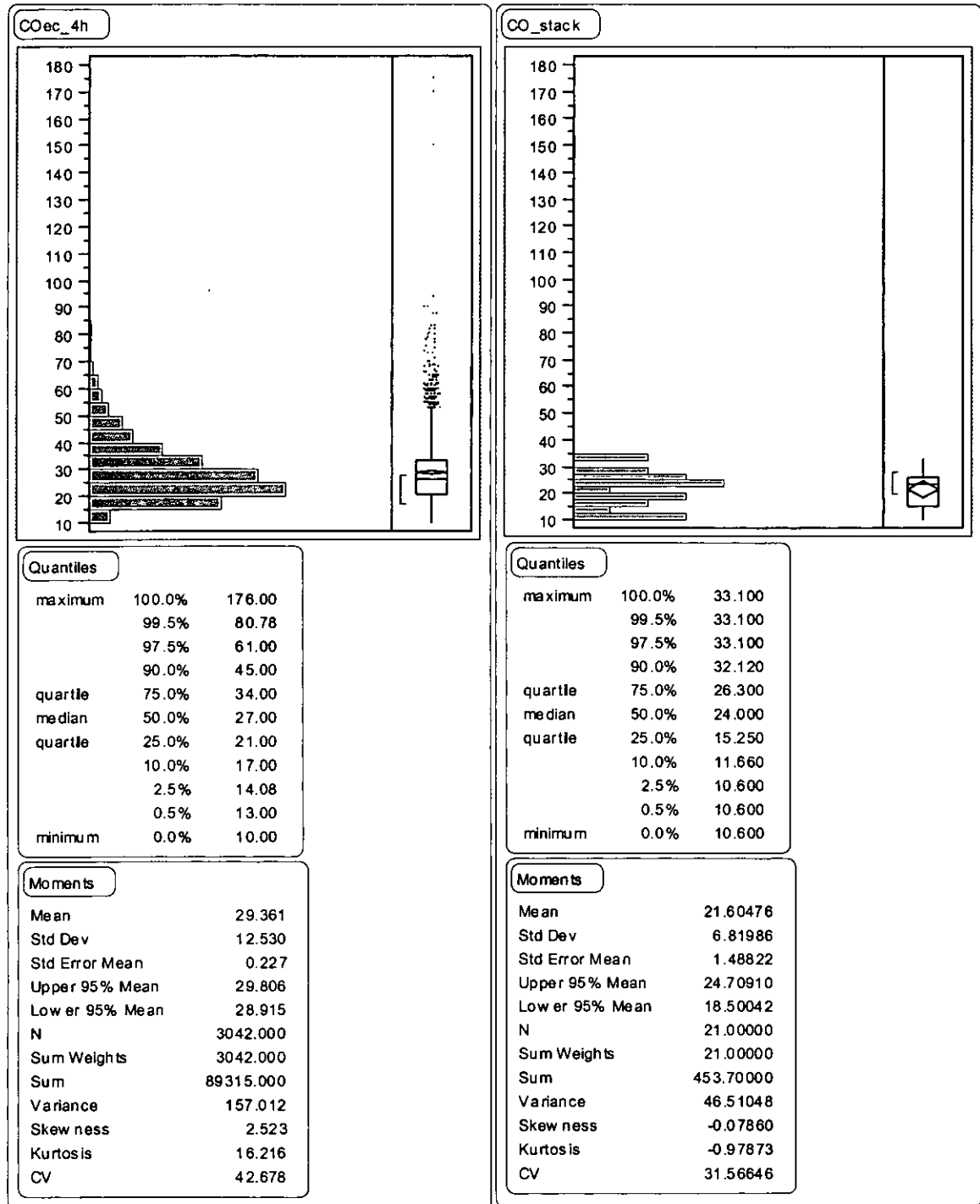
GRAPHS B-6 & B-7: Observed CO Upper Tail Area and Modeled CO Upper Tail Area
Note that the modeled distributions have been normalized such that area under the curve is equal to 0.1000, in accordance with these upper tail areas representing the ten percentile of the parent distribution.

Section Three: Stack Acceleration Factors

In the stack tests, 3 measurements are taken sequentially within the shortest time period possible, and represent the base level *component of variance*. This component encompasses instantaneous gauge repeatability (including gauge bias and linearity effects), as well as the short-term component of process variability. In this project, these two components are statistically confounded and may only be estimated jointly. Decomposition of this confounded component into its base components could be conducted building upon prior research summarized in the recent ASME report “Precision of Manual Stack Measurements” (*Reference Method Accuracy and Precision*, CRTD Vol. 60, American Society of Mechanical Engineers, February 2001). The ASME project quantified instantaneous gauge repeatability of stack metrology utilizing specialized multi-train gauge clusters. Typically, stack measurements are taken with a single train gauge, where confounding of the type we are experiencing is typical.

In this study, the once-per-year stack readings are available for from 4 to 7 years, depending upon the variable. At best, a maximum of 21 readings will be available, compared to over 3000 for the CO Continuous Emission Monitoring (CEM) data. Given that the CO CEM reading is a 4-hour arithmetic average, it would have a gauge frequency roughly similar to the 3 readings per day approach of the yearly stack tests. It is proposed that by comparing the distributional properties between the CO stack test and the CO CEM data, acceleration factors may be estimated that could statistically map stack distributional properties into CEM distributional properties. Upper Prediction Limits (UPL's) consistent with the Six Sigma level could then be estimated for stack constituents in addition to the large CEM data variables.

Consider the observed distributions of CO for the CEM and the stack data, as shown on the next page in Graph C-1:



GRAPH C-1: Observed Distributions of CO: CEM (left) v. Stack (right)

Six Sigma: 3.4 ppm = 3.400E-06

Constituent	units	n	Avg Stack Test D	SD Stack Test E	Accel.Factor F	SD adj G=(ExF)	t-value 0.0000034	Six Sigma UPL (D + (GxH))
VOC/NMHC (1)	ppmdv@7%O2	18	1.764	1.539	2.688	4.138	6.929	30.43
HF (1)	ppmdv@7%O2	18	0.09702	0.05133	2.688	0.1380	6.929	1.053
Be(1)	mcg/dscm@7%O2	15	0.00005713	0.00003506	2.688	0.00009423	7.749	0.0007873
Cd	mcg/dscm@7%O2	12	0.0009106	0.0004663	2.688	0.001254	9.239	0.01249
PM	gr/dscf@7%O2	21	0.001464	0.0009501	2.688	0.002554	6.482	0.01802
Hg	mcg/dscm@7%O2	21	31.70	14.79	2.688	39.76	6.482	289.4
HCl	ppmdv@7%O2	21	21.90	9.679	2.688	26.02	6.482	190.5
Total PCDD/F	ng/dscm@7%O2	21	9.871	9.631	2.688	25.89	6.482	177.7
Pb	mcg/dscm@7%O2	21	0.006277	0.006152	2.688	0.01654	6.482	0.1135

(1) VOC, HF, Be: No NSPS standard, PSD limit from existing Units 1 & 2
 Permit limit for NH3 not addressed as no operational history for 150 ppmdv NOx limit
 Note: The emission limits presented above do not include the removal efficiency standard provided by 40 CFR Part 60, subpart Eb or the time-weighted averages for pollutants requiring continuous monitoring. The removal efficiency is 85% for Hg, 80% for SO2, and 95% for HCl.

TABLE C-4: Stack Constituents and Six Sigma UPL Calculation

Columns C, D, and E are calculated directly from the Stack test data for each constituent.

Column F is the stack acceleration factor calculated in Section Three.

Column G is the product adjusts the sample standard deviation applying the accel factor.

Column H is the t-value associated with the small sample and the Six Sigma (.0000034) probability level.

Column I is the calculated Six Sigma UPL based upon the adjusted standard deviation.

Table D-1 compares the Six Sigma UPL to the NSPS limit.

STACK				
Constituent	units	Six Sigma UPL	NSPS limit	Appl Lim
VOC/NMHC (1)	ppmdv@7%O ₂	30.43	37.00	Six Sigma UPL
HF (1)	ppmdv@7%O ₂	1.053	5.000	Six Sigma UPL
Be(1)	mcg/dscm@7%O ₂	0.0007873	0.0001590	NSPS limit
Cd	mg/dscm@7%O ₂	0.01249	0.02000	Six Sigma UPL
Pb	mcg/dscm@7%O ₂	0.1135	0.2000	Six Sigma UPL
PM	gr/dscf@7%O ₂	0.01802	0.01000	NSPS limit
Hg	mcg/dscm@7%O ₂	289.4	70.00	NSPS limit
HCl	ppmdv@7%O ₂	190.5	25.00	NSPS limit
Total PCDD/F	ng/dscm@7%O ₂	177.7	13.00	NSPS limit
Constituent	units	Six Sigma UPL	NSPS limit	Appl Lim
NOx	ppmdv@7%O ₂	262.4	150.0	NSPS limit
SO ₂	ppmdv@7%O ₂	31.68	29.00	NSPS limit
CO	ppmdv@7%O ₂	150.8	100.0	NSPS limit

(1) VOC, HF, Be: No NSPS standard, PSD limit from existing Units 1 & 2
 Permit limit for NH₃ not addressed as no operational history for 150 ppmdv NO_x limit
 Note: The emission limits presented above do not include the removal efficiency standard provided by 40 CFR Part 60, subpart Eb or the time-weighted averages for pollutants requiring continuous monitoring. The removal efficiency is 85% for Hg, 80% for SO₂, and 95% for HCl.

TABLE D-1: Six Sigma UPL v. NSPS Limits.

Section Four: Summary

A scientific method for determining Upper Prediction Limits has been presented based on available data from the operation of the existing facility. The resulting UPL's have been generated in a statistically sound fashion and represent potential limits for future operations.

The Six Sigma UPL is an estimated numerical value based on an analysis of site data. The UPL is not a known value that emanates directly from actual facility operations. Compliance test results and compliance reports should be researched for actual operating data at the facility and for a comparison with facility permit limits.

Appendix A:

Nonparametric Quantile Analysis and Exploratory Data Analysis of CEM variables

GRAPH A-1: CEM Distributional Analysis

GRAPH A-2: CO_{ec_4h} CEM Distributional Analysis

GRAPH A-3: CO_{ec_4h} Chronological Time Series Plot

GRAPH A-4: Graphical Representation of CO Autocorrelation

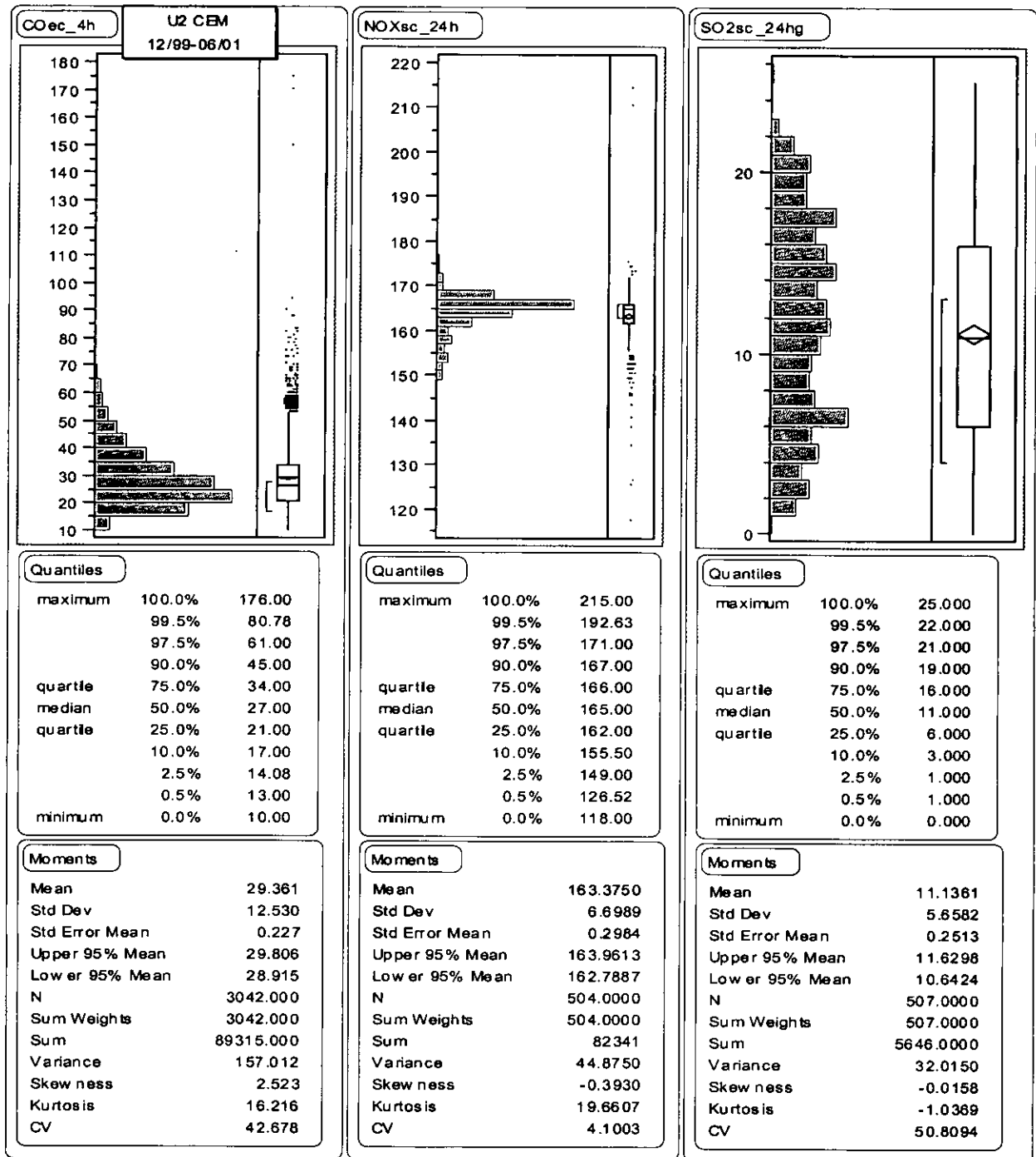
TABLE A-5: Regression Representation of CO Lag 1 Autocorrelation

GRAPH A-6: NO_{xsc_24h} CEM Distributional Analysis

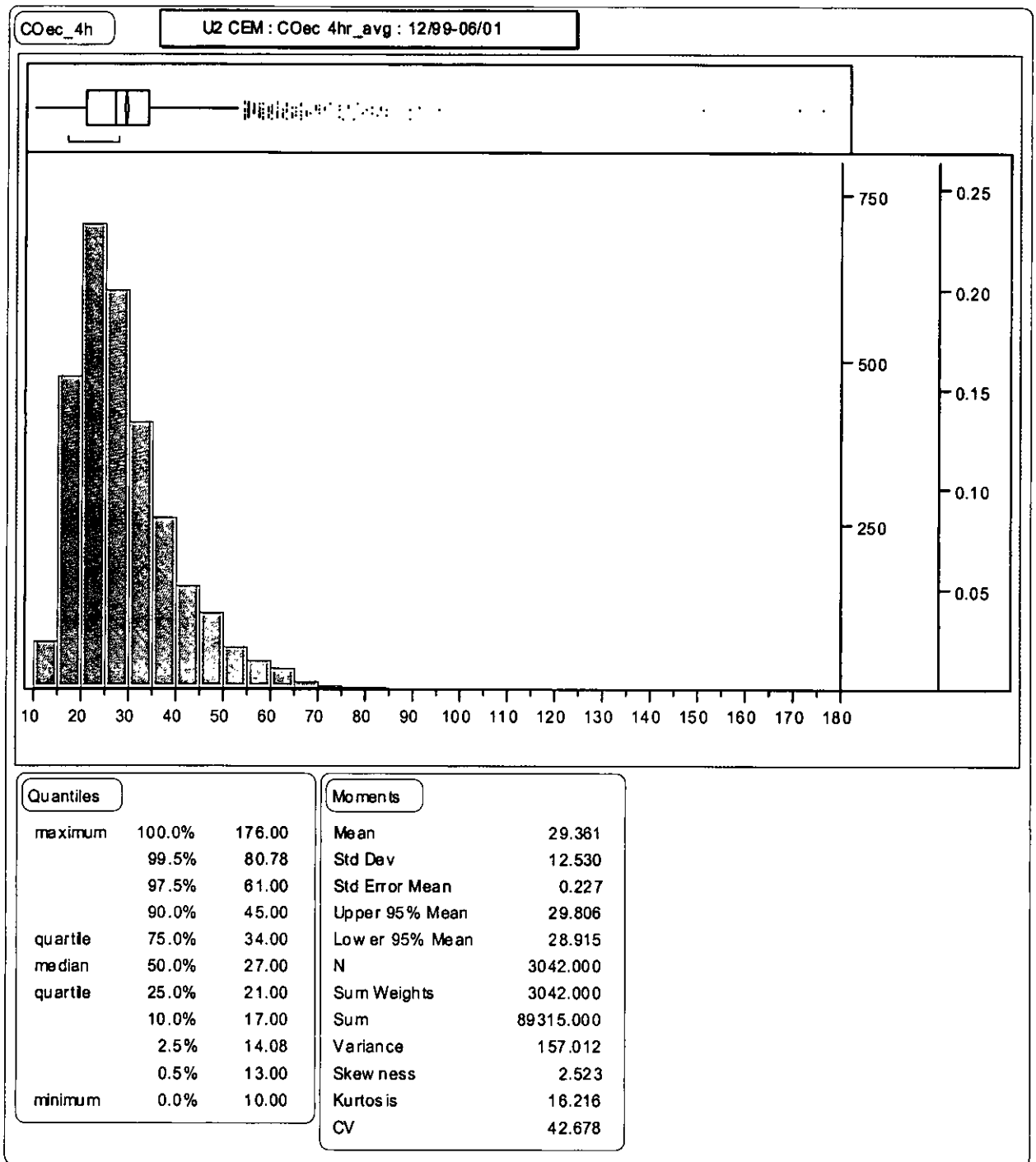
GRAPH A-7: NO_{xsc_24h} Chronological Time Series Plot

GRAPH A-8: SO_{2sc_24h} CEM Distributional Analysis

GRAPH A-9: SO_{2sc_24h} Chronological Time Series Plot

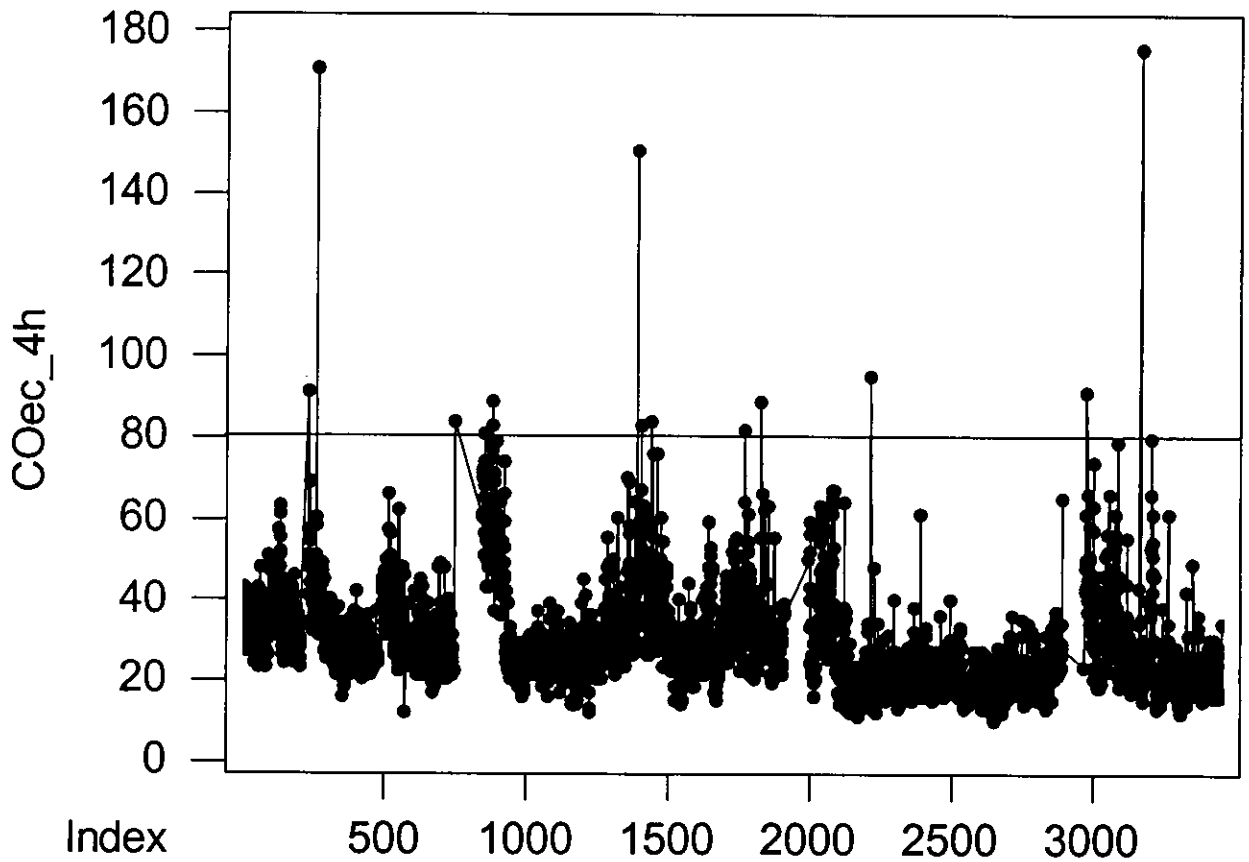


GRAPH A-1: CEM Distributional Analysis



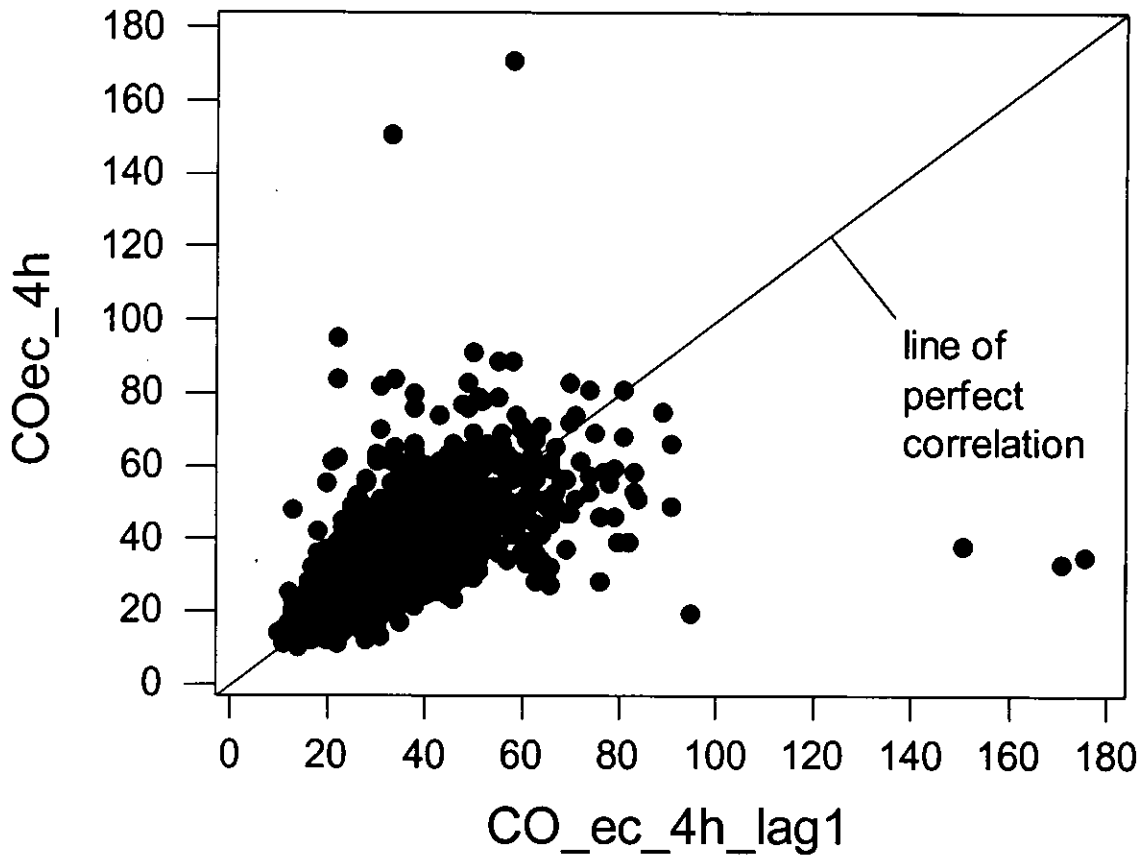
GRAPH A-2: COec_4h CEM Distributional Analysis

CEM Unit 2: COec 4hr avg : 12/99-06/01



Times series plot of Unit 2 COec data 4-hr averages 12/99-06/01 (chronologically). The large sample 99.5% Upper Prediction Limit is plotted. Notice how the series is relatively stationary and consistent.

GRAPH A-3: COec_4h Chronological Time Series Plot .



GRAPH A-4: Graphical Representation of CO Autocorrelation

Regression Analysis

The regression equation is
 $CO_{ec_4h} = 9.06 + 0.691 CO_{ec_4h_lag1}$

3014 cases used 449 cases contain missing values

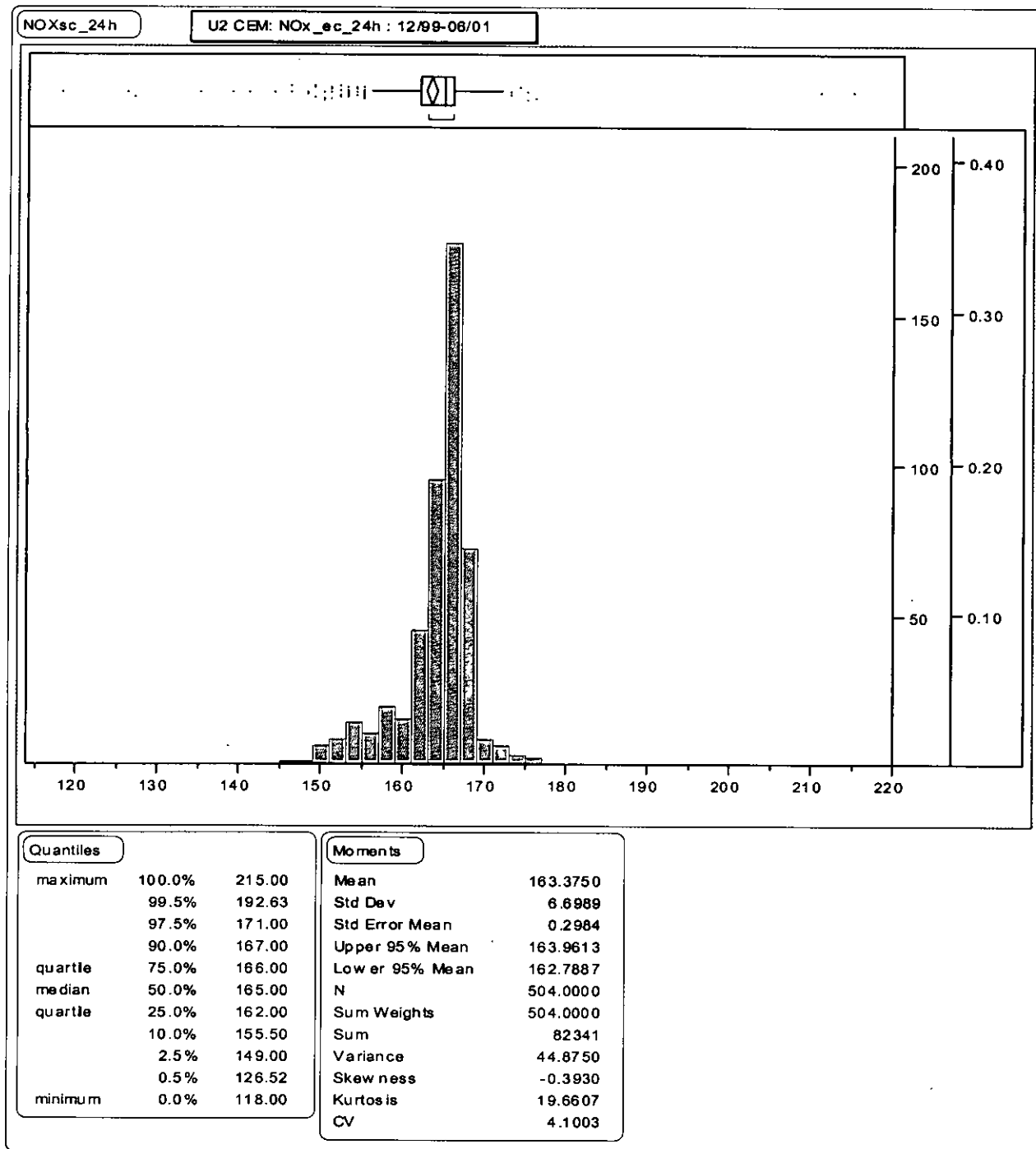
Predictor	Coef	StDev	T	P
Constant	9.0628	0.4028	22.50	0.000
CO_ec_4h_lag1	0.69080	0.01267	54.54	0.000

S = 8.647 R-Sq = 49.7% R-Sq(adj) = 49.7%

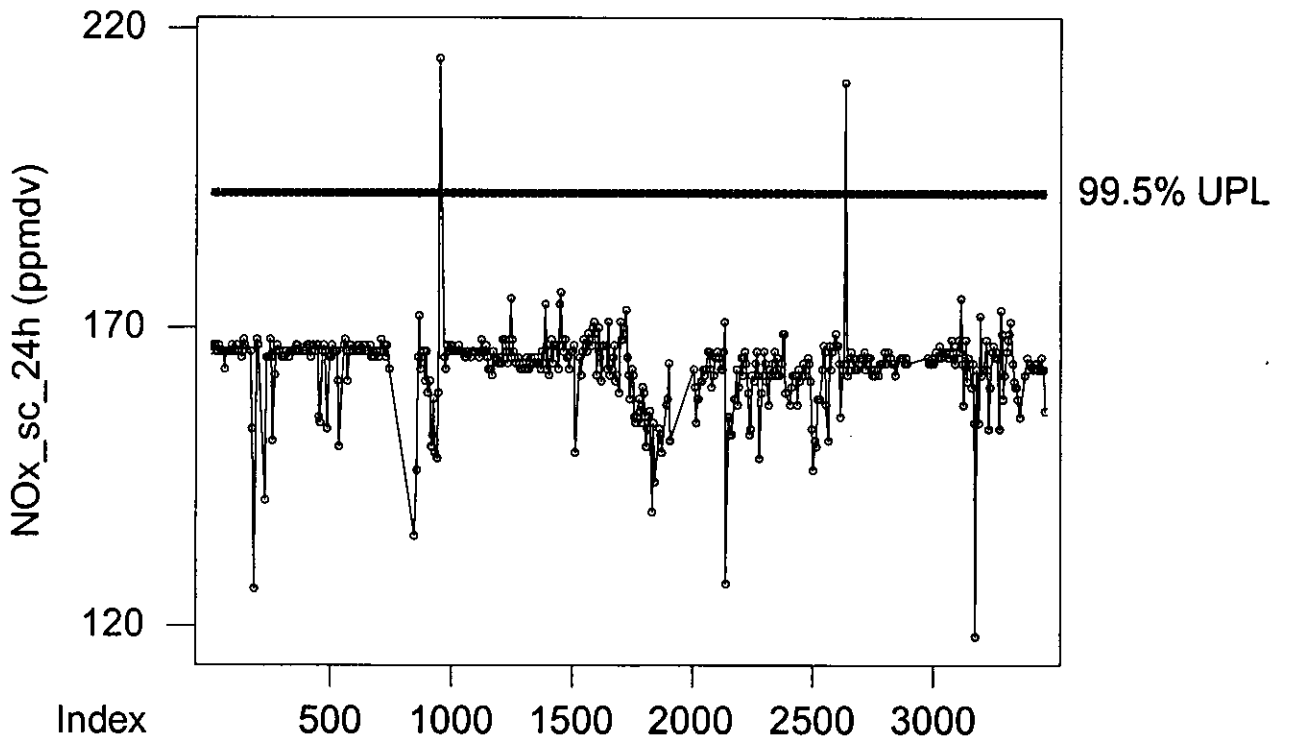
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	222429	222429	2974.67	0.000
Residual Error	3012	225220	75		
Total	3013	447649			

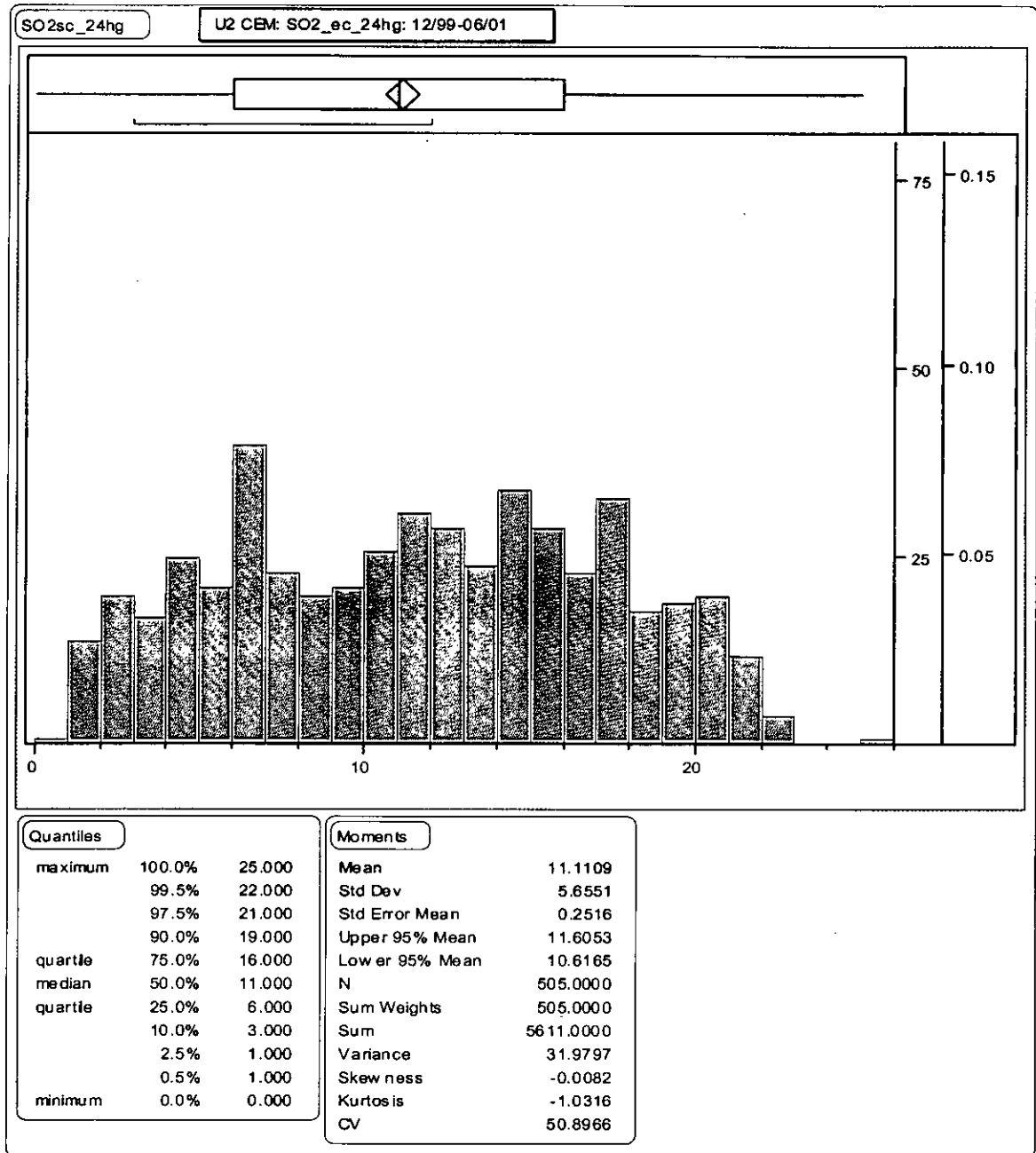
TABLE A-5: Regression Representation of CO Lag 1 Autocorrelation



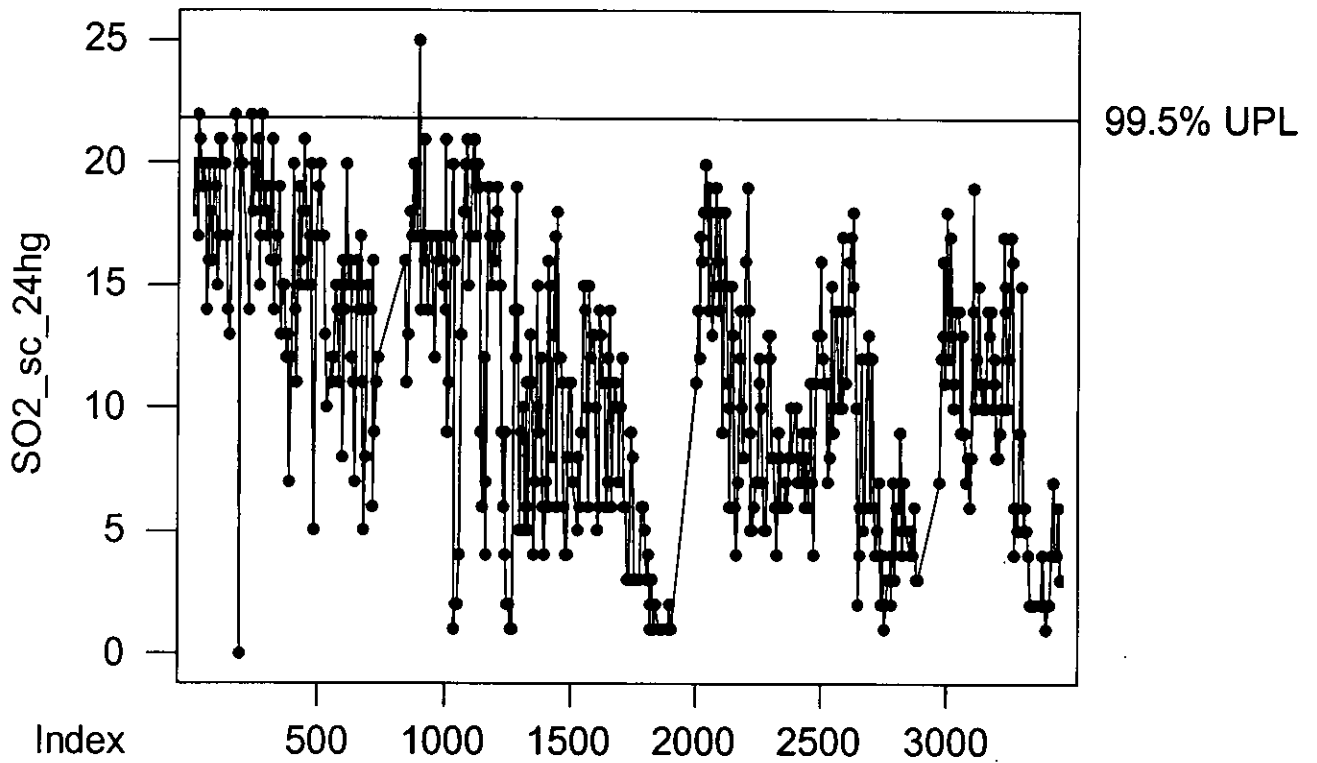
GRAPH A-6: NO_xsc_24h CEM Distributional Analysis



GRAPH A-7: NO_xsc_24h Chronological Time Series Plot



GRAPH A-8: SO₂sc_24h CEM Distributional Analysis



GRAPH A-9: SO₂sc_24h Chronological Time Series Plot

Appendix B:

CEM Upper Tail Exponential Modeling

GRAPH B-1: CEM Upper Tails

GRAPH B-2: Representations of Various Exponential Function Forms

TABLE B-3: CO Upper Tail Modeling Regression Output

TABLE B-4: NO_x Upper Tail Modeling Regression Output

TABLE B-5: SO₂ Upper Tail Modeling Regression Output

GRAPH B-6: Observed CO Upper Tail Area

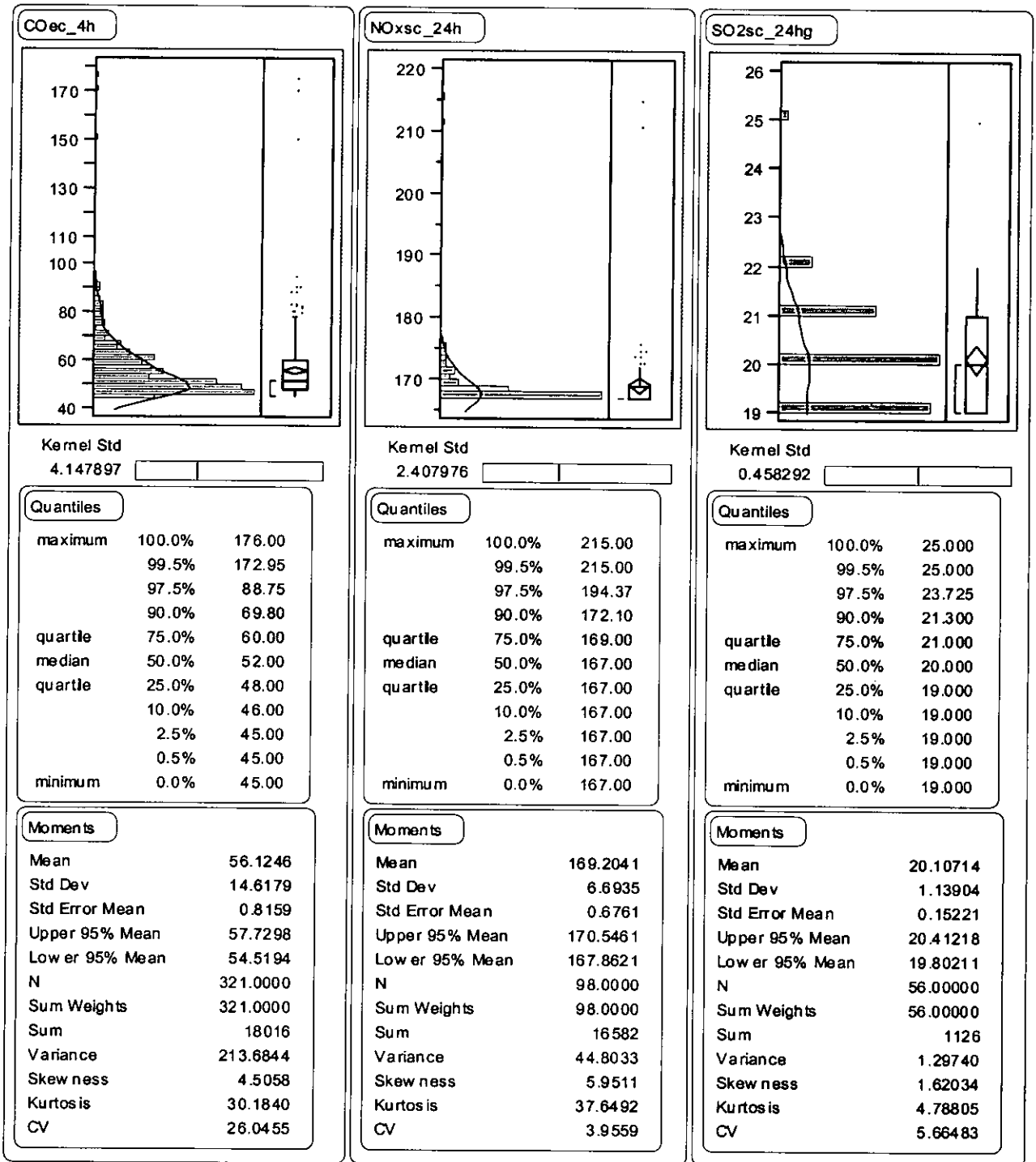
GRAPH B-7: Modeled CO Upper Tail Area

GRAPH B-8: Observed NO_x Upper Tail Area

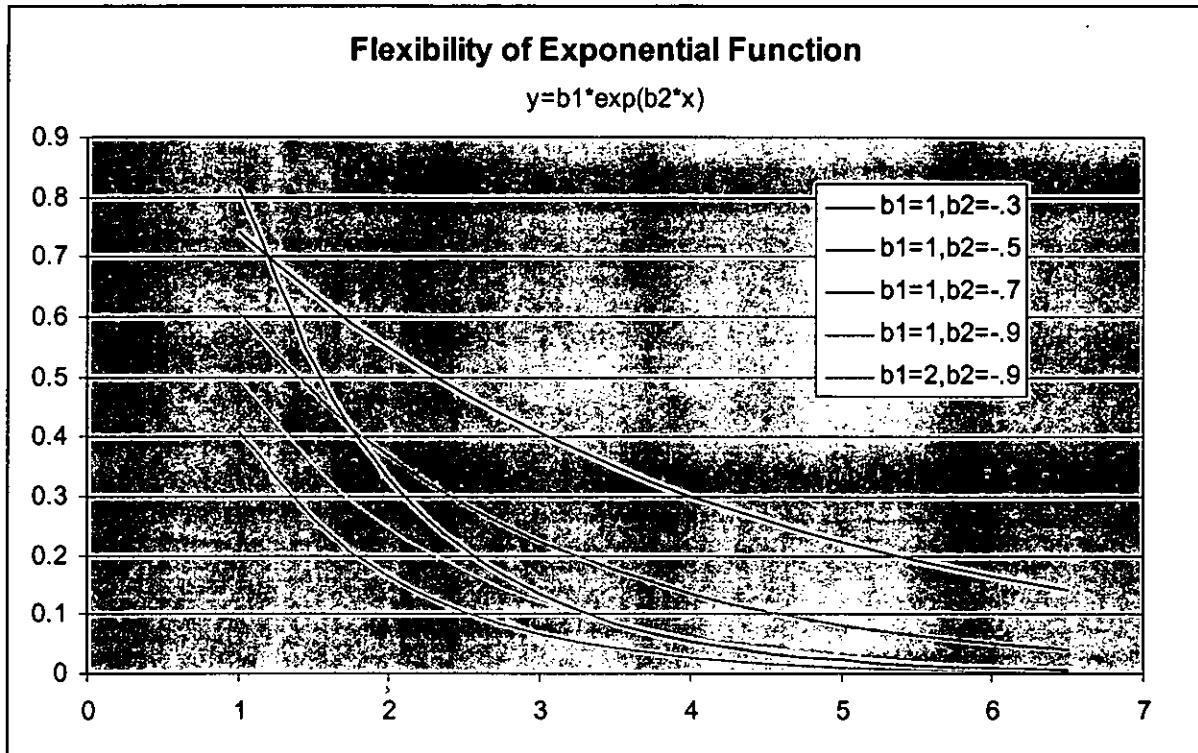
GRAPH B-9: Modeled NO_x Upper Tail Area

GRAPH B-10: Observed SO₂ Upper Tail Area

GRAPH B-11: Modeled SO₂ Upper Tail Area



GRAPH B-1: CEM Upper Tails



GRAPH B-2: Representations of Various Exponential Function Forms ($b_1, b_2 = \beta_1, \beta_2$ of Section Two).

This graph helps explain how CEM Upper Prediction Limits (UPL's) will be calculated. First nonparametric methods will be used to determine the top 10th percentile of values. This upper tail is a smooth, monotonic (constantly decreasing), asymptotic (approaches zero at infinity) function. This class of functions can be readily modeled using the exponential function; Graph B-2 shows how the shape of the exponential function varies with changes in the values of its two parameters (b_1 and b_2). The x-axis is the value of the constituent variable (ppmdv, etc.); the y-axis is the probability of sampling a value that large from the parent distribution given the specific model parameterization. We will calculate the b_1 and b_2 coefficients that maximize the fit of the exponential function to the observed upper tail area; then we make predictions based upon the exponential equation about what value of the constituent variable corresponds to the 1hr/yr UPL.

SUMMARY OUTPUT - SO2 Upper Tail Modeling

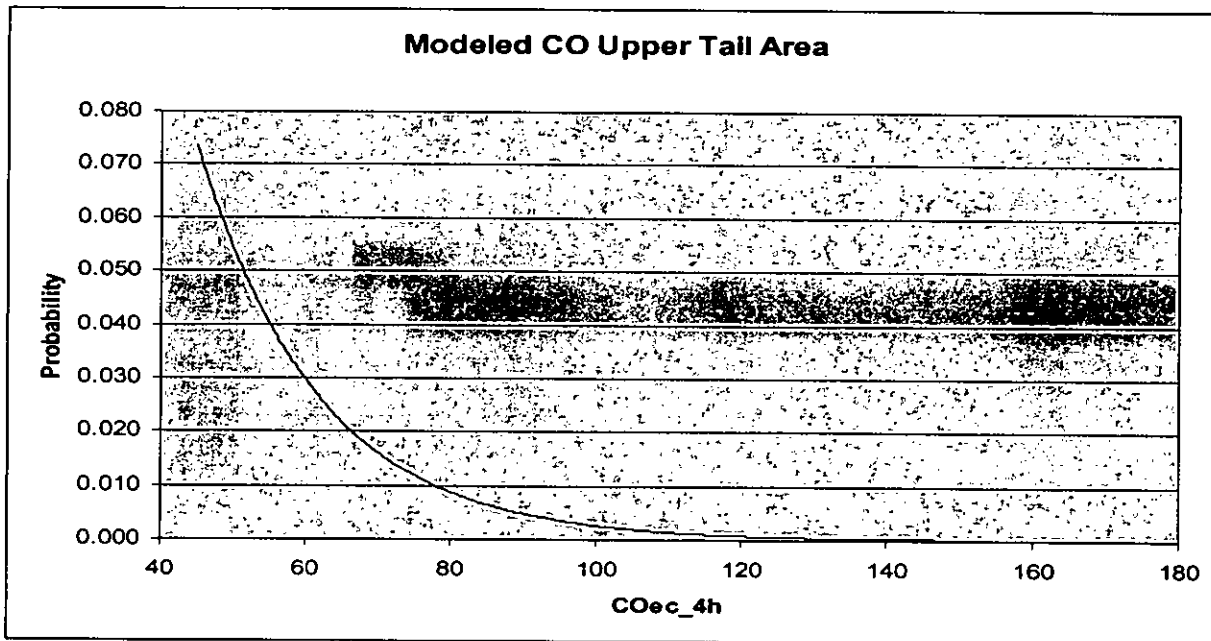
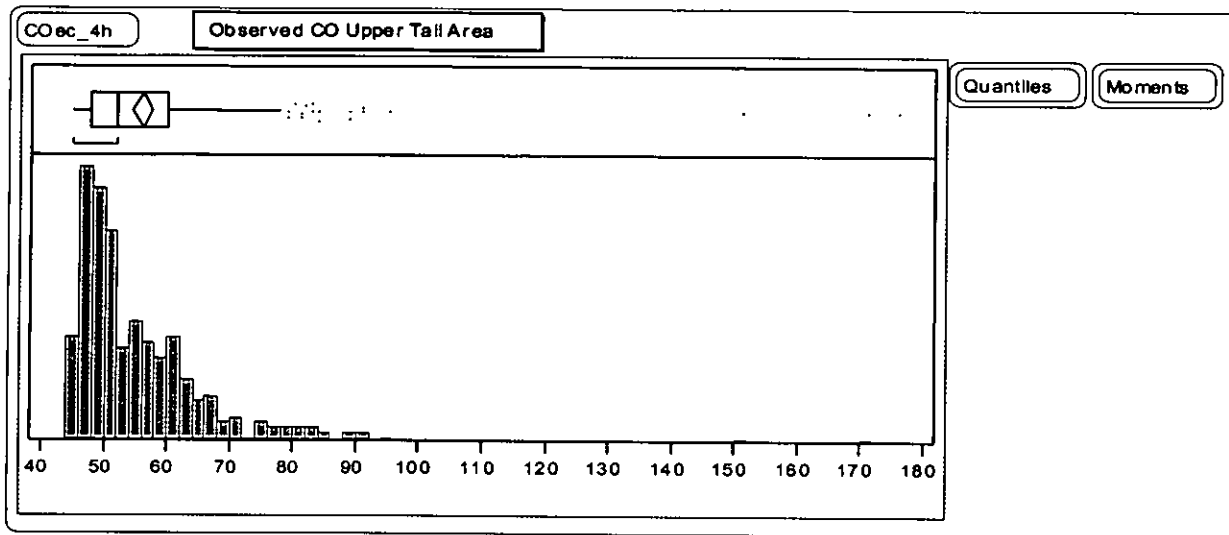
<i>Regression Statistics</i>	
Multiple R	0.939627555
R Square	0.882899942
Adjusted R Square	0.880690507
Standard Error	0.276336661
Observations	55

ANOVA

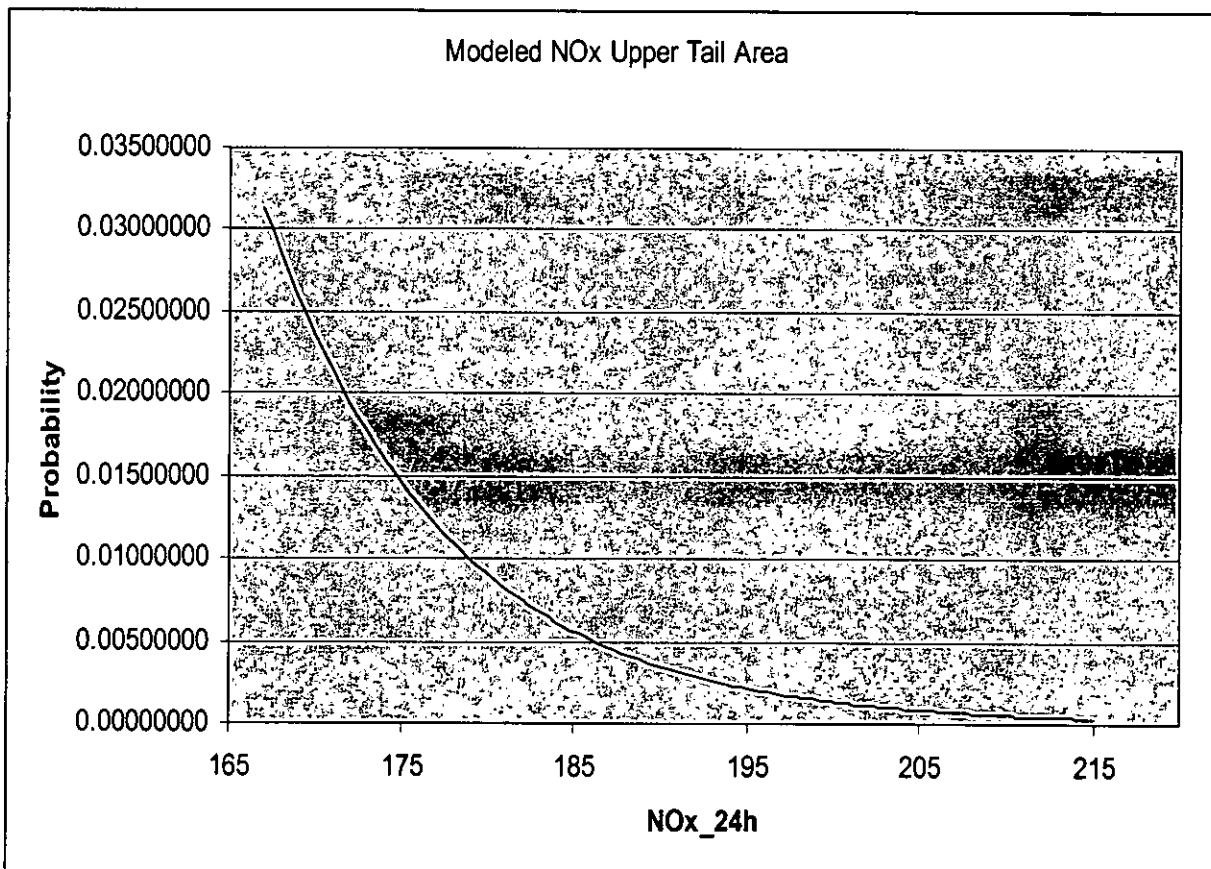
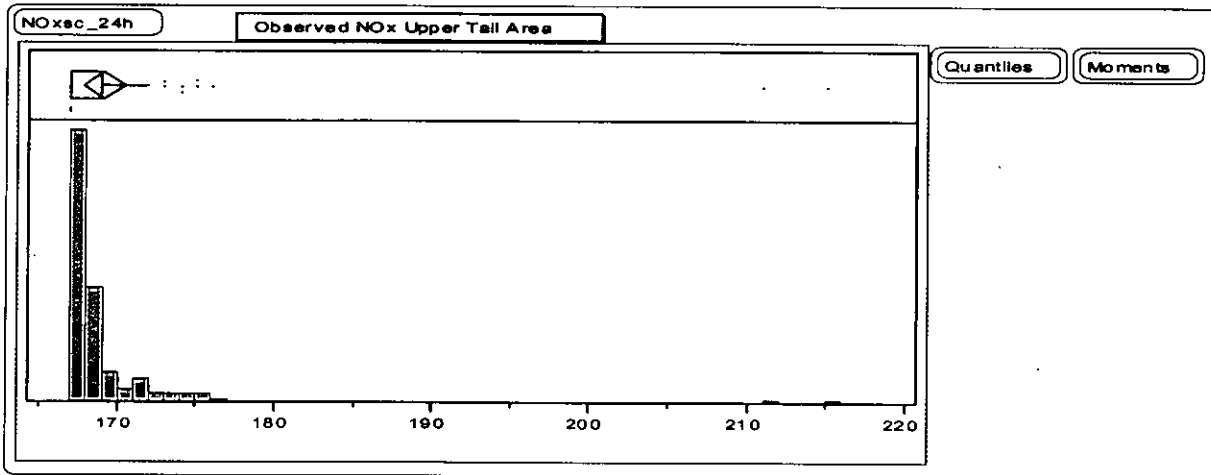
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	30.51457033	30.51457033	399.6043872	2.40171E-26
Residual	53	4.047183362	0.07636195		
Total	54	34.56175369			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	12.93868414	0.807905597	16.01509408	5.86613E-22	11.31823149	14.559137
Slope	-0.805914036	0.040315643	-19.9901072	2.40171E-26	-0.886776938	-0.7250511

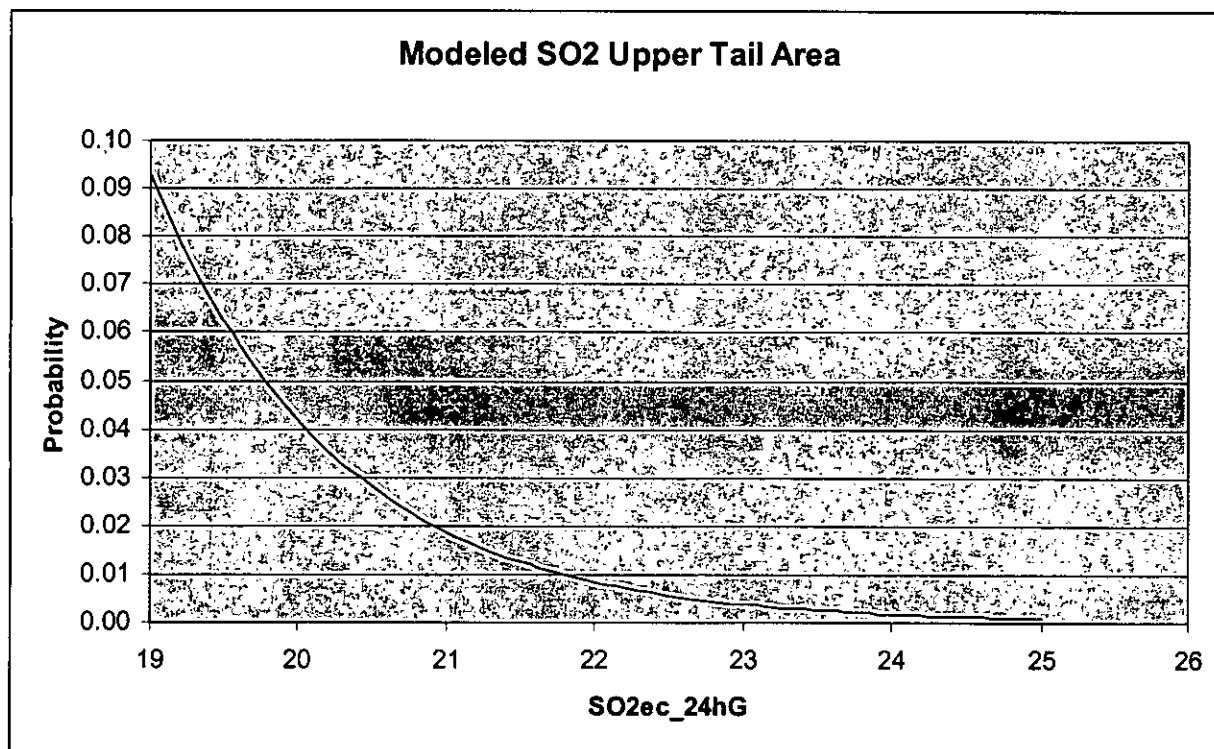
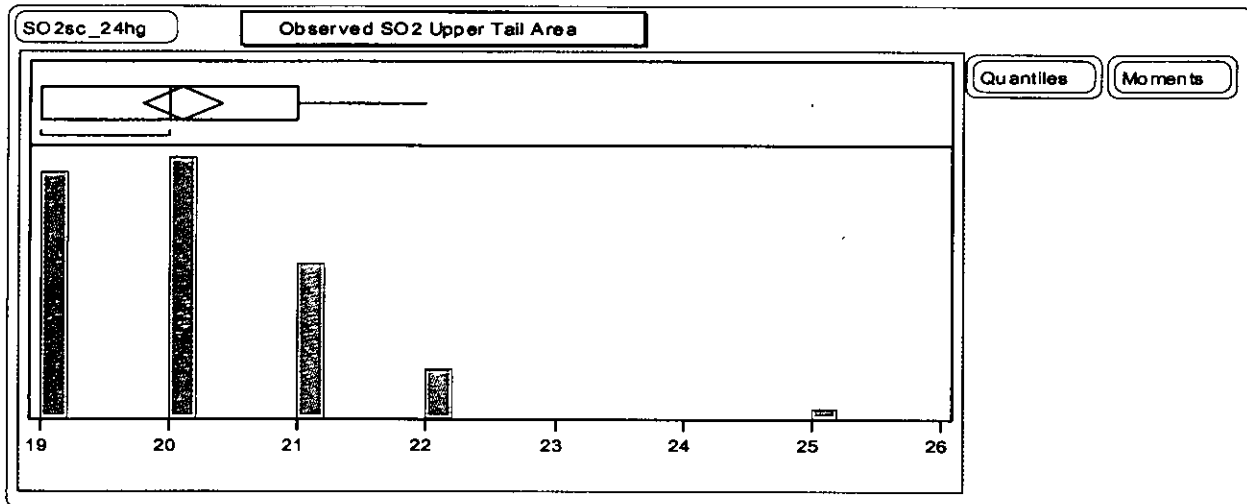
TABLE B-5: SO₂ Upper Tail Modeling Regression Output



GRAPHS B-6 & B-7: Observed CO Upper Tail Area and Modeled CO Upper Tail Area
Note that the modeled distributions have been normalized such that area under the curve is equal to 0.1000, in accordance with these upper tail areas representing the tenth percentile of the parent distribution.



GRAPHS B-8 & B-9: Observed NOx Upper Tail Area and Modeled NOx Upper Tail Area



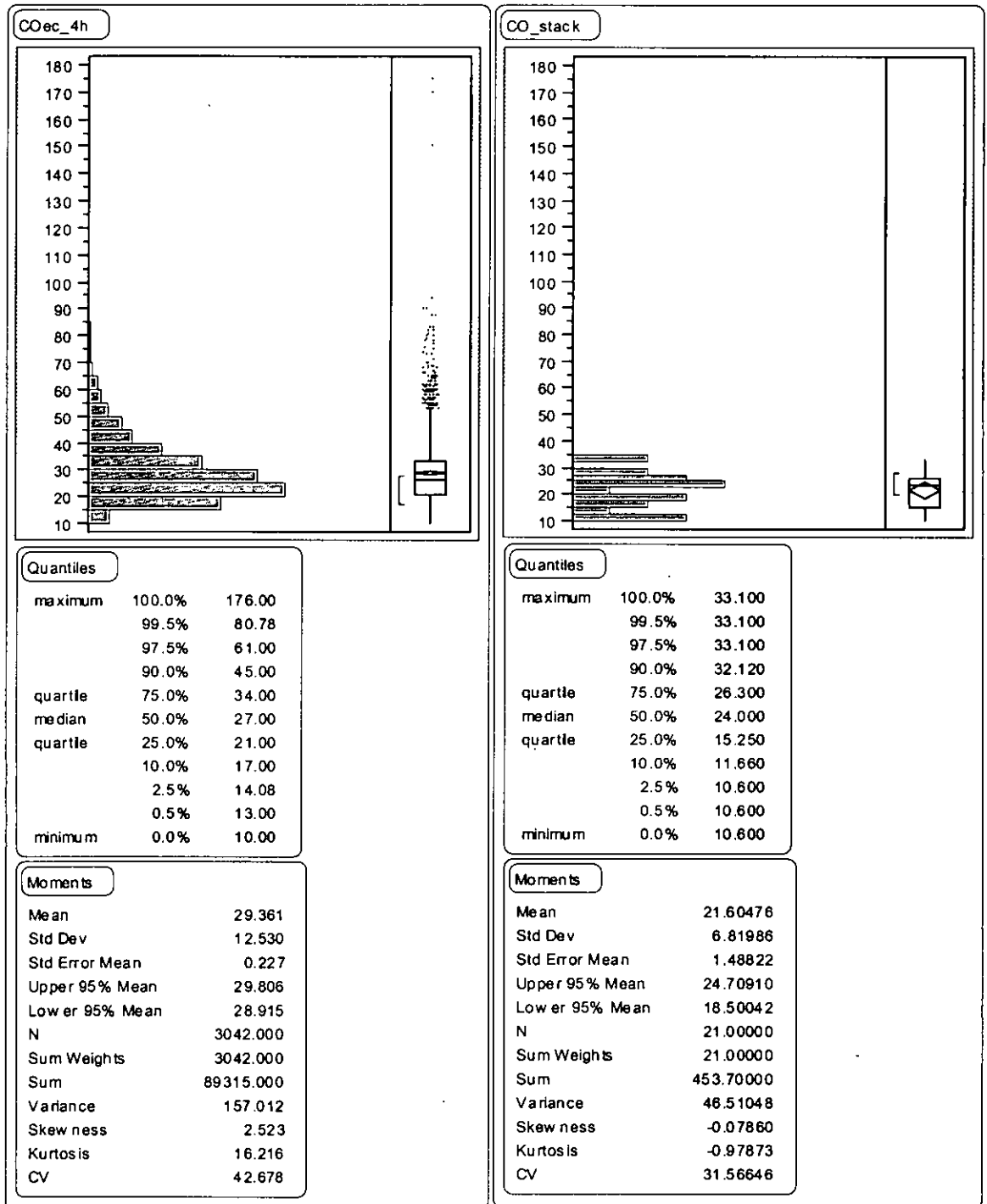
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Appendix C:

Stack Constituents, Acceleration factors, and UPL's

GRAPH C-1: Observed Distributions of CO – CEM vs. Stack

TABLE C-4: Stack Constituents and Six Sigma UPL Calculation



GRAPH C-1: Observed Distributions of CO – CEM vs. Stack

Six Sigma: 3.4 ppm = 3.400E-06

Constituent	units	n	Avg Stack Test	SD Stack Test	Accel.Factor	SD adj	t-value	Six Sigma UPL
			D	E	F	G=(ExF)	0.000034	(D + (GxH))
VOC/NMHC (1)	ppmdv@7%O2	18	1.764	1.539	2.688	4.138	6.929	30.43
HF (1)	ppmdv@7%O2	18	0.09702	0.05133	2.688	0.1380	6.929	1.053
Be(1)	mcg/dscm@7%O2	15	0.00005713	0.00003506	2.688	0.00009423	7.749	0.0007873
Cd	mcg/dscm@7%O2	12	0.0009106	0.0004663	2.688	0.001254	9.239	0.01249
PM	gr/dscf@7%O2	21	0.001464	0.0009501	2.688	0.002554	6.482	0.01802
Hg	mcg/dscm@7%O2	21	31.70	14.79	2.688	39.76	6.482	289.4
HCl	ppmdv@7%O2	21	21.90	9.679	2.688	26.02	6.482	190.5
Total PCDD/F	ng/dscm@7%O2	21	9.871	9.631	2.688	25.89	6.482	177.7
Pb	mcg/dscm@7%O2	21	0.006277	0.006152	2.688	0.01654	6.482	0.1135

(1) VOC, HF, Be: No NSPS standard, PSD limit from existing Units 1 & 2
 Permit limit for NH3 not addressed as no operational history for 150 ppmdv NOx limit
 Note: The emission limits presented above do not include the removal efficiency standard provided by 40 CFR Part 60, subpart Eb or the time-weighted averages for pollutants requiring continuous monitoring. The removal efficiency is 85% for Hg, 80% for SO2, and 95% for HCl.

TABLE C-4: Stack Constituents and Six Sigma UPL Calculation

Appendix D:

What is an Upper Prediction Limit?

An Upper Prediction Limit (UPL) is an estimated numerical value such that we would only expect to see samples with values exceeding the UPL a specified percentage of time. For example, a Six Sigma UPL corresponds to 3.4 readings per million that exceed the UPL bound, approximately 125 years of operation. It is based on statistical reliability theory, and represents the quantitative value such that the probability of compliance during any one-hour sampling period exceeds 99.999%.

UPL's can be calculated from several methods. **Nonparametric** methods assume nothing; they look at the observed data and through rank ordering processes make descriptive declarations about the sample – “hey, here's the upper 10th percentile of the sample”. **Empirical** models are applied for mathematical convenience – “say, that curve looks like an exponential decay curve, can we adequately model it”? **Distributional** modeling provides the most information (it's Normal, or Weibull, or...), but with the most amount of restrictions (that when violated, result in errors with varying manifestations in the system). Each of the modeling methods has its appropriate place in a scientific analysis, and when applied synergistically, will characteristically deliver superior predictive performance.

DUTCH NOTES ON BAT

FOR THE INCINERATION OF WASTE

**MINISTRY OF HOUSING, SPATIAL PLANNING
AND THE ENVIRONMENT**

FEBRUARY 2002

DUTCH NOTES ON BAT FOR THE INCINERATION OF WASTE

**MINISTRY OF HOUSING, SPATIAL PLANNING
AND THE ENVIRONMENT**



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ANNEX: LIST OF EXPRESSIONS ETC.

0. **PREFACE**

This document comprises the contribution of the Netherlands to the exchange of information in the European Union on the use of Best Available Techniques (BAT) to control the environmental impact of industrial processes. This document describes the municipal waste incineration sector and related waste incineration activities.

The Netherlands is a densely populated and highly industrialised country, surrounded by other highly industrialised countries. This leads to a high pressure on the physical environment. To relieve this pressure, the environmental policy of the administration aims for a reduction of emissions, without causing harm to the national economy. In the situation of an open market with international competition, and with regard to the transboundary character of environmental pollution, this policy can only achieve its goals if international co-ordination is a part of it.

One of the essentials of the Dutch environmental policy is the application of the Best Available Techniques, as is stated in the Dutch Environmental Protection Act. Given the need for international co-ordination, this makes the harmonisation of the ideas on BAT very important to the Netherlands.

Article 16.2 of the IPPC-Directive (Integrated Pollution Prevention and Control) of the Council of the European Community has opened up a useful route towards this harmonisation. The exchange of information on BAT will lead to more harmonisation of the environmental approach towards industry in the Member States of the European Union.

Therefore, the initiative of the European Commission to create an information exchange procedure is welcomed wholeheartedly.

This Dutch BAT-Note provides information on technology to reduce environmental impact for the drafting of a European BAT-Reference document. It is based on a survey of the available literature and on information from the concerned industry and the competent authorities. The BAT-note describes the available techniques and gives the conclusions of the Dutch government with regard to the techniques that are considered as BAT.

The information in this document is meant to be used in the process of information exchange. That does not exclude however that this document can also be a useful source of information in other situations, for instance the licensing of industrial activities, the execution of an environmental impact assessment or the planning of industrial operations.

The use of this information will help us to reduce emissions and in the end will contribute to a healthier environment. I hope that this document will prove to be a useful source of knowledge.

The Hague, February 2002

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The Netherlands*

1. **INTRODUCTION**

1.1 **About this document**

The purpose of this document is to support the identification of BAT for the European municipal waste incineration sector (including related incineration activities). The document has been drafted in accordance with the requirements of article 16.2 of Council Directive 96/61/EC, concerning Integrated Pollution Prevention and Control (IPPC-Directive), which has been adopted on 24 September 1996.

The IPPC-Directive provides a definition of BAT (article 2, sub 11):

'Best Available Techniques' means the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where it is not practicable, generally to reduce emissions and the impact on the environment as a whole.

- *'Techniques' include both the technology used and the way in which the installation is designed, built, maintained, operated, and decommissioned;*
- *'Available' techniques mean those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;*
- *'Best' means most effective in achieving a high general level of protection of the environment as a whole.*

Furthermore, article 2 (sub 11) of the IPPC-directive states that a number of considerations must be taken into account when determining best available techniques. These considerations are listed in annex 4 of the Directive and Table 1.1 provides an overview of these considerations.

Table 1.1: Considerations to be taken into account when determining BAT: Annex IV of the IPPC-Directive (EC, 1996)

<p><i>Considerations to be taken into account generally or in specific cases when determining best available techniques, as defined in Article 2 (11), bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention:</i></p> <ol style="list-style-type: none"> <i>1. the use of low-waste technology;</i> <i>2. the use of less hazardous substances;</i> <i>3. the furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate;</i> <i>4. comparable processes, facilities or methods of operation which have been tried with success on an industrial scale;</i> <i>5. technological advances and changes in scientific knowledge and understanding;</i> <i>6. the nature, effects and volume of the emissions concerned;</i> <i>7. the commissioning dates for new and existing installations;</i> <i>8. the length of time needed to introduce best available technique;</i> <i>9. the consumption and nature of raw materials (including water) used in the process and their energy efficiency;</i> <i>10. the need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it;</i> <i>11. the need to prevent accidents and to minimise the consequences for the environment;</i> <i>12. the information published by the Commission pursuant to Article 16 (2) or by international organisations.</i>

An Information Exchange Forum (IEF) has been established to facilitate the requirements of article 16.2. The IEF consists of the Member States, the European Commission, representatives of the European industry, and environmental Non-Governmental Organisations (NGO's). The IEF is provided with information on BAT by the Member States and records this information in BAT-reference notes (BREF's).

The following activities are included in the Directive:

- "Installations for the disposal or recovery of hazardous waste" (Annex I, article 5.1);
- "Installations for incineration of municipal waste" (Annex I, article 5.2).

These installations are part of the sectors to be studied in 2002.

Within the above mentioned framework, the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) has commissioned HASKONING Consulting Engineers and Architects to carry out a study on Best Available Techniques in the waste incineration sector. The main objective of this BAT-document is to identify best available techniques for the reduction of emissions and for energy recovery.

This report is largely based on information obtained from realised projects. Additional information was gathered in conjunction with waste incineration companies and suppliers of equipment and technology.

The project was guided by a supervising commission, which provided valuable comments on the draft reports and offered an appropriate platform for discussion on the scope, themes and results of the study.

During the project, meetings with the supervising commission were held. The commission represented the following authorities and organisations:

- the Netherlands' Ministry of Housing, Spatial Planning and the Environment (VROM);
- the Information Centre for Environmental Licensing (InfoMil);
- (provincial) permitting authorities (Province of Noord-Holland, DCMR for the Southern part of the province of Zuid-Holland and Province of Noord-Brabant, and the National Institute for Inland Water Management and Waste Water Treatment (RIZA) for the various local Water Boards);
- the Union of Dutch waste treatment organisations (VVAV) and representatives of various waste treatment companies, active in the incineration of municipal waste, hazardous waste and sewage sludge (AVI Amsterdam, AVI Moerdijk, AVR and DRSH, see section 2.1).

1.2 Contents and delimitation of the document

This document strives to include all relevant environmental aspects of the presented techniques. Economic aspects of the presented techniques are given as well. However, the availability of economic data is generally limited and incomplete.

This document is based on the main incineration, energy recovery, and flue gas treatment processes in the municipal waste incineration sector as a point of departure. In accordance with Annex I of the IPPC Directive, this document is limited to installations with the following minimum capacities:

- municipal and comparable wastes: 3 tonnes/hour;
- hazardous wastes: 10 tonnes/day.

The document comprises the following elements:

- the introduction (chapter 1) gives a summary of the municipal waste incineration sector (section 1.4) and other incineration sectors (section 1.5). For more detailed information the reader is referred to the following chapters;
- chapter 2 provides a process description of the various incineration technologies for municipal waste, hazardous waste, specific clinical waste, and sewage sludge. This description includes incineration and energy recovery. Presently applied techniques are described, as well as new developments. The chapter ends with a description of co-incineration and current developments in this field;
- chapter 3 provides relevant information on environmental subjects and regulations, such as emissions to air, emissions to water, solid residues, energy aspects, noise, and safety;
- chapter 4 provides an overview of available techniques for reduction of emissions, including pre-treatment of waste, flue gas treatment techniques, and treatment of residues;

- chapter 5 provides the best available techniques (BAT), including the considerations that are taken into account for selecting BAT in the Dutch waste incineration sector;
- chapter 6 provides an overview of other promising technologies.

1.3

Horizontal and local aspects

Some environmental aspects are not specifically related to the (municipal) waste incineration sector. These aspects are relevant for almost all industrial production processes. Examples of these aspects are:

- emissions related to storage and handling of process chemicals;
- environmental aspects of cooling systems;
- external safety.

The above mentioned environmental aspects are not addressed in this document, because these aspects are not specific to the municipal waste incineration sector. In this respect, the Netherlands welcomes the production of 'horizontal documents' within the framework of the IPPC Information Exchange trajectory.

It should be noted that the identification of BAT at individual plants is not necessarily the same for all European plants. 'Local aspects and conditions' may influence the selection of BAT between Member States, or even between production sites within a Member State.

When discussing emission reduction techniques in this document (see chapter 4), reference is made to cross-media effects. This is the shift of environmental pressure from one environmental compartment to the other. This is, for example, the case when a filter is installed; emissions to the air are prevented but waste is generated. When applicable, these cross-media effects are mentioned for each individual technique.

1.4 The municipal waste incineration sector

1.4.1 Main technology

Grate technology is the most commonly used technology for incinerating municipal waste. Figure 1.1 shows the basic structure of this technology, which is described in more detail in section 2.2.

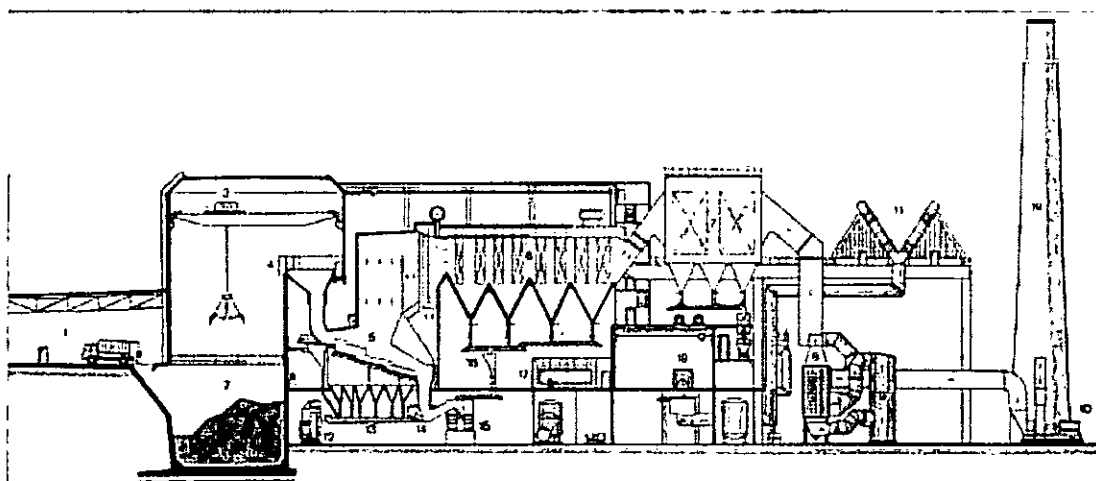


Figure 1.1: Example of a municipal waste incineration plant

Grate technology can be summarised as follows (for a more detailed description see sections 2.2.2 and 2.2.3):

Waste is stored in a bunker and transported by cranes to a hopper. After passing a chute, the waste is dosed on an inclined or horizontal grate, consisting of metal blocks. The waste is transported over the grate by movement of the blocks at regular intervals. Combustion air is added from below the grate.

After a residence time of approx. 1 - 2 hours the incineration process is completed. The remaining bottom ash is discharged in a basin, filled with water. Subsequently the cooled bottom ash can be treated (i.e. separation of metals, crushing and sieving, as described in more detail in section 4.5.2).

The flue gases generated during the incineration process are mixed intensively with secondary air, in order to obtain a good combustion efficiency at temperatures over 850 °C and residence times over 2 seconds at this temperature.

An additional option is to remove nitrogen oxides (NO_x) in the furnace by injection of ammonia, as described in section 4.4.6 (SNCR-process).

The hot flue gases are cooled in a steam boiler of special design (see section 2.2.5). Main boiler characteristics are:

- a large furnace, consisting of membrane walls which are part of the boiler evaporator;

- the lower part of the furnace is protected by refractory lining;
- the convection part of the boiler is designed to avoid high temperatures of tube materials (in order to prevent corrosion), as well as clogging, and erosion caused by dust particles in the flue gas and by the flue gas itself. The boiler is equipped with special cleaning provisions. The resulting boiler ash is collected and transported to a storage facility.

The produced steam is normally used for electricity production. Additionally, it can be used for delivery of process heat to neighbouring industries or for district heating systems etc, as discussed in more detail in section 3.4.

The cooled flue gasses are treated in a flue gas treatment unit, where the remaining fly ash, including polluting components such as heavy metals and organic toxic micro components (e.g. 'dioxins'), are removed. Additionally, gaseous pollutants, such as hydrochloric acid, hydrofluoric acid, sulphur dioxide and nitrogen oxides, are removed (see section 3.1). A wide variety of technologies and systems are available for this purpose, as described in more detail in section 4.4.

The general structure of flue gas treatment systems is:

- removal of the fly ash (by cyclones, electrostatic precipitators or dust bag filters) in the first step;
- removal of acid gases in a second step. For this second step, two main alternative technologies are applied:
 - * dry or semi-dry systems, where acid compounds are absorbed by alkaline components (caustic soda or, most commonly, lime). The resulting flue gas residue must then be disposed of;
 - * wet systems, where the acid gasses are absorbed in the scrubber water. This water must then be treated;
- in most cases, these steps are followed by removing NO_x in a selective catalytic reduction (SCR) system. In other cases, NO_x-removal is already integrated in the furnace (SNCR, selective non-catalytic reduction);
- finally, the flue gasses are 'polished' using activated carbon or comparable adsorbentia.

As described in more detail in section 4.4, the above mentioned technologies can be applied in various configurations.

1.4.2 Development of applied technology

The first industrial installations for incineration of municipal waste date from the end of the 19th century. These plants were of a very simple design, without any, or with very limited, provisions for efficient incineration, energy recovery, and flue gas treatment.

Development of the present technology (grate systems, boilers, flue gas treatment, residue treatment, etc.) started over 50 years ago and can be described as follows:

Development of modern **grate systems** started in the 1940s and 1950s, with following adaptations:

- improved waste mixing on the grate, in order to reduce process variations;

- better division of (primary) combustion air;
- preheating of primary combustion air;
- better control and reliability of waste dosing and grate moving system;
- application of improved grate materials and better cooling of the grate.

Although the principle of grate technology has not fundamentally changed since then, many developments have taken place and still are taking place, especially in the field of process control and improvement of availability (see section 2.2.4).

The development of modern **boiler concepts** for waste incineration started somewhat later, in the 1960s. Original boiler concepts were derived from coal incineration installations. In comparison with coal incineration, waste incineration boilers must cope with larger variations in fuel properties and process conditions, higher chlorine and fly ash contents in the flue gasses, and a lower fly ash melting point.

For these reasons, the following measures were introduced:

- application of improved secondary air systems and a reduction of flue gas velocities;
- reduction of applied steam temperatures;
- adapted configurations of the boiler's convection section;
- introduction of automatic boiler cleaning systems.

Section 2.2.6 provides a more detailed description of these developments, which mainly took place in the 1970s and 1980s, although some developments are still going on, such as application of special non-corrosive materials and flue gas recirculation (see section 2.2.5).

The development of **flue gas treatment systems** was an important issue as well. Up to the mid-1960s, waste incineration flue gas treatment was relatively simple. A common method was to cool the flue gas down to a temperature of 250-300 °C by injecting water (evaporative cooling). The cooled flue gases passed through a cyclone or a multi-cyclone in order to remove the fly ash. With the introduction of electrostatic precipitators and the increased use of boilers, fly ash emission concentrations were reduced to values of 50-100 mg/m³.

In the late 1970s and 1980s, (semi-)dry and wet flue gas treatment systems were developed (including systems to treat the related waste water), followed by removal systems for nitrogen oxides and dioxins (mainly based on active carbon) in the late 1980s and 1990s. These systems included the introduction of bag filters for dust removal.

The development of these sophisticated flue gas treatment systems (as discussed in more detail in section 4.4) was related to the introduction of very strict emission standards in a number of countries. At the same time, analytical techniques to measure these low emissions were developed, as discussed in section 4.4.9.

Incineration and the related flue gas treatment generate following **residues**:

- bottom-ash, from the bottom-end of the grate;
- boiler ash, resulting from the boiler;
- fly ash, resulting from the dust removal step;

- dry flue gas treatment residues, resulting from (semi-)dry flue gas treatment systems;
- residues from the waste water treatment systems, used with wet flue gas treatment;
- residues from the polishing step.

These subjects are described in section 4.5.

The above developments focus on standard municipal waste incineration, using grate technology. Additionally, developments occurred in **other technologies for thermal treatment of waste** were developed, such as fluidised bed incineration (bubbling and circulating) and spreader stoker. These developments are discussed in more detail in chapter 6.

Finally, in addition to the development of incineration systems, there were also important changes in **waste collection systems, pre-treatment of waste and waste composition**. These changes can be summarised as follows:

- separate collection systems (at source) for various waste compounds such as paper, glass, metals, textiles etc., for use as (secondary) raw materials. In the past decade, separating of organic household waste (vegetables, garden and fruit waste or v.g.f.-waste) was also introduced in many countries. After composting (or digestion), this material is used for agricultural purposes;
- mechanical separation systems, based on a combination of milling, sieving, air separation and ballistic technologies. These systems produce a relatively dry, more homogeneous fraction, which can be used for incineration, and a relatively wet fraction, comparable with v.g.f.-waste, but with a higher content of pollutants;
- treatment of monostreams, i.e. specific waste streams from industrial sources that are applicable for incineration in electrical power plants, cement kilns etc.

These developments, insofar as they are applicable to the incineration sector, are discussed in section 4.2.

The economic developments, including developments in waste collection systems and mechanical separation systems, have resulted in a substantial increase in specific calorific value of the waste. This increase had an important impact on waste incineration technology, as discussed in section 2.2 and especially in 2.2.4 and 2.2.6.

1.5 Other related waste incineration sectors

1.5.1 Hazardous waste

Hazardous wastes include a wide variety of materials that require special attention for the following technical and organisational reasons (as discussed in more detail in section 2.3):

- some chemicals require special incineration conditions;
- the variations in incineration behaviour may be (much) larger than for typical municipal waste;
- the material's composition and/or aggregation state may be inappropriate for grate incineration and therefore requires specific incineration techniques;
- the materials are contained in specific packaging;
- hazardous waste requires certain special safety provisions;
- hazardous waste may influence bottom ash quality.

Special technologies are therefore used for hazardous waste incineration, such as rotary kilns and fluidised bed systems. Also, the design of the furnace and boiler system may be adapted to allow for higher temperatures and/or longer residence times, as discussed in more detail in section 2.3.

The application of dedicated incineration systems, cement kilns and 'normal' grate systems for certain hazardous waste categories are also discussed in section 2.3, including the treatment units for caustic water. Caustic water is a specific waste water stream from MSPO-plants (Mono-Styrene Propylene Oxide), containing 10 – 20% of organic compounds and a high sodium load. The water is available in the Dutch petro-chemical industry in large quantities.

1.5.2 Specific clinical waste

The incineration of specific clinical waste, as collected in hospital operating rooms, contamination departments, and of special medical origin (old medicines, blood containing waste, etc), requires special attention. The main reasons for this are:

- health risks, related to this category of waste;
- aesthetic reasons;
- specific incineration behaviour, due to the required long residence times of certain compounds in this waste category.

In the past, many hospitals operated small furnaces with limited emission reduction facilities to incinerate these specific wastes, often in combination with the incineration of less specific waste that was more similar to municipal waste.

With the introduction of the present air emission standards for waste incineration in the Netherlands, these units had to be replaced by systems that were able to meet the emissions standards, such as:

- incineration in a centralised specific clinical waste incineration plant. This system is currently being applied in the Netherlands;
- incineration in hazardous waste incineration plants. This is a supporting system;
- small furnaces, directly connected with (municipal) waste incineration plants. The flue gases of the furnaces are passed through the boiler and the flue gas treat-

ment system of the large municipal waste incineration plant. This system is not in use in the Netherlands.

This subject is discussed in more detail in section 2.4.

1.5.3 Sewage sludge

In the Netherlands, the production of sewage sludge has increased substantially in the past decades because biological treatment of communal and industrial waste water has been increasingly applied. Because agricultural use of sewage sludge is restricted and landfilling is prohibited in many cases, thermal treatment techniques (such as incineration) are increasingly employed. Before incineration, the sewage sludge is mechanically dewatered, from original dry solid (d.s.) contents of 2 - 5% to d.s.-contents of 20 - 35%, depending on sludge characteristics and applied dewatering systems. The dewatered sludge is a pasty material. Normally, 50 - 70% of the dry solid content is organic material.

Main applied treatment technologies for municipal sewage sludge in the Netherlands are:

- biological drying (composting), two plants, approx. 5 - 10% of the total sludge amount;
- thermal drying, four existing and two new plants, approx. 35%;
- incineration, two operational and one stopped plant, approx. 50%;
- wet oxidation, one plant, approx 5%.

Incineration of dewatered sewage sludge is technically feasible, but for economic reasons it is necessary to select an incineration system that is as efficient as possible in terms of energy consumption and recovery. Such incineration systems recover the heat generated during incineration and use it to (partially) pre-dry the sludge (see section 2.5).

To incinerate sewage sludge, the following systems are normally used:

- fluidised bed furnaces. This is the most common type, because of its simple design and satisfactory performance;
- multiple hearth furnaces, which enable incineration of sewage sludges with a high mineral content, resulting in low melting points of the ash;
- rotary kilns, because of their great flexibility.

These technologies are discussed in section 2.5.

Boiler design and flue gas treatment are in many respects similar to those used for municipal waste incineration; however, relevant differences are discussed in section 2.5.

As indicated, fluidised bed incineration is used for approximately 45% of all municipal sewage sludge in the Netherlands (see section 2.1.4).

1.5.4 Incineration of biomass

With the increasing emphasis on the realisation of a sustainable environment and energy production, thermal treatment of biomass has got increasing interest.

The policy of the Dutch government calls for 10% of the total energy production in 2010 to be derived from sustainable sources. Of this 10%, a significant part must be achieved by converting biomass and waste into electricity and heat. Conversion of biomass is considered to be a way of producing energy without emitting CO₂, as biomass is a renewable material with a relatively short carbon-cycle. So, energy production from biomass supports the Dutch climate policy.

In many cases, technologies that are derived from or related to waste incineration are being considered for thermal treatment of biomass. These developments are discussed in section 2.6.

1.5.5 Co-incineration of waste

Another development is the increasing interest in co-incineration of specific categories of waste (monostreams etc.) in other incineration systems (electrical power plants, blast furnaces, cement kilns or in combination with other waste categories). Recent examples in the Netherlands are:

- co-incineration of wood and other biomass in coal power plants;
- co-incineration of sewage sludge in municipal waste incineration plants, coal power plants and/or cement kilns;
- co-incineration of specific hazardous wastes in municipal waste incineration plants and in cement kilns;
- co-incineration of hazardous waste in small industrial boilers.

These developments are also discussed in section 2.6.

1.6 **Cost aspects**

The preceding sections provided an overview of the technological developments in the various waste incineration sectors. Chapters 2, 3 and 4 provide the information that is required to determine Best Available Techniques (BAT).

It should be noted that cost aspects play a more different role in this sector than in many other industrial sectors. This is related to the following factors:

- emission standards for waste incineration are quite severe. Establishing environmental standards is the result of political decisions rather than strict economic considerations;
- economic competition is less effective, especially in the field of municipal waste management, because a satisfactory and reliable waste management system is considered to be a public responsibility;
- in many cases, local factors have an important impact on technology selection and feasibility, such as economy of scale, availability of an appropriate site, availability of clients for recovered energy, air emission standards, possibilities for disposal of waste water, the availability of cooling water, cost of residue disposal etc.

It is therefore ineffective to establish detailed cost factors for each separate element of the applied technologies. Solutions that are cost effective in one situation may be ineffective in others, depending on the overall configuration of the plant.

1.7

Relevant Dutch and European regulations and agreements

Dutch regulations and agreements

The most important regulations for waste treatment and disposal in the Netherlands are laid down in the *Environmental Protection Act (Wet milieubeheer)*. According to this law, provinces are responsible for the adequate planning of various categories of municipal and non-hazardous industrial waste. This responsibility also means that provinces must act as permit authorities for (amongst others) municipal waste incineration plants. For hazardous waste, the national government is the competent authority. For emissions to water, the various local Water Boards are the competent authority.

In order to ensure the required national co-ordination on waste management policy, a national *Waste Co-ordination Board (Afval Overleg Orgaan (AOO))* was established. In 1995, AOO issued the second Ten Year Program on Waste (TJPA-II 1995-2005), for the national planning of waste treatment and disposal.

For hazardous waste management, a National Program on Hazardous Waste (MJPA) was established. At present, the Ministry of VROM and AOO are co-ordinating activities for the establishment of a new *National Waste Management Plan (Landelijk Afvalbeheers Plan (LAP))*, which is expected to be finalised by the course of 2002. The actual draft, on which (comments in) this document are based, is the version of January 11, 2002.

Hazardous wastes are defined in the *Decree on the indication of Hazardous Wastes* (in Dutch: *Besluit aanwijzing gevaarlijke afvalstoffen*, abbreviated as "Baga"). In short, wastes are designated as hazardous, if the waste originates from specifically indicated processes (annex 1 of the decree) or contains pollution above indicated concentration limits (elaborated in annex 2 of the decree). Furthermore annex 3 of the Decree shows a list of excepted wastes, which should not be specified as hazardous wastes.

Presently, the new European regulation EURAL is being prepared, which may cause some differences in the definition of various hazardous waste types. Bottom ash, boiler ash and fly ash of municipal waste incineration can be categorised as hazardous or non-hazardous waste, depending on the actual composition (heavy metals). The introduction of the EURAL in the Netherlands is now scheduled for May 1st, 2002.

Emissions to air, related to the incineration of municipal waste, have to comply with the *Decree on Air Emissions for Waste Incineration (Besluit Lucht-emissies Afvalverbranding (BLA))*. For emission standards to air see table 3.1 in section 3.1.2. A new Decree for emission standards for waste incineration, including co-incineration activities is being prepared (*Besluit Verbranding Afvalstoffen, BVA*). This decree will be an implementation of the EU-Decree. Adaptations in emission values will however be limited with respect to the values of the BLA.

Incineration of hazardous waste (including co-incineration) has to comply with the *Regulations for Incineration of Hazardous Waste* ('*Regeling verbranden gevaarlijke afvalstoffen*') (RVGA) [205]. Emission standards to air are comparable with BLA standards, although there are some differences, as elaborated in section 3.1.2.

Air emissions of other stand-alone waste incineration activities are regulated in the *Netherlands Emission Regulations* (*Nederlandse Emissie Richtlijnen* (NeR)), which include comparable standards, see also section 3.1.2.

For co-incineration of biomass and waste, together with fossil fuels, regulations in the Netherlands are at present under discussion. A draft *Circulaire on emissions for energy recovery from biomass and waste* (*Emissiebeleid voor energiewinning uit biomassa en afval*) was recently published. It distinguishes clean (white-listed) and polluted (yellow-listed) materials. Emission standards for yellow-listed materials are comparable with BLA standards. Emission standards for co-incineration together with fossil fuel are based on a "mixing rule", according to which the actual emission standard is the weighted average for the emission standard for fossil fuel and biomass/waste. For NO_x-emission a system of emission trade will apply. For mercury an input limit is formulated. For more details see section 3.1.2.

Emissions to surface water are the responsibility of the various regional Water Boards, with co-ordination by the national Committee for Integrated Water Management and with professional support by the National Institute for Inland Water Management and Waste Water Treatment (RIZA). Furthermore it is noted that the Dutch *Pollution of Surface Waters Act* (in Dutch '*Wet verontreiniging oppervlaktewateren*, *Wvo*) is applicable for direct and indirect discharges to surface water of installations, which are active in the field of waste treatment and storage.

The *Building Materials Decree* (in Dutch '*Bouwstoffenbesluit*') was drawn up for the use or application of stone-like materials (such as residues from waste incineration), to protect the environment in general and the soil, groundwater and surface water in particular. It became effective per 1 July 1999. In short, this decree means that construction materials, depending on their form, composition and leaching behaviour, are divided into various categories which determine their use. The users of the construction materials have to demonstrate to the competent authorities to which category the construction materials belong. For further details see sections 3.3.2 (bottom-ash) and 4.6.2 (treatment of bottom-ash).

The recovery of non-fossil energy from waste is considered to be of increasing importance. In order to promote the energy efficiency of waste incineration, the Dutch waste incineration sector has signed an Agreement with the Ministry of Economic Affairs.

European standards

At present, the following EU-directives are in force for waste incineration plants:

- 89/369/EEC for new municipal waste incineration plants;
- 89/429/EEC for existing municipal waste incineration plants;
- 94/67/EC for incineration of hazardous waste (including co-incineration);
- 00/76/EC for the incineration of waste (including co-incineration).

It should be noted that the last mentioned directive [195] has replaced the first three directives per December 4, 2000. However, the transitional arrangement of Directive 00/76/EC determines that existing waste incineration plants have to comply with this new directive per December 28, 2005 at the latest. In the meantime, existing waste incineration plants have to comply with Directives 89/369/EEC, 89/429/EEC and 94/67/EC.

1.8

Standardisation and oxygen reference percentages

In this document, gas concentrations are presented in international standardised cubic metres of gas (m_o^3 : 1 m^3 air at 273,15 K, 101,3 kPa; dry). They are recalculated to contain a reference percentage of oxygen of 11 vol. % by dilution with dry air.

However, the Dutch RVGA (for hazardous wastes, see section 1.6) prescribes a correction to 3 vol.% O_2 , in case only oily liquid hazardous wastes are incinerated. In case hazardous wastes are co-incinerated, the gas concentrations have to be presented into international standardised cubic metres of gas (273 K and 101,3 kPa) without any correction for the oxygen percentage, if it is below 11%. Furthermore, RVGA offers the competent authorities the possibility to prescribe a different oxygen percentage, if hazardous wastes are incinerated with pure oxygen.

In the new European Directive (00/76/EC, see section 1.6), the emission standards are not corrected for O_2 -percentages lower than 11%. This may lead to a decreasing interest in achieving lower O_2 -percentages. Furthermore, it should be noted that the former directives are still in force for existing plants.

The achievable emission levels in this document should be read as hourly average values based on standardised (inter)national sampling and analytical techniques. The specific emission levels are expressed in units per tonne. It should be noted here, that the Dutch RVGA prescribes 24 hour, half hour and/or 10 minute's averages for the incineration of hazardous wastes.

2. PROCESS DESCRIPTION

2.1 Introduction

In the Dutch municipal waste incineration sector all (eleven) plants are based on grate technology, as described below.

There is one centralised plant for the incineration of hazardous wastes, with two (rotary kiln) incineration lines. Additionally, there are a number of smaller dedicated units for special hazardous waste categories. These units are owned and operated by various industries. The description of these units in this BAT-document is less detailed.

For specific clinical waste, one centralised plant is operational.

Sewage sludge is incinerated in two (formerly three) plants in the Netherlands.

This section gives an overview of these plants.

2.1.1 Dutch municipal waste incineration plants

GEVUDO, Dordrecht:

This plant, which has been in operation since the early 1970s, consisted originally of three lines (capacity 3 x 7,5 t/h). The applied grate system is the reciprocating grate of Martin München. Two of the lines were connected with a multiple hearth sewage sludge incineration unit that was removed at the beginning of the 1990s. There were no facilities for electricity production. Flue gas treatment consisted of a wet scrubber system, for removal of fly ash and gaseous compounds.

By the end of the 1980s and beginning of the 1990s, the plant was adapted to current air emission standards by a complete adaptation of the wet scrubbing system and was expanded with a fourth line of comparable design and capacity. The new line (line no. 4) and one existing line (line no. 1) were equipped with boilers for electricity production.

After the introduction of the new air emission standards (BLA, see section 3.1.2), the plant's flue gas treatment system was adapted once again. In the present situation line 1 (with steam boiler) and line 2 (without energy recovery) have a combined flue gas treatment system, as well as line 3 (without energy recovery) and line 4 (with steam boiler). The configuration is as follows:

- (further) flue gas cooling by water evaporation (separate per line);
- reactor (combined for two lines) with injection of adsorbents (zeolite for dioxin removal and Na_2S_4 for heavy metals absorption);
- dust bag filters for removal of adsorbents and fly ash;
- two stage wet scrubbers (acid and neutral pH, including physical-chemical treatment of process waste water);
- two parallel wet electrostatic precipitators;
- SCR-DeNO_x for removal of NO_x and remaining dioxins.

The steam system of the plant is connected with the steam systems of the adjacent sludge incineration plant of DRSH (see section 2.1.4) and the specific clinical waste incineration plant of ZAVIN (see section 2.1.3);

AVR Rotterdam:

This plant has been in operation since 1962, with four incineration lines (capacity 4 x 13,4 t/h), with reciprocating grate (Martin München), electricity production, and electrostatic precipitators for reduction of dust emission. In 1993, the plant was overhauled, including the installation of wet flue gas treatment system (including physical-chemical treatment of process waste water), activated carbon fixed bed flue gas polishing and SCR-DeNOx;

AVR Botlek:

AVR Botlek is in operation since 1972, with a capacity of 6 lines x 19.8 t/h, roller grate (system Düsseldorf), steam production for electricity production and production of distilled water by using low-temperature heat from the steam cycle. Flue gas treatment consisted of electrostatic precipitators for dust removal. In 1994, the existing lines were provided with wet flue gas treatment systems (including physical-chemical treatment of process waste water), activated carbon fixed bed flue gas polishing and SCR DeNOx. In the same period a seventh line (25 t/h) was realised. The environmental permit of the plant includes the incineration of 85.000 t/y of hazardous waste. The installation is equipped with nozzles for the injection and incineration of liquid (hazardous) waste;

AVR AVIRA, Duiven:

This plant is in operation since 1974, with 3 lines x 12 t/h, roller grate (system Düsseldorf), without energy recovery, with electrostatic precipitators for dust removal. In 1984, one of the lines was equipped with a hot water boiler for supply of heat to the local district heating system. In 1989, a wet flue gas treatment system (including physical-chemical treatment of process waste water) was installed on all three lines, followed by the application of SNCR-DeNOx and a DeDiox system. In the latter system, activated carbon is injected into the scrubbers. Subsequently the two other lines were equipped with steam boilers for electricity production as well as supply of heat to the district heating system (1991 and 1996). The installation of the boilers was combined with a capacity increase of the units from 12 till 15 t/h. The plant is equipped with provisions for the co-incineration of sewage sludge. The sludge can be spread over the waste in the bunker area; the sludge co-incineration system is however not in operation;

AVI Roosendaal (SITA ReEnergy, formerly WATCO):

The original municipal waste incineration plant dates from 1975, with 2 lines with a forward moving inclined grate system (Brun&Sorensen), supply of heat to a neighbouring nursery gardening centre and with electrostatic precipitators. In the 1980s, a sludge drying unit was added, using hot flue gases as its energy source. In 1995, the plant was completely overhauled, including new horizontal forward moving grate systems (Noell), capacity 2 lines x 4 t/h, hot water boilers for supply of heat to the nursery gardening centre, the possibility to use hot flue gases for sludge drying and electrostatic precipitators. Flue gas treatment consists of a combined unit for both lines with semi-dry flue gas treatment based on injection of lime slurry, with the option to dose soda-bicarbonate (NaHCO_3) at peak loads, injection of activated carbon, dust bag filters and SCR-DeNOx;

ARN Beuningen:

This incineration plant has been operational since 1987, with two mechanical sorting lines and one incineration line of 9 t/h, horizontal forward moving grate (Noell), electricity production and wet flue gas treatment. In 1995, the plant was expanded with additional mechanical sorting capacity and a second incineration line of 21 t/h of RDF, horizontal forward moving grate (Noell), electricity production, dust removal with electrostatic precipitators and wet flue gas treatment (waste water free by use of a spray dryer), SCR-DeNOx and entrained bed flue gas polishing (including dust bag filter). The grates of both lines were adapted from air cooling to water cooling;

AVI Amsterdam (GDA):

Operational since 1993, with 4 lines x 25 t/h, forward/backward moving horizontal grate (W+E, now ABB), electricity production, supply of heat to neighbouring industries, dust removal with electrostatic precipitators, wet flue gas treatment (waste water free) and SNCR-DeNOx. The plant is equipped with provisions for the co-incineration of sewage sludge by direct injection in the furnace in one of the four lines;

AVI Alkmaar (Huisvuilcentrale):

Operational since 1995, with 3 lines x 18.5 t/h, forward moving inclined grate (Von Roll), electricity production, dust removal with electrostatic precipitators, wet flue gas treatment (waste water free), SCR-DeNOx and entrained bed flue gas polishing;

AVI Wijster (Essent Milieu):

This incineration plant has been operational since 1995 with three mechanical sorting lines and an incineration capacity of 3 x 18 t/h, forward/backwards moving inclined grate (11°), electricity production, dust removal with electrostatic precipitators, wet flue gas treatment (waste water free) and SCR-DeNOx and DeDiox. The grates were adapted to water cooling in 1998 (Stiefel);

AVI Moerdijk (AZN):

Operational since 1996, with 3 lines x 28 t/h, forward moving inclined grate (Von Roll), steam production for a neighbouring combined cycle power plant, SNCR-DeNOx, dust removal with electrostatic precipitators, wet flue gas treatment (including physical-chemical treatment of process waste water) and entrained bed flue gas polishing;

AVI Twente (Twence):

Operational since 1997, with 2 lines x 18 t/h, reciprocating grate (Martin München), electricity production, wet flue gas treatment (waste water free), SCR-DeNOx and entrained bed flue gas polishing.

Summary of applied technologies

Table 2.1 (next page) gives an overview of the applied technologies, including the amounts of incinerated municipal waste in 1999. In the years 2000 and 2001 there have been no substantial changes in incinerated amounts of waste. More detailed descriptions of the applied technologies are found in sections 2.2 – 2.6 and Chapter 4.

Lower Heating Value (LHV) of the waste, treated in the various municipal waste incineration plants varies from 8.4 MJ/kg (AVI Roosendaal) until 12 – 13 MJ/kg (ARN and AVI Wijster, after mechanical sorting). A typical average value is just below 10 MJ/kg (AVI Twente 9 MJ/kg, AVI Amsterdam 9.5 MJ/kg, GEVUDO Dordrecht 9.8 MJ/kg).

Table 2.1: Municipal waste incineration plants in the Netherlands

Municipal waste incineration plant	Incineration	Energy/cooling	Flue gas treatment	Incinerated amount (1999) in t/y
GEVUDO	rg	sb.ep.ss.ec	bfa.ws.wesp.scr	171,000
AVR Rotterdam	rg	sb.ep.hs.wc	esp.ws.fxbac.scr	385,000
AVR Botlek	rolg	sb.ep.ssdiw.wc	esp.ws.fxbac.scr	1,105,000
AVR AVIRA	rolg	sb/hwb.ep.hsdh.ec/ac	sncr.esp.wsa	300,000
AVI Roosendaal	fhg	hwb.hsgar.hssd.ac	esp.sda.scr	55,000
ARN Beuningen	fhg/wc	sb.ep.ec.lths	esp.sd.esp.ws.scr.bfa	250,000
AVI Amsterdam	fbhg	sb.ep.ss.wc	sncr.esp.sda.esp.wsa.edv	790,000
AVI Alkmaar	fig	sb.ep.ac	esp.sd.esp.ws.bfa.scr	450,000
AVI Wijster	fig/wc	sb.ep.ac	esp.sd.esp.ws.scrd	435,000
AVI Moerdijk	fig	sb.sswkc	sncr.esp.ws.bfa	600,000
AVI Twente	rg	sb.ep.ac	esp.sd.esp.ws.scr.bfa	285,000
Total				4,830,000

ac : air cooling	lths : low-temperature heat supply
bfa : adsorbent injection, followed by bag house filter	rg : reciprocating grate
ec : evaporative cooling	rolg : roller grate
ec/ac : evaporative cooling and air cooling	sb : steam boiler
edv : electro dynamic venturi	sb/hwb: steam boiler, hot water boiler
ep : electricity production	scr : scr-denox
esp : electrostatic precipitation	schr : scr-denox and dediox
fbhg : forwards/backwards moving horizontal grate	sd : spray dryer
fhg: forward moving horizontal grate	sda : spray dryer with adsorbens injection
fhg/wc: forward moving horizontal grate, water cooled	sncr : sncr-denox
fig : forward moving inclined grate	ss : steam supply
fig/wc: forward moving inclined grate, water cooled	ssdiw : steam supply for distilled water production
fbac : fixed bed reactor with activated carbon	sswkc : steam supply to a combined cycle power plant
hs : heat supply	wc : water cooling
hsdh : heat supply for district heating	wesp : wet electrostatic precipitation
hsgar : heat supply for gardening centre	ws : wet scrubber
hssd : heat supply for sludge drying	wsa : wet scrubber with adsorbens injection
hwb : hot water boiler	

2.1.2 Dutch hazardous waste incineration plants

AVR Chemie, Botlek

AVR Chemie is the central hazardous waste treatment plant in the Netherlands. Operations started in 1972 with (amongst other treatment facilities) one rotary kiln incineration line. In 1986 and 1992 two extra rotary kiln incineration lines were added. The second line (1986) was modernised in 1994 followed by the shutdown and removal of the first line in 1997.

The existing two incineration lines are equipped with after-burner rooms, boilers, electrostatic precipitators, wet flue gas treatment systems (including physical-chemical treatment of process waste water) and activated carbon fixed bed polishing. Total incineration capacity is approximately 100,000 tons/year.

In 1999 and 2000 four static vertical incinerators were put in operation. These are dedicated incinerators for the treatment of caustic water (see also section 1.5.1 and 2.3.3) but the units can also incinerate other low caloric waste water streams. The lines are equipped with dip quenches (including physical-chemical treatment of process waste water), heat recovery, venturi scrubbers and wet electrostatic precipitators.

Various dedicated incineration units

These units are mainly operated by (petro-)chemical companies, such as Akzo Nobel (Amsterdam, Botlek, Bergen op Zoom), Arami (Delfzijl), ATM Moerdijk, AVR Chemie (Botlek), DOW (Terneuzen), DSM (Geleen, Hoek van Holland, Schoonebeek), DuPont (Dordrecht), Elf Atochem (Vondelingenplaat, Vlissingen), GE Plastics (Bergen op Zoom), Servo (Delden), Shell (Pernis, various units).

These units mainly incinerate well-defined liquids or gaseous waste streams. In some cases, sludges are incinerated in fluidised bed units. Most of these units are equipped with wet scrubbers only, though in some cases more complex flue gas treatment systems are installed.

As applied process technology is normally rather specific, a more detailed description of these units is beyond the scope of this BAT-document. To complete the overview, four examples (Akzo Nobel Botlek, Shell Pernis, ATM Moerdijk, AVR Chemie Caustic Water Incineration) of such units for specific waste categories are described in section 2.3.3.

2.1.3 Dutch specific clinical waste incineration plant

ZAVIN, Dordrecht;

This plant has been operational since 1991. The plant incinerates specific waste bins, collected from hospitals and other medical care institutions. The unit has a capacity of 1 t/h. The applied process is two stage pyrolysis/incineration, energy recovery with a boiler for saturated steam production, wet flue gas treatment (including physical-chemical treatment of process waste water), entrained bed polishing and SCR-DeNOx. For more details see section 2.4.

2.1.4 Dutch sewage sludge incineration plants

DRSH, Dordrecht;

This plant has been in operation since 1993 and is located on the same site as the GEVUDO municipal waste incineration plant. The original plant capacity was 3 lines x 2.25 tons of dry solids (d.s.)/h. An extension came into operation in 1998, with a capacity of 1 line x 4.5 tons d.s./h. As the incinerated (mechanically dewatered) sludge has an average dry solids content of approx. 22%, one ton of dry solids corresponds with approx. 4.5 tons of sludge material.

The incinerated sludge originates from a large number of waste water treatment plants, mainly located in the province of Zuid-Holland. It is transported by trucks and stored in a large closed bunker.

The applied process technology is partial pre-drying in disc dryers, incineration in bubbling fluidised bed furnaces, SNCR-DeNOx, steam production (used in the dryers) in saturated steam boilers, dust removal in electrostatic precipitators, two stage wet flue gas treatment, including additional cooling and use of the condensate in the scrubbers, fixed bed flue gas polishing and bag filters, as described in more detail in section 2.5;

VIT, Hengelo:

This plant has been in operation since 1994. The capacity is 1 line x 4 ton d.s/h. The applied technology is pre-drying in a rotary kiln dryer, grate incineration (Lambion), dust removal by means of a dust bag filter, wet flue gas treatment, thermal afterburning and SCR-DeNOx. The plant has been closed recently (spring 2001), due to technical problems which reduced technical availability, leading to bankruptcy and is not expected to resume its operation.

SNB, Moerdijk:

The plant is in operation since 1997. The design capacity is 4 lines x 3.8 ton d.s./h. The incinerated sludge originates from various waste water treatment plants, mainly located in the province of Noord-Brabant. It is transported by trucks and stored in a large closed bunker.

The applied technology is partial pre-drying in disc dryers, incineration in a bubbling fluidised bed furnace, SNCR-DeNOx, steam generation in a boiler, dust removal by electrostatic precipitators, wet flue gas treatment, entrained bed polishing.

2.2 Incineration of municipal and comparable wastes

2.2.1 Introduction

This section will include some information about municipal waste composition, and waste acceptance and storage. Subsequently, incineration technology and related boiler technology for incineration of municipal waste are discussed in appropriate detail. Other related technologies, such as mechanical sorting, size reduction of bulky wastes, flue gas treatment and treatment of residues are discussed in Chapter 4.

The various sections of these chapters are concluded with a short enframed summary, indicating advantages, disadvantages and applicability.

Composition of municipal waste in the Netherlands

Municipal waste consists of a wide variety of components. Table 2.2 provides a typical example of the composition of municipal waste. The indicated composition is typical for "grey" municipal waste, i.e. the waste that is collected for waste incineration, excluding fractions that are collected separately, such as paper and board, v.g.f.-material, glass etc.

Table 2.1: Composition of "grey" municipal waste (RIVM 1999, [207])

Compounds in "grey" municipal waste	Percentage
Main compounds	
- V.g.f.-material (organic household waste)	32.6%
- Paper and cardboard	32.3%
- Plastics	11.5%
- Glass	3.4%
- Ceramics	4.5%
- Ferrous	3.5%
- Non-ferrous	0.8%
- Textiles	3.0%
- Wood	2.1%
Miscellaneous	
- Bread	2.2%
- Animal refuse	1.7%
- Carpeting/mats	0.9%
- Leather/rubber	1.0%
- Special waste	0.4%
- Small hazardous waste	0.2%
Total	100%

With regard to incineration, the components can be classified in three main categories:

- combustible material. During incineration, this category is decomposed by oxidation under the release of heat;
- ash. This category concerns material that is not decomposed during incineration and therefore does not contribute to the heat production. It remains a (solid) residue after the incineration process;
- water. This component evaporates during the incineration process and therefore has a negative influence on the energy production. Another effect of the water content is the reduced speed of the incineration process.

When regarding municipal waste as a fuel, it has a number of properties that must be taken into account:

- the large variety in average composition, with varying (average) LHV's, different behaviour during incineration, and varying process emissions;
- the required long residence time during incineration, because of:
 - * the presence of materials with limited accessibility to oxygen;
 - * the water content, reducing incineration velocity;
- the large fluctuations around the average composition of the waste;
- the presence of a large number of polluting non-organic components, such as chlorine, sulphur, fluorine and a wide variety of heavy metals, including mercury and cadmium;
- the high ash content. Additionally, it should be mentioned that the complex composition of the ash normally leads to relatively low ash melting points, which may have negative effects on the energy recovery process in the boiler (ash clogging, see section 2.2.5).

Waste acceptance and storage

Municipal waste is normally delivered to the incineration plant by trucks. If the collection area is relatively nearby, the collection trucks drive directly to the municipal waste incineration plant. If, however, the distance to the plant is further than approximately 25 kms, the municipal waste is transferred to bulk transport trucks in transfer stations. Also, in some cases, bulk transport is done via trains or ships. AVI Amsterdam, AVI Moerdijk and AVI Wijster are examples of Dutch municipal waste incineration plants that receive a substantial amount of waste via trains. A substantial amount of the municipal waste for AVI AVR Botlek located in Rotterdam harbour, is transported by ship in bulk. AVI AVR Rotterdam, also located in Rotterdam harbour, receives much waste locally by ship. Also AVI Alkmaar has recently realised a facility to receive waste by ship bulk transport. AVI Moerdijk has available a quay, but this quay is normally only used for transport of bottom-ash.

Upon arrival, the waste is weighed on a weighing bridge and registered. In order to prevent the delivery of other, non-permitted waste categories, an acceptance procedure is followed that includes facilities for inspecting the waste.

In case the environmental permit of the plant allows for certain categories of hazardous waste (as is the case for several Dutch municipal waste incineration plants, such as AVR Botlek and AVI Amsterdam) a specific acceptance procedure has to be followed. This procedure includes the following aspects:

- the required data concerning composition, including way of sampling;
- moment of transfer of ownership of the waste;
- supply conditions (way and size of packaging);
- provisions for specific acceptance;
- acceptance conditions (composition, viscosity, flash point, vapour pressure, toxic behaviour etc.);
- operational procedures;
- administrative procedures, in relation with permit procedures.

The waste is unloaded from a platform into the bunker. Normally, completely covered platforms and bunkers are used to prevent odour nuisance, noise, and the pollution with litter of the area surrounding the plant. Only in some older plants semi-covered platforms are used.

Bulky waste, which is included in the supplied waste, may lead to technical problems. Therefore, devices to reduce the size of this waste are installed at most incineration plants (see also section 4.2.3).

The waste is stored in a bunker, where the waste is mixed and then transported, via an overhead crane, to the incineration line hoppers. In order to ensure permanent availability, two (or more) overhead cranes are installed.

Adequately mixing the waste before incineration has a beneficial effect on the waste incineration process. The operation of process control systems, as discussed in section 2.2.4, is easier with less variations in the waste quality. In order to mix adequately the waste bunker should have sufficient capacity. Crane personnel should use available crane and bunker capacity. Direct personal communication between crane operators and process operators is recommended, as this leads to a better motivation of the crane operators to keep their full attention on adequate mixing.

The bunker (including the covered platform) is ventilated by extracting most of the incineration air out of this area. In this way, odour emissions are effectively prevented from polluting the plant's direct environment. An equally important effect of such a ventilation is the improvement of working conditions in the unloading hall.

The bunker area is equipped with appropriate equipment for detecting and extinguishing fires. In some cases, dust emissions in the bunker area are reduced by spraying small amounts of water over the waste surface.

Platforms and bunkers must be large enough to cope with daily, weekly, and seasonal fluctuations in the amount of supplied waste. For these reasons, a minimum of two incineration lines is required. Generally, the bunker's storage capacity can provide for at least four days of full incineration capacity.

The platform must be large enough to accommodate large bulk transport trucks. Also, the number of unloading positions is determined by taking into account the usual fluctuations in the hourly number of trucks arriving at the plant.

The cranes are operated from air-conditioned cabins. Crane operation systems are at least semi-automatic. This means that hopper positions are pre-programmed, and that cranes are prevented from colliding with each other and are equipped with automatic weighing provisions. Modern developments include a further automatisisation of crane procedures.

2.2.2

Grate technology

Grate technology is the basic technology for municipal waste incineration (and also applicable for various other waste categories). Various suppliers offer specific technical designs that show operational differences. The main design principle can be described as follows (see also figure 2.1).

The waste, which is stored and mixed in the bunker is dumped by a crane into a hopper. From the hopper, the waste passes a chute, normally filled with waste, before arriving at the dosing system, which doses the waste on the grate. The waste in the chute prevents the introduction of air to the furnace ('false' air). For this purpose, the level of waste in the chute is controlled. Simultaneously, the incidental leakage of hot flue gases from the furnace to the bunker area (in case of unexpected pressure variations) is prevented. Additionally, the chute is cooled. The hopper and chute are designed to prevent plugging of waste.

The dosing system moves the waste towards the front side of the grate. The dosing of the waste is controlled by the speed of the system, which normally operates by means of a hydraulic drive.

The grate itself forms a surface, consisting of metal blocks that move between each other systematically. The waste is transported by this movement and/or by gravity, depending on the design of the grate. Various suppliers offer a number of different grate designs. The main differences are the slope of the grate, from horizontal grates to grates with a slope of approximately 30°; the presence of steps in the grate; and the movement of the grate blocks (forwards, backwards, and combinations). Other differences are the grate's driving system, the block form and material, the connections between the blocks, the way of cooling the blocks, the air distribution system, etc. Additionally grates with rotating rollers (see figure 2.2) are used.

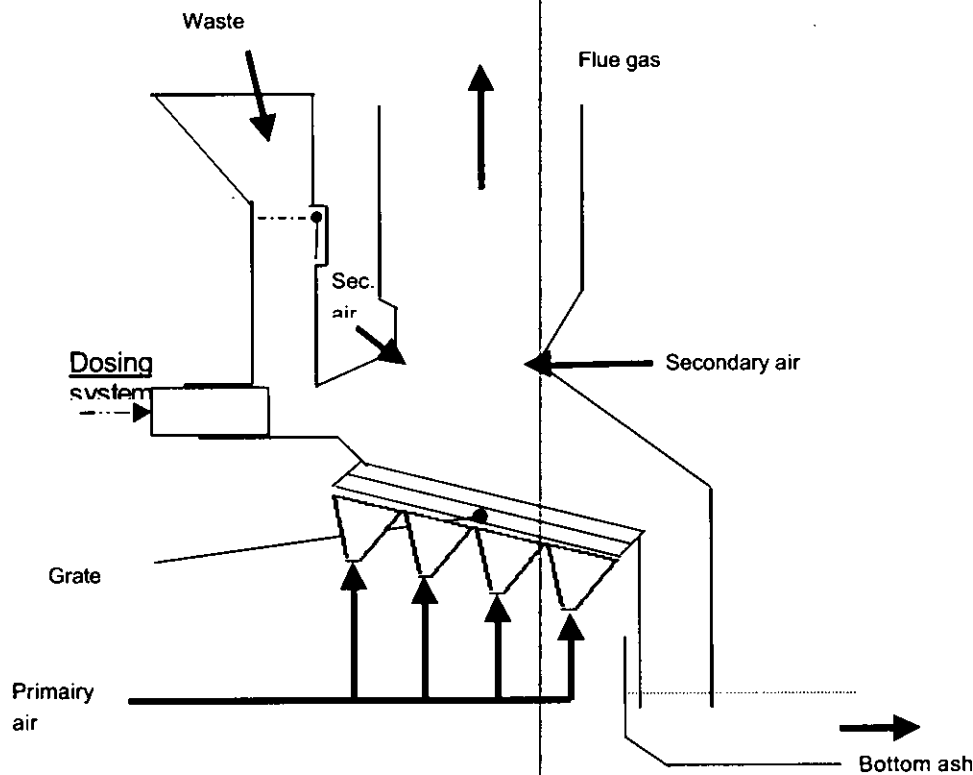


Figure 2.1 Grate technology

Primary combustion air passes through the grate from below, simultaneously cooling the grate blocks. From the front side of the grate to the end, the waste passes through the following stages: heating up, drying, gasifying, ignition, incineration and burning out. In order to adapt the amount of air to the requirements of the various stages of the process, the air distribution system for primary air is divided into a number of compartments. Large grates can have compartments in length and in width. The amount of air per compartment can be controlled. For waste with a high moisture content, air can be preheated, which will speed up the drying process and improve the gasifying and incineration stages of the process.

The waste's total residence time, from dosing to arrival at the end of the grate, is approximately 1 – 2 hours. At the end of the grate, the waste falls through a chute into a water basin. In this manner, the incineration residue, or 'bottom-ash', is cooled down before further treatment takes place. The amount of bottom-ash is approximately 25 weight % (or approximately 10 volume %) of the original waste. The water basin also prevents false air from entering the furnace, because false air can disturb the optimal distribution of incineration air. Fine materials, which have passed through the grate, are collected. Depending on the grate design, this amount is limited and is added to the bottom-ash.

Normally, grates are between 7 - 10 meters long. The width of the grate is largely dependent on the capacity of the incineration unit and can vary from several meters to more than 10 meters for large capacity units (25 - 30 t/h).

The grate designs used by the various suppliers show certain **differences in the relative movement of grate blocks and in the inclination of the grate**, such as:

- reciprocating movement, in which half of the grate blocks move backwards on a steeply inclined grate (Martin München), resulting in an efficient mixing of the waste on the grate. However, as the grate must be rather steep, movement of waste is more difficult to control;
- forward moving grates, with a less steep, or even horizontal, slope of the grate (Von Roll, Noell);
- combined forward and backward movements of the grate blocks (ABB), in combination with a horizontal grate;
- roller grates (Deutsche Babcock, System Düsseldorf), see figure 2.2.

The design of the roller grate results in a less controlled movement and distribution of the waste over the grate than with other grate types. This leads to a less effective mixing of the waste and a less controlled air distribution. These negative effects can be compensated by specific design measures.

These design measures consist mainly of:

- adaptation of the grate bars;
- reinforcement of the roller construction (which results in less deformation and a more controlled distribution of primary incineration air);
- placing the end position of the furnace over the grate (see figure 2.4).

The main advantage of the roller grate system over the grate block system is the intermittent exposure of the grate material to the incineration process, resulting in lower average material temperatures and, therefore, a longer lifetime for the grate bars and less maintenance.

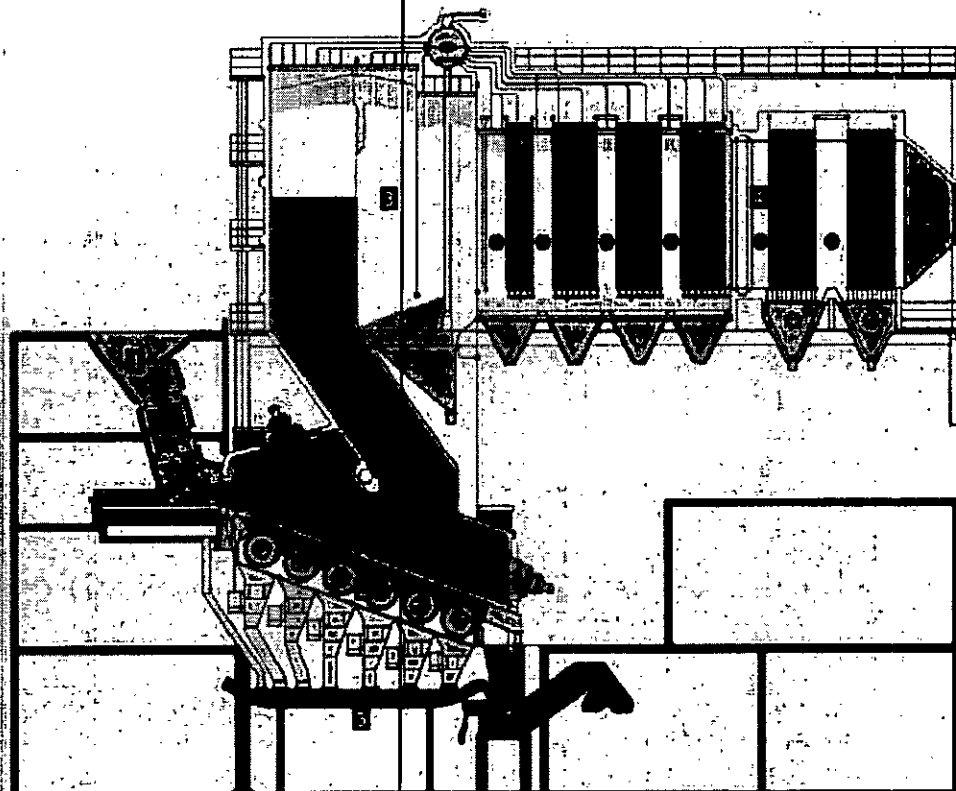


Figure 2.2: Roller grate technology

Deslagger systems

Deslaggers are filled with water and normally operate waste water free. They form a water seal, in order to avoid the entrance of false air in the furnace at the end of the grate. Additionally, the bottom ash is cooled, before further treatment takes place.

There are two main types of deslaggers:

- water basin deslaggers with chain conveyers;
- pusher deslaggers.

In terms of process, there are no significant differences between these two types. However, mechanical load of the water basin deslagger is somewhat lower than that of the pusher deslagger; and the water content of the bottom ash of the pusher deslagger is normally somewhat lower than the one of the water basin deslagger. Main operational problems are blockages of the deslaggers by bulky parts and/or breaking of conveyer chains.

Hot bottom ash causes water evaporation; therefore the deslaggers can be used for disposing of contaminated (non-organic) waste water streams (e.g. leachate of the open-air bottom ash storage area).

Furthermore, it can be mentioned here, that wet deslaggers can also be used for washing the bottom-ash, see section 2.2.4.

Dry deslagger systems are also discussed in section 2.2.4.

Short summary

grate incineration

- all eleven Dutch waste incineration plants use **grate technology**, of various designs.
- this shows that grate technology is a satisfactory system for incinerating municipal waste, because of its flexibility with respect to character, composition and lower heating value (LHV) of the waste.
- grate design can be adapted to suit various types of waste and the expected waste characteristics.
- the grate system must have an adequate mechanical design, based on sufficient practical experience .
- the grate system should enable adequate dosing and mixing of the waste on the grate.
- grate systems can operate with various inclinations.
- the grate system must enable an adequate distribution of primary incineration air, with preheating possibilities, depending on waste characteristics.
- roller grate technology is more sensitive for inadequate mixing and primary air distribution is more difficult to control.
- pre-heating of primary incineration air has a positive influence on incineration, especially on waste with relatively low Lower Heating Value (LHV) levels.
- main application of grate technology is the incineration of municipal and comparable waste, but the system can be applied for many other solid waste types as well. Only certain types of waste (various hazardous wastes, sludges etc.) cannot be incinerated, or can only be incinerated in limited amounts.

deslagging

- both the water basin and pusher deslagger are satisfactory systems.
- both systems can operate waste water free and even offer the possibility to evaporate other waste water streams.
- the lower mechanical load of the water basin deslagger is an advantage.
- the lower water content of the bottom ash of the pusher deslagger is an advantage.

2.2.3 Furnace with secondary air system

During drying, gasifying, incineration, and burn-out on the grate, the combustible waste materials are transformed into gaseous form. These gases are a mixture of many volatile components, which must be further oxidised. For this purpose, additional air (so-called secondary air) is introduced into the furnace. The amount of secondary air is normally between 20% and 40% of the total amount of incineration air.

For a complete burn-out of the flue gases, the following conditions are of importance:

- availability of sufficient oxygen by supplying sufficient excess air. For grate incineration, an oxygen content of approx. 6% in the flue gas after incineration is considered as a minimum;

- sufficient temperature ($>850^{\circ}\text{C}$);
- sufficient residence time (2 seconds over $> 850^{\circ}\text{C}$);
- sufficient homogeneity; i.e. sufficient mixing of the flue gas.

The indicated conditions for temperature and residence time are included in the European and Dutch environmental standards, for oxygen content only in the present Dutch standard. It is, however, important to note that these values are included in present legislation but are not to be considered as absolute conditions from a technical point of view. More important is that the incineration process is well controlled and complete, resulting in low emission concentrations for CO and C_xH_y .

The development of modern technology is directed towards an improved homogeneity of the incineration process, allowing lower O_2 -concentrations and in some cases also lower incineration temperatures.

The incineration temperature is influenced by the Lower Heating Value (LHV) of the waste (in particular the moisture content). The incineration temperature can be raised by preheating the incineration air, and lowered by allowing in more incineration air. Sufficient residence time mainly depends on the dimensions of the furnace.

To mix the hot flue gases, secondary air is blown into the furnace through a large number of nozzles, which ensures that the furnace's entire cross section is sufficiently covered. Because the mixing of hot gases requires sufficient mixing energy, the secondary air is blown in at relatively high speed. Additionally, dimensions of the furnace are selected, which ensure adequate flue gas flow patterns and sufficient overall residence times. As indicated above, the (legal) standard is a minimum of 2 seconds for temperatures above 850°C .

Grate incineration has a large flexibility with regard to LHV and waste characteristics. Figure 2.3 provides an example of a waste incineration diagram, indicating the variations in capacity and LHV that are acceptable for a grate incineration system.

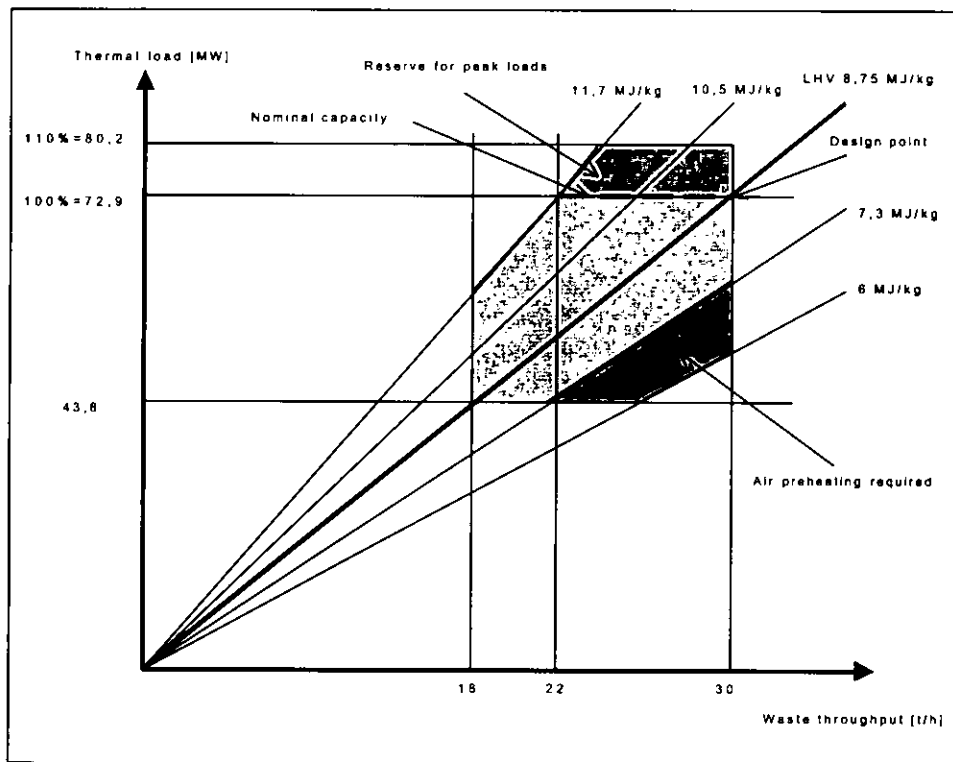


Figure 2.3: Example of an incineration diagram

In the diagram, the horizontal axis represents capacity in tons; the vertical axis represents the thermal load, given in GJ per hour and in MW. The average LHV may vary considerably (in this example between 6.0 and 11.7 GJ/ton). The hatched area indicates normal operation. Waste with low LHV requires air preheating (darkly hatched). Because of variations in the waste composition, approx. 10 - 15% of spare capacity is required for short additional peak loads.

As with the grate designs, the furnace designs of various suppliers also differ in some respects, such as:

- the protection of the membrane walls;
- the position of the furnace above the grate;
- the use of additional empty passes before the convection part of the boiler.

These differences are discussed hereafter.

Protection of the membrane walls

The furnace is formed by membrane walls¹, which are part of the boiler's evaporation section. In the lower section of the furnace especially, the membrane walls must be

¹ consisting of rows of vertical tubes, connected by strips, welded together in order to form a closed (membrane) wall.

protected against the corrosive and abrasive effect of the flue gases, which are not yet fully incinerated at that position. For this purpose, the furnace walls of the lower section are covered with a layer of ceramic material. An additional advantage of this wall protection is the reduction of the heat transfer to the boiler, which facilitates the realisation of a sufficient residence time for flue gases above 850°C.

It should be mentioned, that with the present high LHV of municipal waste, this temperature level is normally reached without problems. The main purpose of the ceramic layer is therefore the protection of the furnace walls against high temperature corrosion. As a result of higher steam conditions and a higher LHV of the incinerated waste, this aspect has had an increased importance for Dutch municipal waste incineration plants, resulting in a larger part of the furnace walls being covered with ceramic material. An alternative solution is the use of specific anti-corrosive alloys (see section 2.2.6).

In the furnace, it is possible that large amounts of solidified ash will form deposits against the side walls. This is the result of slightly molten fly ash, which coagulates under certain process conditions (depending on temperature and eutectica of the ash components). These formations can become more than one meter thick and damage the walls and/or reduce furnace space so much that incineration capacity is substantially reduced. Removing these formations must be done manually and therefore requires a full stop of the unit.

Several techniques have been developed to prevent the formation of solidified ash deposits. The first option is to cool the furnace's side walls, which lowers the ash temperature, causing the ash to solidify before it reaches the furnace wall. The second option is to design the furnace with a lower specific heat load (larger dimensions for the same thermal capacity).

Position of the furnace above the grate

There are three main configurations for positioning the furnace above the grate (see figure 2.4):

- front position;
- middle position;
- end position.

The main advantage of the front position is that the furnace is over the front side of the grate, where heating up and drying the waste requires intense heat. Heat radiation is an efficient method for this purpose. The main advantage of the end position is the fact that all flue gases, including those from the drying zone, have to pass above the hottest part of the grate, resulting in better conditions for ensuring the complete combustion of flue gases in the furnace. The middle position is a compromise between the other two configurations.

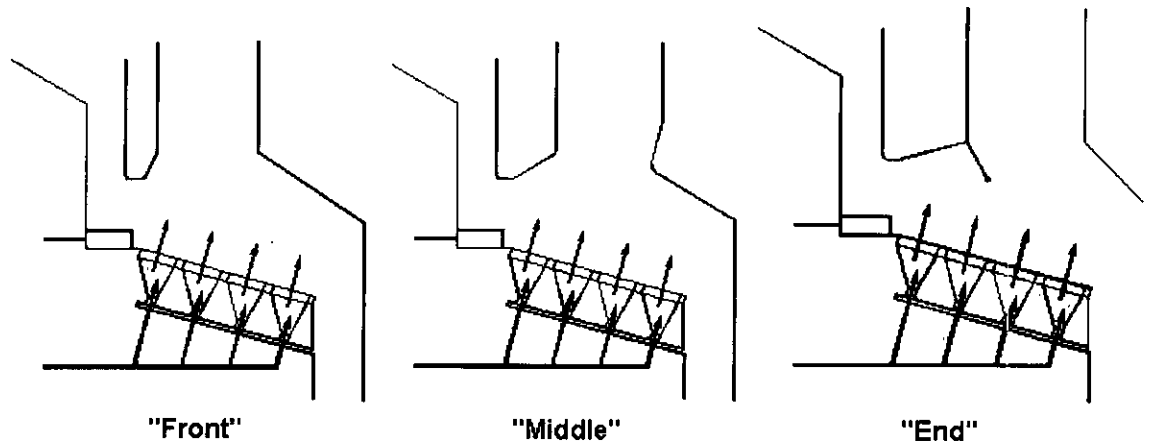


Figure 2.4: Furnace positions

Various suppliers use different designs for the furnace position, depending on their experience. With all designs, however, a satisfactory incineration process can be achieved, if there is sufficient mixing of flue gases in the furnace by secondary air.

Application of start-up and auxiliary burners

According to the EU-directive on waste incineration, municipal waste incineration plants should use oil or gas burners for start-up and additional heating in case incineration temperatures are below 850 °C. The application of these burners is however connected with consumption of fossil energy and with relatively high investment and operational costs and efforts.

Competent licensing authorities can deviate from this regulation if conditions allow so, especially for the emission of organic pollutants.

Recent investigations (see lit. [191]) have shown, that adequate incineration conditions during the start-up phase (i.e. a well controlled start-up process on the grate) can be realised without the use of start-up burners. An important condition is that there is maintained a good waste quality (high LHV, homogenous material) and a well-controlled position of the waste on the grate. In that case, start-up effects, caused by the heating-up phase in furnace and boiler are comparable with a start-up by means of start-up burners.

As already has been remarked, incineration temperatures >850°C can be maintained without problems with the actual relatively high LHV of the municipal waste and with modern incineration control systems. Therefore the regulations on start-up and/or auxiliary burners can be waived under certain conditions.

Application of additional empty passes after the furnace

In some cases the furnace is followed by one or more empty boiler passes, which reduces flue gas temperatures before the flue gases come in into direct contact with the convection section of the boiler. This has the additional advantage that part of the

boiler ash is removed before the convection surface is reached. In this respect there is no stated preference, provided the furnace and boiler designs are satisfactory with regard to specific heat load, temperature levels and (even) flue gas flow conditions.

In order to check an even distribution of flue gas flow, two- or three-dimensional flow tests with computer simulations or in scale models can be used.

Short summary

furnace design

- the furnace is an important element in the design of a grate incineration system. In modern municipal waste incineration plants, the furnace walls form part of the boiler system (evaporation).
- the dimensions of the furnace must be sufficiently large to enable low flue gas speeds and sufficient residence time (>2 sec over 850°C).
- the furnace volume can be increased by adding one or more empty passes.
- the design of the secondary air system is important. Secondary air should be effective over the entire cross section of the furnace.
- for new furnace designs, adequate flue gas flow patterns should be first tested in a computer simulation or a laboratory scale model.
- refractory lining must be used to protect the lower section of the furnace.
- the positions of the furnace over the grate all have their advantages and disadvantages. The middle position is a good compromise.
- empty boiler passes have a favourable effect on process conditions in the convection part of the boiler (less fly ash, lower temperatures), but are not necessary if furnace design is adequate. Application depends on suppliers and operators experience and preference.
- start-up and auxiliary burners are included in EU-directives, but research has shown, that with adequate provisions a safe operation is possible without such burner systems.

2.2.4 Modern developments in incineration technology and furnace design

Incineration control systems

One of the main problems with municipal waste incineration is the wide variety of waste composition, including properties that have a determining effect on the incineration process. This results in an incineration process that can cope with large variations in process conditions. When unfavourable process conditions occur, manual interventions in operation control are required.

The introduction of sophisticated control systems is, therefore, an important development. These systems result in an incineration process that has less variations in time (improved stability) and place (more homogeneous). The improved process control has many advantages, such as (the main reason(s) for the improvement are given in parentheses):

- better bottom-ash quality (due to sufficient primary air distribution and a better positioning of the incineration process on the grate);
- less fly ash production (due to less variations in the amount of primary incineration air);

- better fly ash quality (less unburned material, due to more stable process conditions in the furnace);
- less CO and C_xH_y-formation (due to more stable process conditions in the furnace; i.e. no 'cold' spots);
- less NO_x-formation (due to more stable process conditions in the furnace; i.e. no 'hot' spots);
- less (risks on) formation of dioxin(-precursors) (due to a more stable process in the furnace);
- better utilisation of the capacity (because the loss of thermal capacity by variations is reduced);
- better energy efficiency (because the average amount of incineration air is reduced);
- better boiler operation (because the temperature is more stable, there are less temperature 'peaks' and thus less risk of corrosion and clogging fly ash formations);
- better operation of the flue gas treatment system (because the amount and the composition of the flue gases is more stable);
- the indicated advantages also result in less maintenance and better plant availability.

In order to be able to control the incineration process, detailed process information is required, a control system ('philosophy') must be designed, and it is necessary to be able to intervene in the process. Design of the overall control system depends on the specific grate and furnace design of each supplier. In this report, therefore, we have confined ourselves to providing an overview of potential process information, control philosophy systems and process interventions.

Process information may include:

- grate temperatures for various positions;
- thickness of waste layer on the grate;
- pressure drop over the grate;
- furnace and flue gas temperatures at various positions;
- determination of temperature distribution over the grate surface by optic or infrared measurement systems;
- CO-, O₂-, CO₂- and/or H₂O-measurements (at various positions);
- steam production.

The control philosophy may be a classic control system, which is included in the process control computer. Additionally, fuzzy control systems are applicable.

Control interventions include:

- the dosing system for the waste;
- frequencies and speed of grate movements in various parts of the grate;
- amount and distribution of primary air at the various grate compartments;
- temperature of the primary air (if preheating facilities are available);
- amount and distribution of secondary air in the furnace (and, if available, of recirculation gas).

Washing of bottom ash in deslaggers

As will be indicated in section 3.3.2, bottom ash has problems to comply with the Dutch Building Materials Decree for use as secondary civil construction materials. As indicated there, critical aspects are the too high leachability of copper and molybdene.

Leachability of bottom ash can be reduced by washing the bottom ash in the deslagger. In this case the deslagger cannot operate waste water free. The waste water from the deslagger can be treated in combination with the waste water of a wet flue gas treatment system (see section 4.5.2).

Bottom ash quality may additionally be improved by addition of specific chemicals (phosphate, sulphides etc.). Though various experiments have been executed in this field, practical experience and evaluation of results is limited.

For treatment techniques for bottom ash we further refer to section 4.6.2.

Dry deslagging systems

The bottom ash from the normally applied wet deslaggers is drenched with water. This has following disadvantages:

- an increase of weight;
- reduced possibilities for further bottom ash treatment. Separation of iron scrap and non-ferrous metals from the bottom ash is more difficult.

Additionally, it can be noted, that the pH of the bottom ash increases, due to the presence of quick lime (CaO) in the bottom ash after incineration. This results in the formation of (hydr-)oxides of elementary metals (iron, aluminium), reducing the possibilities of recovery and in a sintering process, reducing the possibilities of sieving out glass, stone, ceramic materials etc.

For these reasons there is an increasing interest in dry deslagging systems. However, experiments on practical scale have not yet been executed in the Netherlands.

Water (or steam) cooled grates

In the past few decades, the LHV levels in municipal waste have substantially increased. This is partly due to an increased consumption of paper and plastic materials, etc. Also, the wide-spread introduction of segregated collection of organic waste, with its relatively low LHV has resulted in an increase of the LHV of the remaining waste. Especially incineration plants with preceding mechanical separation of organic wet material must cope with relatively high LHV's of the combustible fraction.

In common grate types, the grate material is cooled by primary combustion air. Normally, the grate blocks are designed to facilitate sufficient contact between air and block. In roller grates, the cooling of the grate material is improved by intermittent exposure to the burning waste material.

Nevertheless, the lifetime of the grate material is limited, especially for the grate material in the incineration zone. Moreover, the lifetime of the grate material is reduced

considerably by higher LHV's in the waste, even if specific alloys are used as grate block materials.

This has resulted in the development of water cooled grates. With these grates, grate block temperatures are kept significantly lower. An additional advantage is that there is more flexibility in selecting the optimal amount and distribution of primary air.

Although warm cooling water can be applied for heating purposes, water cooling results in a slight reduction of energy efficiency. Approx. 3 - 5% of thermal capacity is lost and therefore is not available for steam (and electricity) production. This results in a reduction of electrical efficiency of less than 1%. Plant capacity, however, is slightly increased by reduction of the thermal load of the flue gas stream.

Practical experience with water cooled grates is limited in comparison with air cooled grates, but operational experience is reported to be good.

A new, comparable development is the use of steam as a cooling medium. With this concept, grate material temperatures are higher than with water cooling, but can be kept at sufficiently low levels. An advantage of steam cooling is a better overall energy efficiency and a higher temperature of the grate material, which can improve combustion behaviour. There is however no practical experience with steam cooled grates in the Netherlands.

Special secondary air distribution systems

As indicated in section 2.2.3, an adequate secondary air system is of prime importance for an optimal incineration process in the furnace. Secondary air is introduced from both sides (front and rear) of the furnace.

In modern incineration plants with high capacities, furnace dimensions are so large, that an equal distribution of secondary air is difficult to realise, as the distance over which the air must be blown in is too large. For this reason, cooled beams with additional air nozzles, located across the furnace can be applied.

Recirculation of flue gases

To achieve an adequate homogeneity of flue gases, a certain amount of secondary air is required. However, more secondary air results in a higher flue gas amount. This has a negative influence on the energy efficiency of the plant, leading to larger flue gas treatment units and, therefore, higher costs.

A current development is to use part of the cooled flue gases, after the dust has been removed, instead of (part of) the required secondary air. The technical configuration for the recirculation of flue gas is shown in figure 2.5.

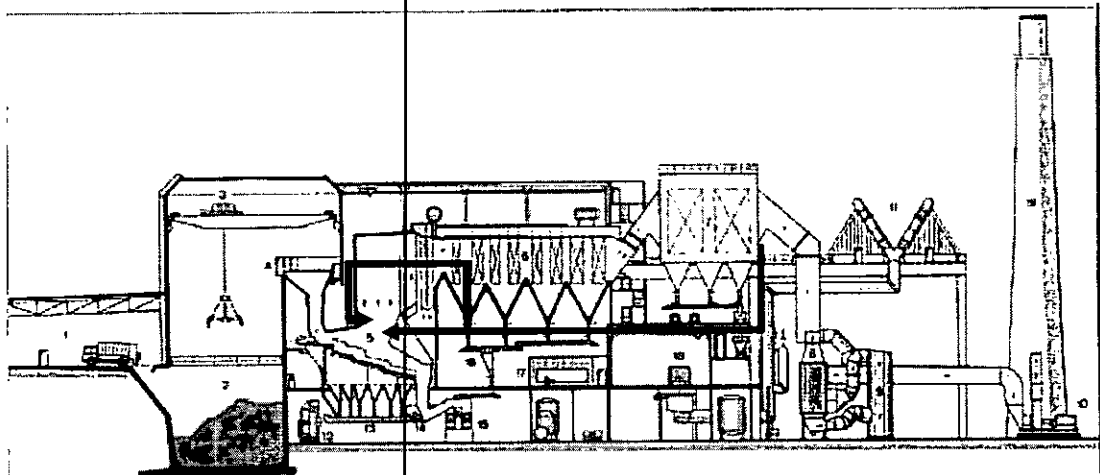


Figure 2.5. Recirculation of flue gases (in combination with secondary air)

Approximately 50% of the required amount of secondary air can be replaced by recirculating flue gases. This results in a 10 - 15% reduction of the total amount of incineration air and flue gases. The load of the flue gas treatment system is reduced proportionally (resulting also in a reduction of emission loads) and the thermal efficiency of the plant increases by approximately 2 - 3%. This increase has however a limitation, as oxygen content of the flue gas cannot be reduced without restrictions (<6%).

Recirculation of flue gas as a replacement for primary air is not used in existing municipal waste incineration plants. In the past, plants have used this system, but the acid gases which remain in the flue gases after dust removal led to serious corrosion problems in the relatively cool installation parts under the grate.

AVI Amsterdam will research and test this system in future, as indicated in figure 2.6. The primary air for the first one or two zones will (partially) be replaced by recirculating flue gases. Expected advantages are a better drying behaviour, resulting from the higher temperatures, and a slower ignition of the waste, resulting from the lower oxygen content. This will result in a better positioning of the incineration process on the grate. Additionally, the energy efficiency is improved.

Corrosion problems will be solved by using special materials or by keeping the system on a higher temperature level.

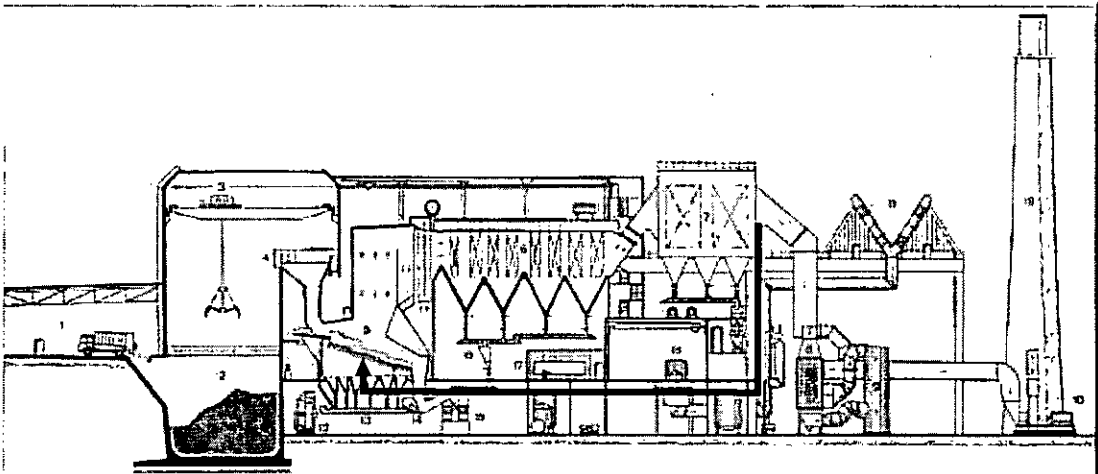


Figure 2.6: Recirculation of flue gases (as part of the primary air)

Application of oxygen-enriched air

The effectiveness of the incineration process can be improved by enriching the incineration air with (technically) pure oxygen. In this way, the amount of incineration air can be reduced. This results in an increase in thermal efficiency (higher incineration temperatures, less flue gas losses) and a reduction of the flue gas amount that requires treatment. Test results have shown, that an adequate control of the incineration process is facilitated by application of oxygen enriched air.

Energy consumption for oxygen production is however substantial, compensating the increase of thermal efficiency, and cost effectiveness is low. There has been executed a theoretical study on the effects on a Dutch grate incineration plant, including some laboratory tests. Results show that the application of enriched air can be connected with locally increased temperatures and increased concentrations of damaging compounds, resulting in increased risks on corrosion.

The system is not applied in existing Dutch municipal waste incineration plants. Based on the results of the indicated study, the application of oxygen-enriched air will most likely be limited to very specific cases.

Application of higher incineration temperatures

By adaptation of the furnace design, it is possible to achieve higher incineration temperatures of up to 1100 – 1200 °C. To achieve these higher temperatures, the following (combinations of) measures are required:

- preheating the incineration air;
- reducing the amount of incineration air;
- adaptation of the furnace design (no membrane boiler walls, but isolated refractory).

The purpose of this design is to improve the incineration process, thereby reducing the formation of components like CO, C_xH_y and other organic compounds, such as dioxin(-precursors). NO_x-concentration levels, however, could be substantially higher.

Achieving higher incineration temperatures requires substantially higher investment costs, and plant availability may be reduced.

There is no practical experience with this type of municipal waste system in the Netherlands. A demonstration plant has been realised in Bremerhaven (Germany). In the Netherlands, higher incineration temperatures are used when incinerating hazardous waste.

Short summary

new developments on incineration technology

- all existing Dutch municipal waste incineration plants use modern incineration control techniques in order to improve the incineration processes. Although there are differences in set-up, this option is considered to be an important improvement (a.o. application of fuzzy logic).
- possibilities to improve bottom ash quality by washing bottom ash in the deslagers are in an experimental stage.
- there is an increasing interest in application of dry deslagers.
- most of the existing Dutch plants use traditional air cooled grates. Under the influence of increasing LHV's, there is a clear preference/tendency for water cooled grates.
- also improvement of secondary air systems is actually an important development.
- recirculation of flue gases is used as a replacement for part of the secondary air in several cases. The advantages are a reduction of flue gas volume, of NO_x-concentrations and an improvement of energy efficiency.
- recirculation of flue gases as primary air has not yet been applied, but will be researched.
- there is no application of oxygen-enriched air in the Netherlands. Application will probably be limited to very specific cases
- there is also no application of extra high incineration temperatures (> 1100°C) for municipal waste incineration in the Netherlands.

For a description of incineration systems, other than the grate incineration type see section 2.2.7.

For reference literature on sections 2.1 – 2.2.4, see chapter 7, references [1] – [25].

2.2.5 Related boiler technology

This section provides a description of the boiler technology used for the incineration of municipal waste. The description is based on the use of grate incineration technology. It should be mentioned however, that boiler designs of other incineration systems are comparable.

The hot flue gases that are emitted from the furnace are cooled down in the boiler. Boiler design must be adapted to the special characteristics of the waste incineration flue gases:

- the flue gas contains solid particles and fly ash, which are polluted with a wide variety of heavy metals, salts and other compounds;
- the flue gas also contains high concentrations of gaseous polluting components, such as hydrochloric acid, hydrofluoric acid, sulphur dioxide and nitrogen oxides.

These compounds can cause boiler clogging, erosion and/or corrosion. Special attention must be paid to the high temperature corrosion of the boiler tube material, due to the presence of chlorine. Normal boiler tube material suffers corrosion at tempera-

ture levels exceeding 400 °C. At higher temperatures, the corrosion rate increases rapidly.

Another phenomenon that requires special attention is the relatively low melting point of the fly ash. This is caused by the complicated composition of the fly ash, which includes various salt compounds. The low melting point means there is a greater risk of the fly ash clogging at high temperatures.

The following design principles are implemented to avoid encountering the above mentioned problems:

- large furnaces, resulting in low gas velocities. This provides sufficient time for reducing flue gas temperatures before the first convection bundles of the boiler are reached (preferably below 650 °C). It also reduces the fly ash content of the flue gases;
- application of additional 'empty' passes in the boiler, which further reduces the flue gas temperature before the convection section. The fly ash content is reduced by the change in direction of the flue gas stream;
- a first convection bundle with a relatively low temperature (evaporation section of the boiler) and large distance between the tubes. This section provides a sudden reduction of the flue gas temperature, resulting in a further solidification of the fly ash particles. It also protects the higher temperature boiler parts (superheaters) from peaks in flue gas temperature and improves the even distribution of the flue gas before the first superheater;
- application of moderate steam conditions. The temperature of the boiler tube material is mainly determined by the interior temperature of the tube, as heat transfers from the interior is much better than from the outside. Application of moderate steam temperatures is therefore the best method to reduce the risk of high temperature corrosion. A temperature level of 400 °C is considered to be safe. A commonly used set of steam parameters is 400 °C and 40 bar. Higher temperatures may lead to accelerated corrosion rates. This low steam temperature results in a relatively low efficiency of electricity production, if compared with fossil power plants, where higher steam temperatures and pressures are used;
- an additional method to achieve some reduction of the maximum temperatures of boiler tube materials is to use concurrent flow (flue gas and superheated steam) for the last superheater. This results in a larger superheater surface, but the combination of the highest steam temperatures and flue gas temperatures is avoided;
- the distance between the tubes in the convection bundles is large enough to avoid clogging of fly ash. In critical areas, the tubes are arranged "in-line", which leads to a larger convection surface, but also to reduced clogging risks;
- convection bundles are equipped with special cleaning devices, such as soot blowers, knocking systems (which vibrate pipe bundles) or circulation systems for steel bullets. With these systems, time span between manual cleanings of the boiler surface is increased substantially.

Even with an optimal design, the boiler is one of the parts of the plant that needs adequate maintenance and is normally determining its overall availability.

Figures 2.7.a, b and c show examples of the boilers that incorporate the above mentioned design principles.

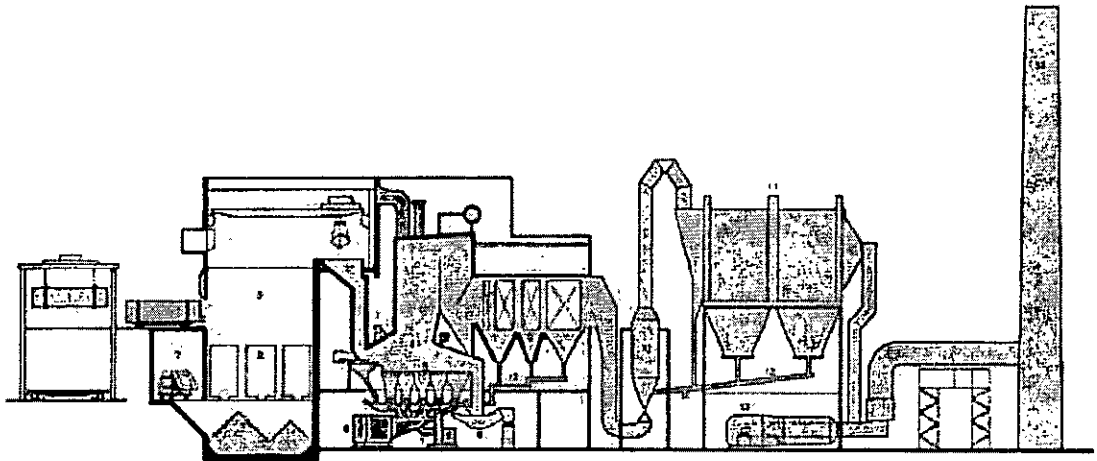
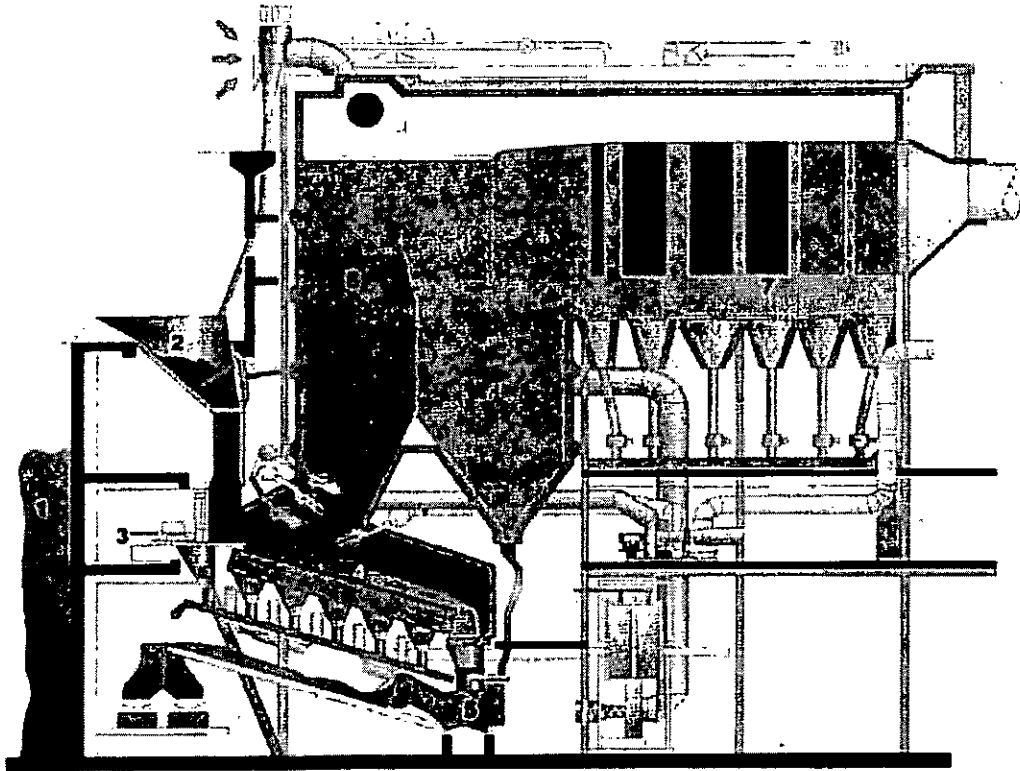


Figure 2.7.a/b Boilers for waste incineration

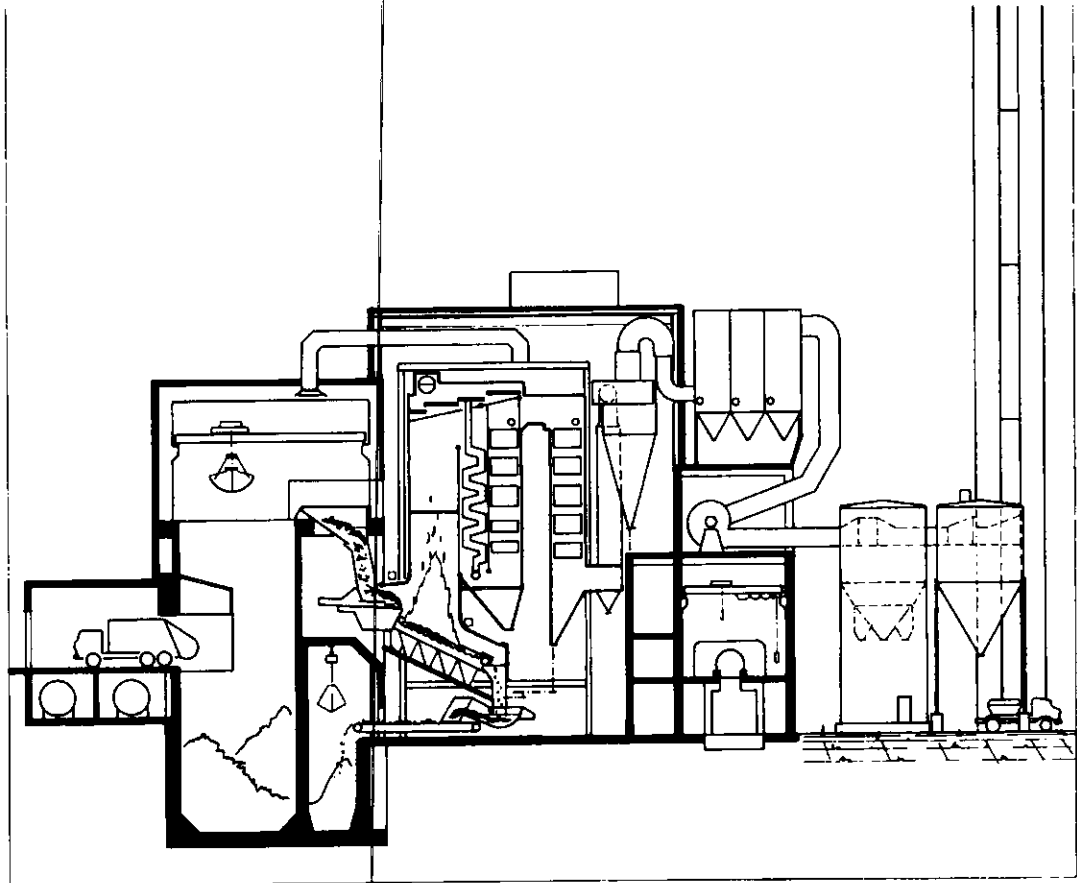


Figure 2.7.c Boiler for waste incineration

Short summary
boiler technology

- modern waste incineration boiler concepts are adequately able to cope with specific problems, such as high amounts of fly ash and gaseous pollutants (especially chlorine).
- an important design condition is the use of moderate steam conditions. This results however in a limited efficiency of electricity production.
- other design principles are low flue gas velocities, low flue gas temperatures before the first convection bundle and large distances between boiler tubes.
- another important feature of waste incineration boilers is the use of a specific cleaning system, in order to remove fly ash and to extend the time span between boiler cleaning.

2.2.6 Modern developments in boiler technology

As there is an increasing interest in energy recovery with an optimal thermal and electrical efficiency, there are a number of developments in boiler design, as described in this section.

Special configurations of the water/steam-cycle

As described in section 2.2.5, the efficiency of electricity production of municipal waste incineration is limited by the maximum acceptable temperature of boiler tube materials and by the related maximum steam temperature of approx. 400 °C.

To avoid these high temperatures of boiler tube material, the superheating of the steam can be achieved by using flue gases, which contain much less or no chlorine. This is possible if the municipal waste incineration plant can be combined with a power plant of sufficient capacity, using a fuel with a substantially lower chlorine content (e.g. fossil fuel or specific type of biomass).

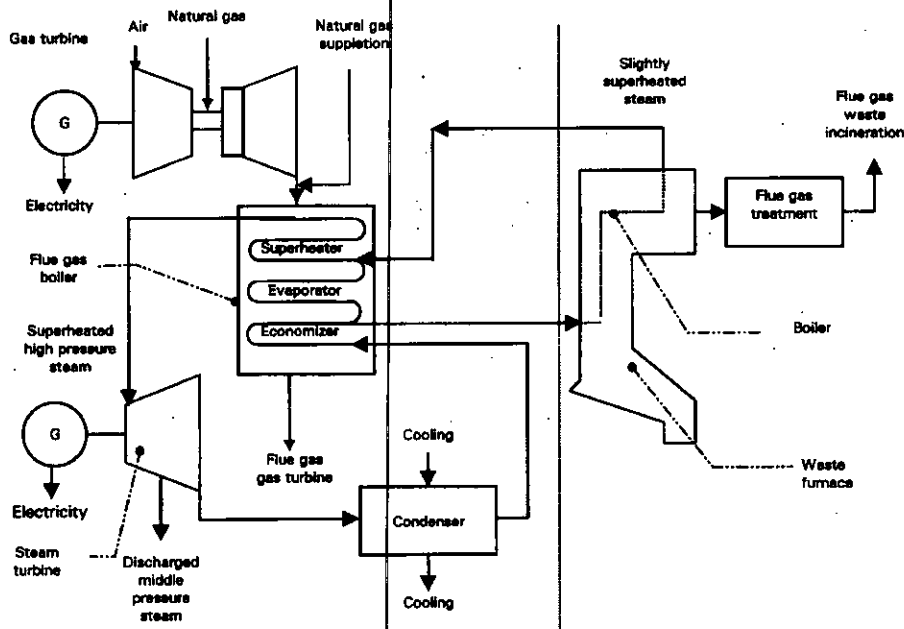


Figure 2.8: Configuration of a waste incineration plant, combined with a gasturbine power plant

This method is used at the municipal waste incineration plant in Moerdijk, the Netherlands. This waste incineration plant is combined with an adjacent combined cycle natural gas power plant, as indicated in figure 2.8. Steam of 100 bar, slightly superheated to 400 °C is supplied to the waste heat boilers of the gasturbine plant, where it is superheated to approximately 520 °C. Both the municipal waste incineration plant and the gas power plant have three separate lines. The design of the both plants' combined process schemes enables all incineration and gasturbine lines to operate independently, although, under these circumstances, with a lower energy efficiency.

A similar configuration can be used in the combination of a waste incineration plant with a coal power plant. The basic configuration of the combination is shown in figure 2.9. The coal power plant superheats the steam of the municipal incineration plant. In order to do this, the pressure of the steam, produced by the municipal waste incineration plant has to be higher than usual.

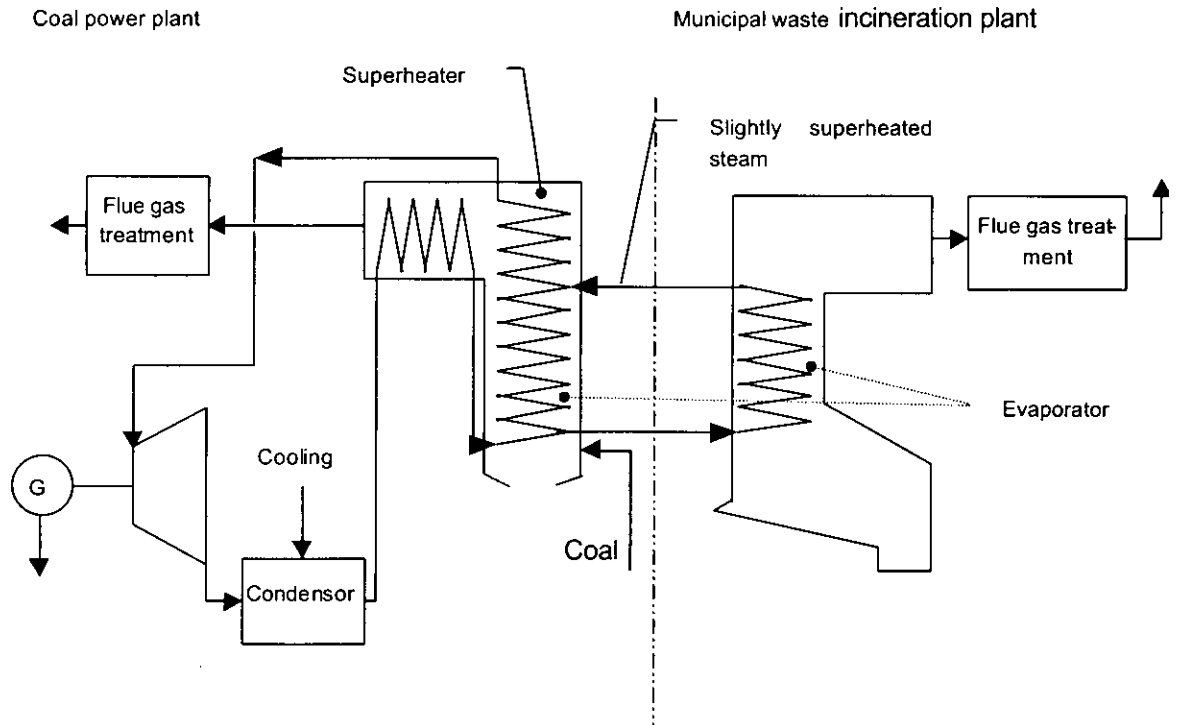


Figure 2.9: Municipal waste incineration plant in combination with a coal power plant

This configuration was already applied in the 1970s, by the combination of a municipal waste incineration plant in Munich with a large coal power plant. As the plant only functioned effectively when both the coal-fired boiler and waste incineration plant were operational simultaneously, the combination was not cost effective.

However, as a result of the increasing interest in higher energy efficiencies and the improved reliability and technical availability of municipal waste incineration plants, this design is once again under consideration in the Netherlands.

Application of re-superheating

Another option to increase the efficiency of electricity production is the application of re-superheating. For this application, steam temperature is limited to 400°C, but steam pressure increases. Figure 2.10 provides a simplified process scheme for this option.

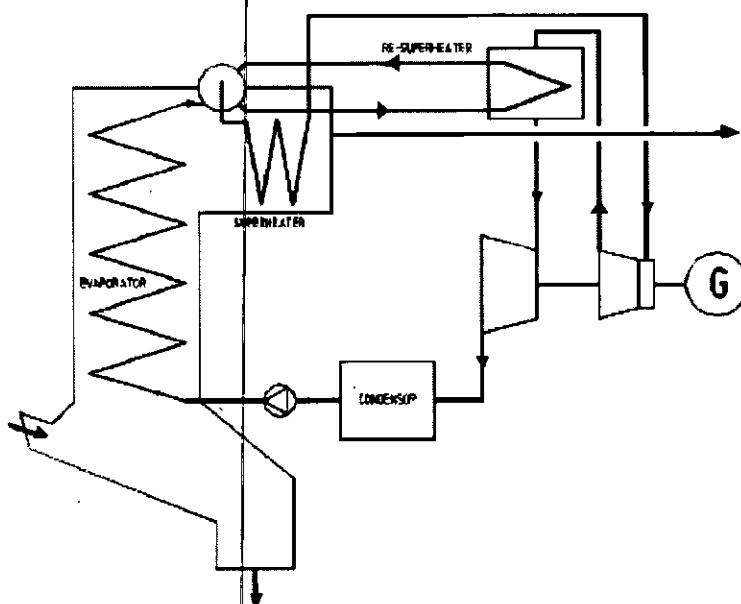


Figure 2.10: Example of re-superheating of steam

After the first passage through the high pressure section of the turbine, the resulting steam is superheated again and subsequently used in the turbine's middle and low pressure sections. This results in an increased electrical efficiency of approximately 2 – 3%-points.

This option has never been used for municipal waste incineration, although technological risks are considered to be limited. Application may be influenced by economic feasibility, which is mainly determined by additional investment costs and by electricity prices.

Application of special materials (ceramics, special alloys) for membrane walls and superheaters

The high temperature corrosion of membrane walls and superheaters can be reduced or prevented by the application of ceramic materials and/or special alloys, such as specific types of stainless steel.

As indicated in section 2.2.3, the lower part of the membrane walls around the furnace is covered with ceramic material, to protect the boiler against corrosion. With the increasing LHV of the waste and with increasing steam temperatures and pressure, temperatures in the upper part of the furnace have been increased also. To prevent corrosion in this part of the furnace application of ceramic materials (tiles) is introduced. Available operational experience is still limited, but results are promising.

In order to prevent corrosion on non-covered boiler parts (membrane walls, superheaters) many experiments with special alloys have been performed, using a wide variety of stainless steel types. In the first few years, most experiments failed, since additional energy efficiency did not compensate for higher material cost and the insufficient availability.

In recent years however good results have been reported with inconel and comparable alloys for application on (the upper part of) the membrane walls in the furnace of a.o. AVI Amsterdam, AVR Botlek, AVR AVIRA and AVI Wijster (see section 2.1.1). This technology was apparently a good solution for high temperature corrosion problems in the upper part of the furnace. These problems were the result of increased furnace temperatures, by the incineration of waste with a high LHV and/or by application of higher steam pressures. This results in a higher evaporation temperature of the water/steam cycle and therefore in higher membrane wall temperatures. The main advantage of this technique over a ceramic cover on the furnace walls is the better transfer of heat to the boiler, resulting in a lower temperature of the flue gases before the first convection bundles.

Application of special alloys on superheaters is still more in the developing phase.

Reduction of flue gas temperatures after the boiler

Normal flue gas temperatures at the tail end of the boiler (after the economiser) vary between 180 and 225 °C. The lower temperatures are realised in relatively clean boilers. During boiler operation, tail end temperature increases, resulting in a lower overall energy efficiency. So after a certain operational period, manual boiler cleaning is required.

Below 180 °C, there is an increased risk of low temperature corrosion, when staying below the dew point of the various acids (HCl, SO₂).

A new development is the use of heat exchangers made of special materials (enamel, carbon), which are able to reduce flue gas temperature after their passage through the economiser. Depending on the design of the flue gas treatment system, this reduction of flue gas temperature can be executed behind one or even more steps of the flue gas treatment system. An example is AVI Amsterdam, where the heat exchanger is located after the spray absorber system (see section 4.4.2) and the related ESP. The recovered heat (temperature level approx. 120 °C) can be used for heating purposes and/or for pre-heating of boiler feed water, etc. An additional advantage is the related reduction of scrubbing temperature, which improves the efficiency of the scrubbing system (see section 4.4.4).

Cleaning of waste boilers by explosions

A recent development in cleaning procedures for waste boilers is the use of small explosives, placed in the boiler in a controlled manner. The boiler ash is removed, resulting in substantially better heat transfer. The labour-intensive regular manual cleaning of the boiler (normally required every three months to once per year) can be reduced in frequency.

The experience with the system is still limited. It has not yet been established if it is cost-effective and if there are long-term negative effects on the mechanical design of the boiler. (references a.o. AVI ARN Beuningen, AVI Amsterdam, AVR, AVI Wijster, see section 2.1.1).

Cleaning of membrane walls by high pressure water injection

Another recent development is the cleaning of the membrane walls of the boiler in the upper part of the furnace by injection of water under high pressure. By this system, furnace walls are cleaned during normal operation in order to prevent accumulation of slag layers on the walls of the upper part of the furnace. This application results in a cleaner boiler and therefore in a better local heat transfer. Important advantage is, that the temperature of the flue gases will be reduced more effectively before they reach the first convection bundles, reducing the risks of deposits of sticky fly ash and high temperature corrosion

There is relatively little experience with this system, so information about cost-effectiveness and eventual negative effects is limited.

For reference literature on sections 2.2.5 – 2.2.6, see chapter 7, references [26] – [37].

Short summary

new developments on boiler technology and energy conversion

- the efficiency of electricity production of waste incineration plants is limited. The efficiency can however be improved by special configurations of the water/steam cycle. There is practical experience with the system, but special conditions are required.
- also a design with re-superheating of the steam may improve energy efficiency. Practical experience is not yet available.
- experience with special tube materials for superheaters, enabling higher steam temperatures and therefore better energy efficiency are promising. Cost level seems however rather high.
- another option for improvement of energy efficiency is the application of heat exchangers (material: enamel or carbon) for further reduction of boiler outlet temperature. Experience with these systems is still limited.
- current developments on boiler technology include new methods for boiler cleaning by explosions and/or by high-pressure water cleaning of the furnace

2.2.7

Application of other incineration systems for municipal waste

Grate incineration is the only system that has found large scale application for municipal waste incineration without preceding waste treatment. However, after mechanical treatment (see section 4.2.2) into a fluffy or pelletised RDF (refuse derived fuel), other incineration systems can be applied, such as:

- a. bubbling fluidised bed;
- b. circulating fluidised bed;
- c. spreader stoker.

Although these systems are not used in the Netherlands at this time, a short description is given, as application is occasionally considered.

a. Bubbling fluidised bed

In this system, RDF is fed into a sand bed, which is fluidised by an upward flowing air stream. Incineration takes place on a temperature level of approx. 850°C. Figure 2.11 shows the design of this type of plant.

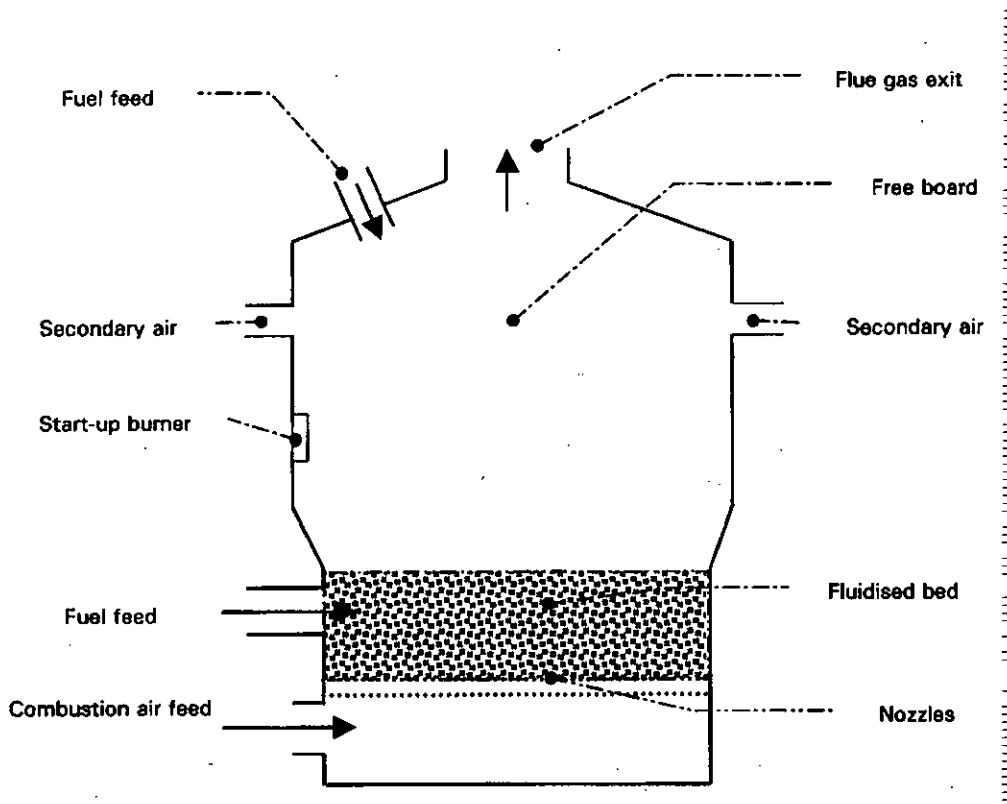


Figure 2.11: Bubbling fluidised bed incineration

The principal advantages of fluidised bed incineration are:

- the simple mechanical design;
- the intensive mixing of the fluidised bed, resulting in an effective incineration process;
- the possibility to add chemicals to the bed, which can reduce air emissions by absorption.

The following limitations, however, must also be considered:

- applied fuel must have a relatively small, regular particle size;
- process control is sensitive to changing compositions and calorific values;
- there is a risk of the formation of molten salt 'stones' in the bed. Especially alkaline salts (potash) may cause clogging problems.

Although some European countries have carried out demonstration projects (Berlin, Madrid), bubbling fluidised bed incineration is not considered as a preferable option for RDF from municipal waste, because of the limitations, indicated above. Application of bubbling fluidised bed is normal practice for sewage sludge incineration (see section 2.5, in particular 2.5.3) and for various types of biomass (see section 2.6, in particular 2.6.2).

b. Circulating fluidised bed

In circulating bed technology, air speed is increased in comparison with bubbling fluidised bed. This causes part of the particles to be blown out of the bed. The larger particles are removed from the flue gas stream by means of a high temperature cyclone and returned to the bed. An example of a circulating fluidised bed plant is shown in figure 2.12.

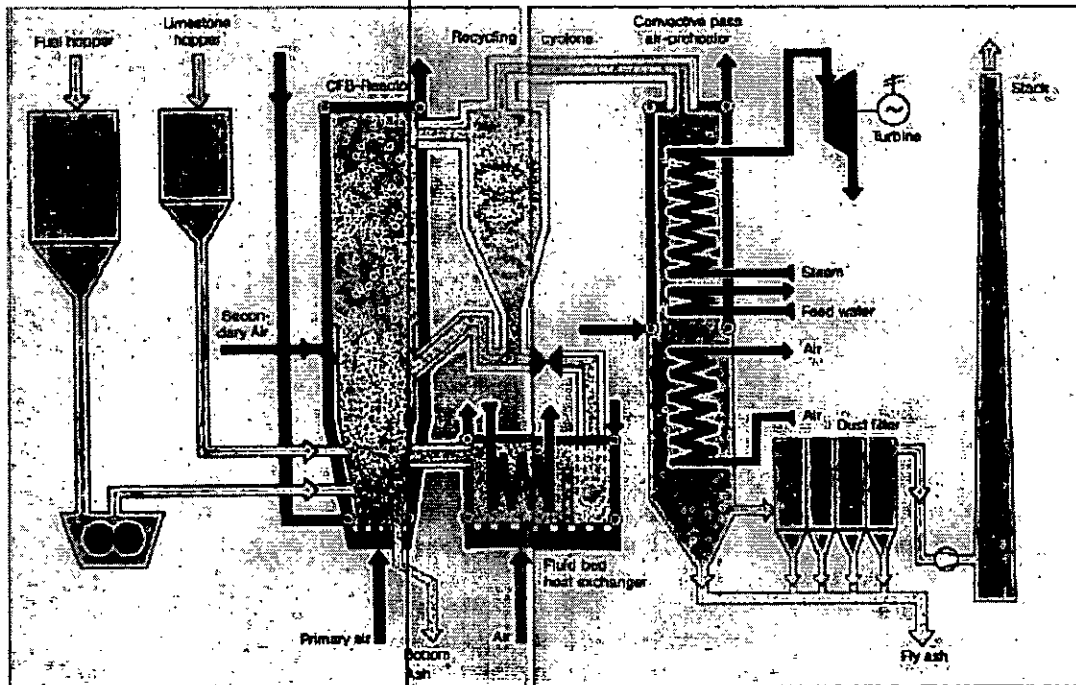


Figure 2.12: Circulating fluidised bed incineration

The advantages of the circulating bed technology over the bubbling bed technology are:

- its sensitivity for differences in particle size is less;
- also process control is less sensitive;
- the risk of clogging in the bed is reduced.

On the other hand, the mechanical design of a circulating bed system is more complicated.

The circulating fluidised bed system offers a special option: the hot recirculating ashes can be used for superheating purposes (in a separate fluidised bed heat exchanger). This option is applied with various circulating fluidised bed incineration plants in coal incineration and in the paper industry (in a.o. Austria and Scandinavia), as well as recently in a municipal waste sorting and incineration plant in Galicia, Spain (SOGAMA-project).

In this way, the final superheating of the produced steam can be executed without direct contact with the chlorine containing flue gases. This may reduce high-temperature corrosion effects and therefore lead to a higher efficiency of electricity production. There is however only limited experience with this ash cooler/superheater system

As a result of the advantages mentioned above, the circulating fluidised bed system is considered to be a potential option for incineration of monostreams, and eventually also for RDF from municipal waste. Presently, there exist various projects for the incineration of specific waste categories ('monostreams') in circulating fluidised bed systems in the Netherlands.

c. Spreader stoker

In this incineration system, RDF is fed into the furnace pneumatically at a height of several meters. Fine particles participate directly in the incineration process, while larger particles fall on the travelling grate, which is moving in the opposite direction. As the largest particles are spread over the greatest distance, they spend the longest time on the grate in order to complete the incineration process. Large amounts of secondary air ensure that the flue gases are adequately mixed in the incineration zone. Figures 2.13.a and b give an overview of the system.

The system should be considered as an intermediate system between grate and fluidised bed incineration. Its main advantage over grate incineration is its less complicated grate construction (due to a smaller thermal and mechanical load). The advantages over fluidised bed are that uniform particle size is less important and that there is no risk of bed clogging.

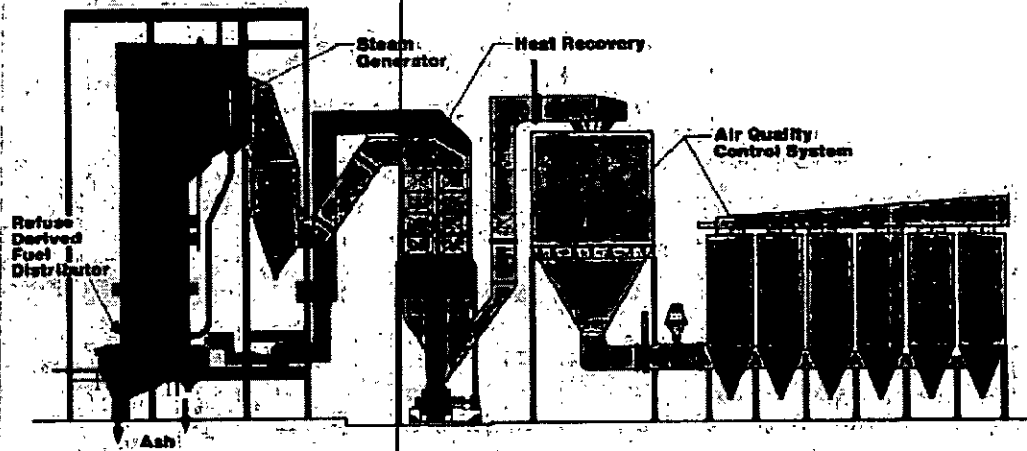


Figure 2.13.a: Spreader stoker waste incineration plant

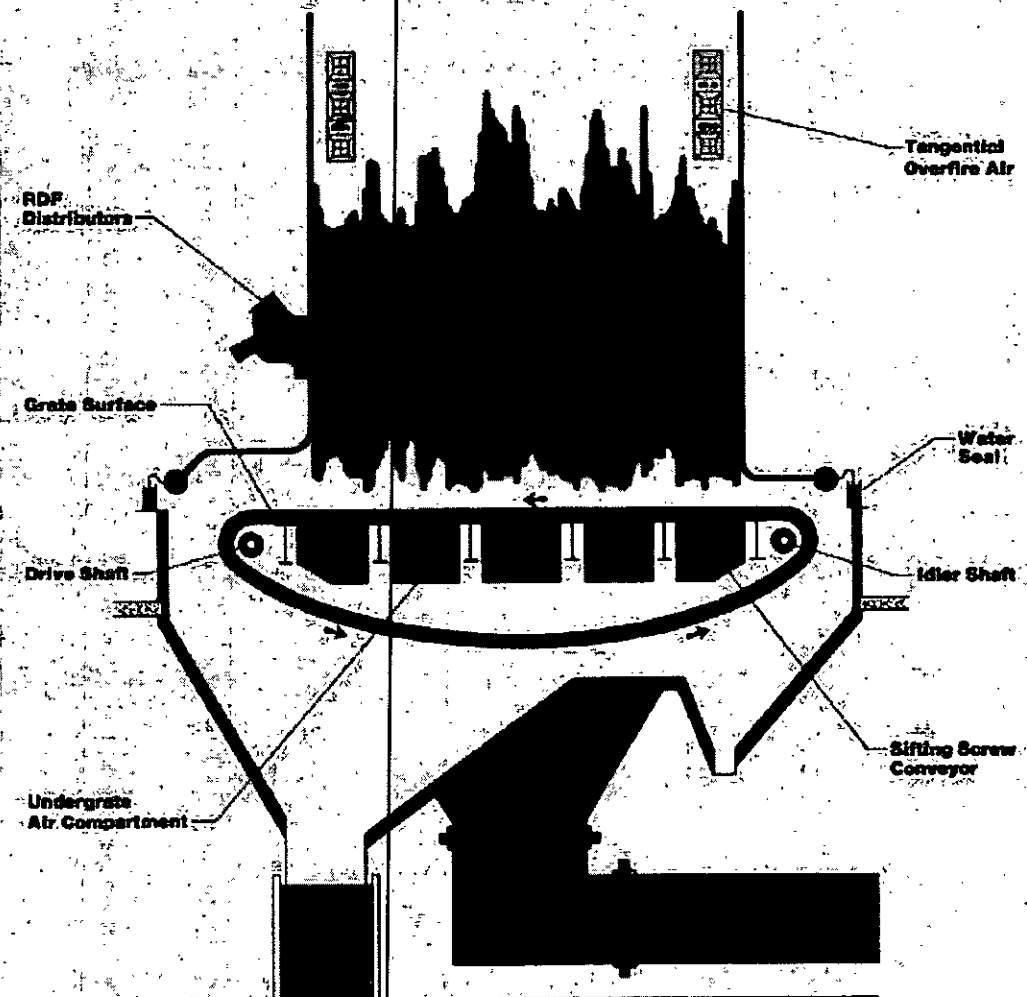


Figure 2.13.b: Spreader stoker incineration system

The system, developed in the USA is not used in the Netherlands. In Europe, the system for well defined monostreams, such as poultry manure (Fibrowatt, United Kingdom) and waste from the olive industry (El Tejar, Cordoba and others, Spain). Presently, a project for the incineration of poultry manure is in preparation with this technology in the Netherlands.

For reference literature on sections 2.2.7, see chapter 7, references [38] – [77].

Short summary

other waste incineration systems than grate incineration

- alternative incineration technologies, such as bubbling fluidised bed, circulating fluidised bed, and spreader stoker are not used in the Netherlands for municipal waste incineration.
- bubbling fluidised bed finds application in sewage sludge incineration and for various types of biomass.
- there is growing interest, especially in circulating fluidised bed incineration (CFB). Various new initiatives are based on this technology. The ability to increase steam temperatures with this system without encountering corrosion problems attracts attention, though operational experience is limited.
- the planned application of CFB is related to the incineration of various monostreams or combinations of monostreams and not to mixed wastes. Up till now there is no experience with CFB in the Netherlands.
- there is no experience with spreader stoker technology in the Netherlands.

2.3 Incineration of hazardous wastes

2.3.1 General

Incineration is an option for treating a wide variety of hazardous wastes. Composition of these wastes shows so much variation, that a typical composition cannot be given.

Although some of these hazardous wastes can be well incinerated in grate furnaces, other categories of hazardous waste need additional provisions. This may be related to the following points:

- some chemicals require special incineration conditions (higher temperatures, longer residence times) because of their high thermal stability (PCB's etc.), melting behaviour or high water content;
- the variations in incineration behaviour may be (much) larger than for typical municipal waste, thus requiring special control provisions;
- the composition and/or aggregation state of the waste may be inappropriate for grate incineration. This is especially the case for liquids and sludges, but also for chemical waste in drums;
- the materials are contained in specific packaging (drums, barrels, etc.);
- hazardous waste requires certain special safety provisions (for highly toxic chemicals, etc.), including special provisions for operating personnel;
- hazardous waste may influence bottom ash quality.

The most common type of furnace for handling general hazardous waste is the rotary kiln furnace. Furthermore, some types of hazardous wastes are incinerated in dedi-

cated incineration units or co-incinerated with other fuels, as discussed in section 2.3.3.

2.3.2 General hazardous waste incineration plants, based on rotary kiln incineration

Technical aspects

Figure 2.14 gives scheme of a rotary kiln incineration plant.

After completion of the acceptance procedure, waste is stored in various categories, such as:

- liquids with high Lower Heating Value (LHV) and low LHV;
- sludges;
- solid materials;
- packaged waste (in drums, barrels etc.).

Within these categories, various sub-categories are distinguished, depending on differences in LHV, chlorine, fluorine and sulphur content etc. Heavy metal content can lead to definition of a separate category.

Adequate acceptance procedures (see end of this section), as well as adequate and safe storage provisions form an essential part of the design of the incineration plant. This includes provisions for the prevention of air emissions during the loading and storing of hazardous wastes (controlled ventilation), safety provisions to prevent soil and surface water contamination, fire protection (injection of nitrogen in storage tanks), health and safety provisions for personnel, etc.

A fuel mix is determined based on operational experience and the amounts available in the various categories and subcategories.

Solid waste and sludges are fed through an air sluice in the front end of the rotary kiln. The kiln, which is positioned with a slight inclination, rotates slowly. This ensures waste transport.

Moreover, liquids can be incinerated in the rotary kiln. Dosing occurs through nozzles at the front end, but also in the post-combustion chamber (see below).

The interior of the kiln has a temperature resistant refractory lining. Incineration temperatures in the kiln can exceed 1000 °C, sufficient to create molten ash. The capacity of the kiln should be large enough to cope with large, unexpected variations in waste input, because the kiln will be fed with 200 litre drums with varying contents (from nearly empty drums via drums with watery solutions to polluted oil fuels).

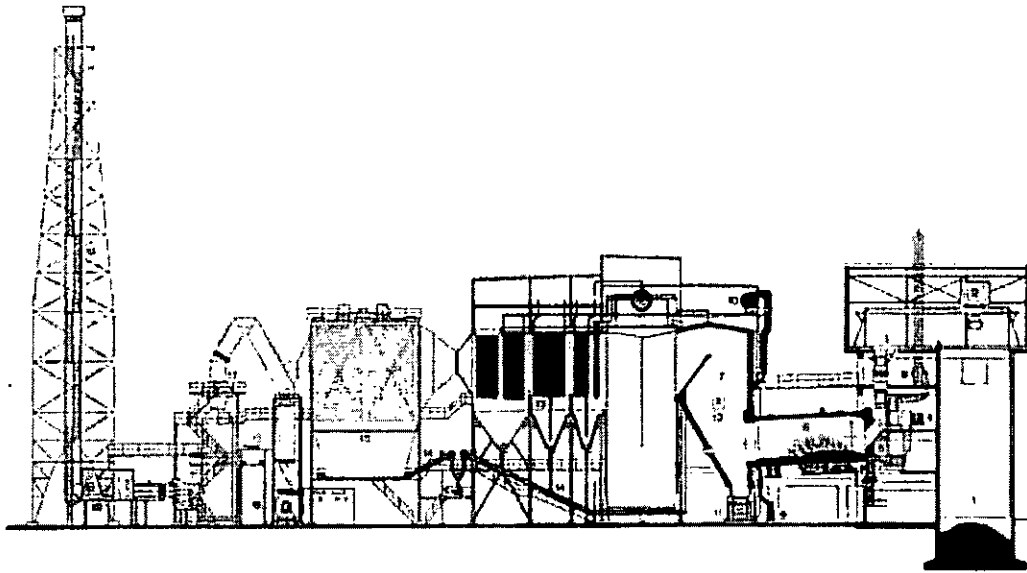


Figure 2.14: Hazardous waste rotary kiln incineration plant

The flue gases from the kiln subsequently pass through a post-combustion chamber where the required high incineration temperature is reached (depending on composition of the waste). The post combustion chamber has provisions to incinerate additional liquid wastes with high LHV's and to adequately inject secondary and tertiary incineration air, in order to ensure adequate combustion.

In addition to municipal waste incineration (where waste can be dosed according to the normal routine, after adequate mixing in the bunker has occurred) feeding of the rotary kiln requires 'recipes', which ensure that the combustion process is satisfactorily controlled. This requires a well-developed system of hazardous waste management. Furthermore, additional attention must be paid to safety regulations and the personnel's working conditions.

Boiler technology and flue gas treatment technology are, in principle, comparable to the technology used for municipal waste incineration (see sections 2.2.5 and 4.4).

Specific operational aspects, related to acceptance and control

Due to several incidents, causing pollution of the environment with hazardous waste, standards were developed to get more control over hazardous waste treatment and incineration. These standards address the following subjects:

- a) waste acceptance;
- b) waste handling and waste treatment;
- c) the way in which the administration is set up;
- d) the way in which the internal control is carried out.

Each of the addressed subjects is part of a compliance control loop. This means that any deviation in the process must be traced back to the cause. The exceeding of an emission parameter must be traced back to potential causes, such as inadequate

waste analysis, a miscalculation while drawing up the burnplan or a malfunction of the flue gas treatment unit, etc.

Ad a)

Limitations are set for the size, the composition, quantity, quality, etc. of the waste based on the hardware and the permit(s) of the facility. As a reference the performance of the individual units that make up the total facility must therefore be listed. A facility with one or more waste pre-treatment options can accept for instance a larger variation of wastes than a facility, which has to incinerate the waste in the way it is delivered.

There must be a clear relation between the performance of the installation and the waste which the incinerator intends to accept. It must also be clear that waste which can be 're-used' for other purposes, shall not be accepted for final destruction by incineration.

Ad b)

The incinerator must follow procedures to ensure that waste is handled and treated in the most efficient and most environmentally friendly way. The work must be performed by trained and qualified personal.

A proper menu for the pre-treatment units, together with a burnplan must be drawn up.

An extensive waste analysis plan, an analysis of process parameters as well as monitoring end of pipe emissions and the quality of the residues, must be part of these procedures.

A waste incinerator should be able to draw up a periodic mass balance for the facility as well as for the individual waste streams.

Ad c)

A system of record keeping must be described. The way in which the data acquisition, data control, the quality control and quality assurance of these data is guaranteed must be listed, together with whose responsibility it is.

It must be possible to trace the waste from the moment it is delivered, stored, pre-treated, and incinerated, to the effects its incineration has on flue gas treatment, the end of pipe emissions and the quality of the residues.

Ad d)

The quality control and assurance system of the facility must be organised in a way that for instance an operator is not responsible for the validations of the data generated by him. Internal cross control is just as important as the implementation of all the subjects discussed under a) to c).

An extensive and detailed document, where the subjects mentioned under a) to d) have been described, including the relevant procedures, which has been approved by the authorities, has to be part of the permit application. It must be a controlled document that is part of the facilities quality system.

2.3.3 Dedicated incineration units

As indicated in section 2.1, various (chemical) companies have dedicated incineration systems in operation for certain specific categories of hazardous wastes. A complete description of these units is beyond the scope of this BAT-document. As an example, a brief description is given for four of these units:

Other dedicated industrial waste incinerators have been listed in section 2.1.2.

1. The chlorine recycling unit of Akzo Nobel, Botlek, Rotterdam

This incineration unit for highly chlorinated liquid wastes (chlorinated hydrocarbons) is located on an industrial site. Total plant capacity is approx. 36,000 t/y. The processed waste originates from Akzo Nobel, as well as from external customers. Wastes are limited in content of solids (<10g/kg), fluorine, sulphur and heavy metals. PCB's are allowed.

Incineration takes place in two furnaces at a temperature level of 1450 – 1550 °C (residence time 0.2 - 0.3 sec). This temperature level can normally be maintained without auxiliary fuel. Water is injected in order to suppress the formation of Cl₂. After leaving the furnace, the flue gas passes through a quench-section, where the temperature is lowered to approx. 100°C. Insolubles and heavy metal salts are removed from the circulating liquid in a quench tank. The flue gas continues through an isothermal and an adiabatic absorber. The recuperated hydrochloric acid is distilled at elevated pressure and temperature, after which the gas is cooled down to -15 °C in order to reduce the water content to practically zero. The recovered anhydrous HCl is reprocessed in a vinyl-chloride-monomer plant.

In order to comply with Dutch emission standards, flue gases pass through an alkaline scrubber and an activated carbon filter (for dioxin absorption). Compounds like TOC, HCl NO_x, O₂, CO and dust are continuously analysed. The concentration of dioxins and PCB's is below 0.1 ng TEQ/m₀³.

The effluent from the quench and the scrubber unit is treated in a physical/chemical unit and in a biological waste water treatment unit. Dioxin content is < 0.006 ng TEQ/l. PCB's are below the detection limit (<10 ng/l).

A process scheme is given in figure 2.15.

Akzo Nobel Chlorine Recycling Unit

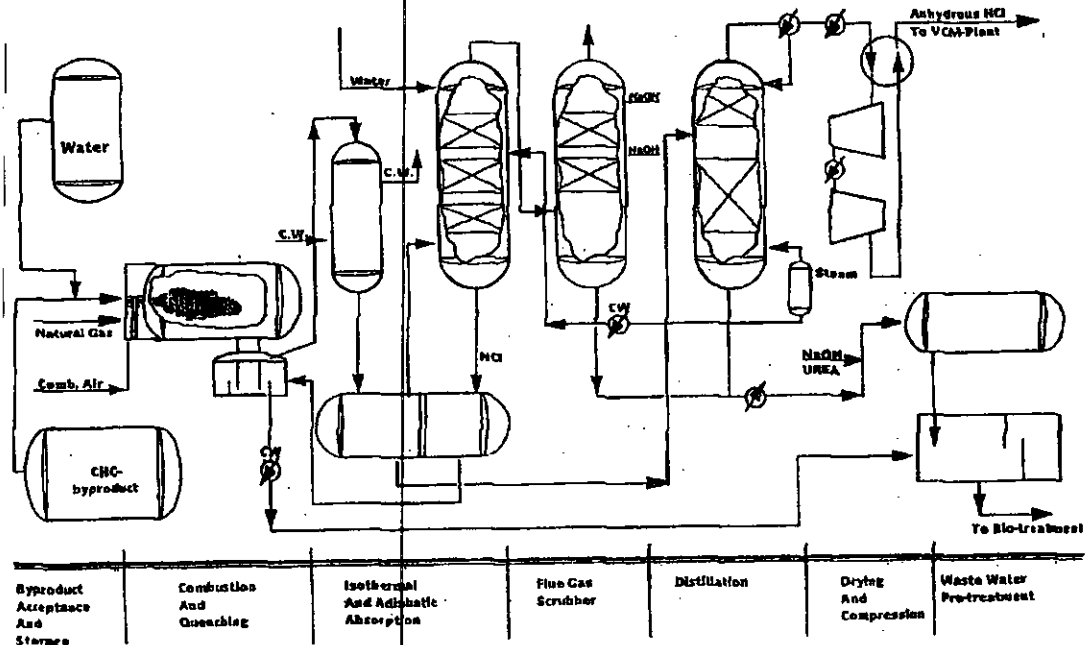


Figure 2.15: Process scheme of Akzo Nobel chlorine recycling unit

Main advantage of this dedicated incineration unit is, that chlorine can be recovered. Overhead costs are reduced by the fact that it is part of a larger chemical plant.

2. Sludge incineration unit of Shell Pernis, Rotterdam

This incinerator for petrochemical and chemical industry sludge is based on bubbling fluidised bed technology. Incineration air is pre-heated by a heat exchanger that transfers heat out of the flue gases. Remaining heat is used in a boiler that produces steam for the refinery's utility system. The flue gas treatment consists of an electrostatic precipitator and a wet scrubbing system. Total plant capacity is approximately 30,000 tons/year of sludge.

RWZ Incinerator

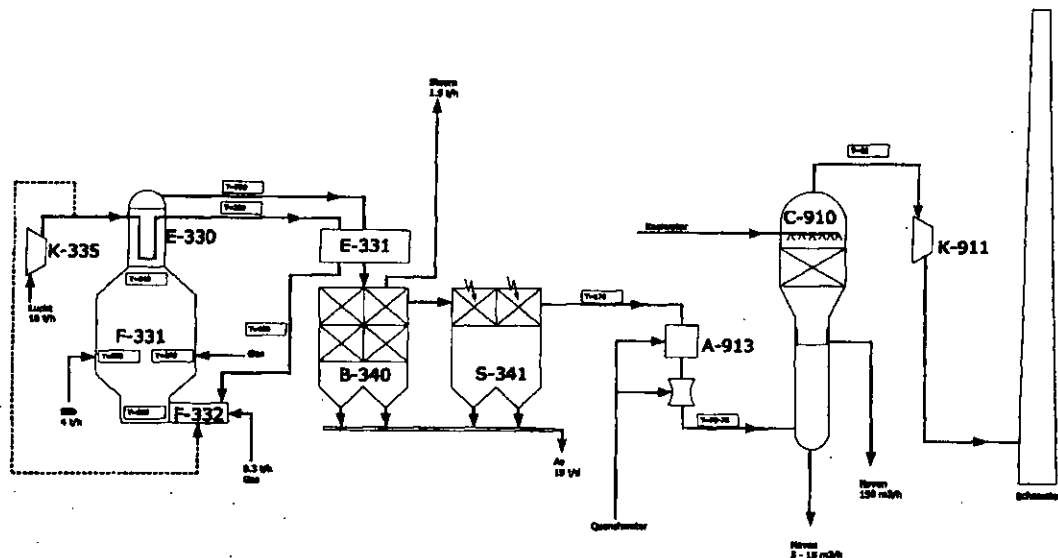


Figure 2.16: Process scheme of Shell Pernis fluidised bed sludge incineration unit

Main advantage of this dedicated incineration unit is, that it can be operated continuously on a sufficient economy of scale. An energy surplus can be used in Shell's refinery. External transport of waste is avoided. Overhead costs are reduced by the fact that it is part of a large petro-chemical plant.

3. 'Pyrolysis'-unit of ATM Moerdijk

In this unit solid industrial sludges and shredded paint waste/chemical packings are treated by Afvalstoffen Terminal Moerdijk (ATM). ATM is a company, active in the treatment of a wide variety of solid and liquid industrial wastes and polluted soils.

The 'pyrolysis'-unit is combined with a thermal treatment plant for polluted soil, in which synthesis gas (syngas) from the pyro-unit is used as fuel. The pyro-unit consists of two parallel reactors. Both are equipped with screws, which transport the feed material through the reactors. Feed materials include filter cake and sediment of ATM's waste water treatment facilities, as well as paint waste. Average organic material content varies between 25 – 85%, average water content is approx. 25%.

At start-up, the reactors are heated up with natural gas until approx. 500°C. Then feeding starts and the use of natural gas is stopped. The amount of air is kept below stoichiometric demand. In fact, a gassification process is taking place (though ATM calls it pyrolysis). Gassification temperature is approx. 900 – 1200°C. Capacity of the reactors is approx. 2 x 4 tons/hour.

The syngas is cooled down in a quench-condenser. Remaining syngas (LHV approx. 7 MJ/Nm³) is used as fuel in ATM's unit for thermal treatment of polluted soil. Incin-

eration and flue gas treatment takes place according to Dutch emission standards. The condensed water of the quench is treated in a decanter for the separation of carbon. The water fraction is used for moisturising the reactor residues.

The residue of the reactor (temperature level approx. 500°C) passes a magnetic separation system for removal of iron parts from the paint waste and packings fraction. The remaining fraction is cooled down and moisturised with condensed water, as indicated above and is landfilled as hazardous waste, C3-category.

A general process scheme, including main mass flows in given in figure 2.17.

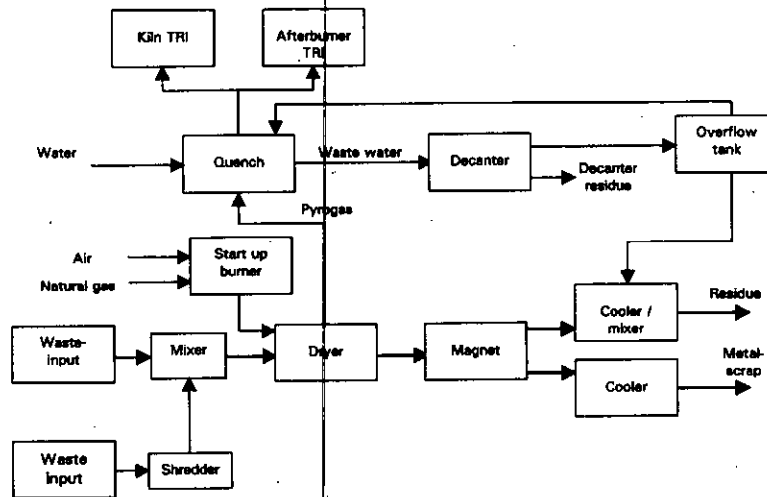


Figure 2.17: Process scheme of ATM's 'pyrolysis'-unit

Main advantage of the pyrolysis unit for ATM is, that the surplus on LHV, present in the treated filter cake, sediment and paint waste can be directly used in the thermal treatment unit for polluted soil. Energy efficiency, therefore, is at least comparable with waste incineration. Furthermore, the iron scrap fraction (15%) is removed for re-use, while the volume of the treated waste is reduced with approx. 50%. Remaining residues can partly be treated in ATM's own facilities. Overhead costs are reduced by the fact that it uses the incinerator and flue gas treatment of a large polluted soil and waste treatment plant.

4. Caustic Water Treatment Plant of AVR Chemie, Botlek

As indicated in section 1.5.1, caustic water is a specific waste water stream from MSPO plants (Mono-Styrene Propylene-Oxide). This water is produced in several washing steps in the process. It contains approximately 10% to 20% organic components and has a high sodium load (mainly NaCl). Caustic Water is available in the Netherlands in large quantities.

Both the high organic fraction and the sodium make it difficult or even impossible to use biological water treatment. The caloric value of this water is too low for unsupported incineration, so co-incineration or the use of supporting fuel is necessary. The high sodium content, in combination with the large quantities, causes problems with co-incineration in municipal waste incinerators.

Applicable treatment technologies are wet oxidation and incineration. For this purpose, AVR Chemie has four static vertical incinerators (total capacity approx. 350 - 400 kton per year), which are in operation since 1999/2000.

The incinerators are static vertical top-down incinerators. The low caloric waste (caustic water with 10 - 20% organics) can be led through a falling film evaporator. This evaporator operates on excess low-pressure steam, coming from the incinerator wall cooling, thus using less fuel in the incinerator.

The remaining liquid and the produced vapour are incinerated with natural gas and/or high caloric liquid fuel (waste or fuel oil). The resulting flue gasses are partially cooled by a membrane wall, producing steam of 27 bar. Subsequently the flue gasses are quenched to clean the gasses from sodium salts and other water soluble impurities.

In the heat recovery section, recirculation water is sprayed over the flue gasses. This recirculation water flashes out in the flash chamber, generating approximately 30 t/h vacuum-steam per unit, which is used for the production of distilled water for the Botlek/Europoort area.

After the heat recovery the flue gasses pass through a venturi scrubber and a wet electrostatic precipitator where aerosols and dust are removed.

The incinerators operate at a temperature level of 930 - 950°C, with low excess air (3 - 4% O₂). Depending on the concentration of organics, the throughput of caustic water is 10 - 15 t/h per unit.

The water from the quench is treated in ion-exchange beds for removal of heavy metals. Special ion-exchange beds concentrate the Molybdenum (catalyst in the MSPO process) to a re-usable grade.

Main advantage of these incinerators is the possibility to incinerate large quantities of low caloric waste with high salt concentrations.

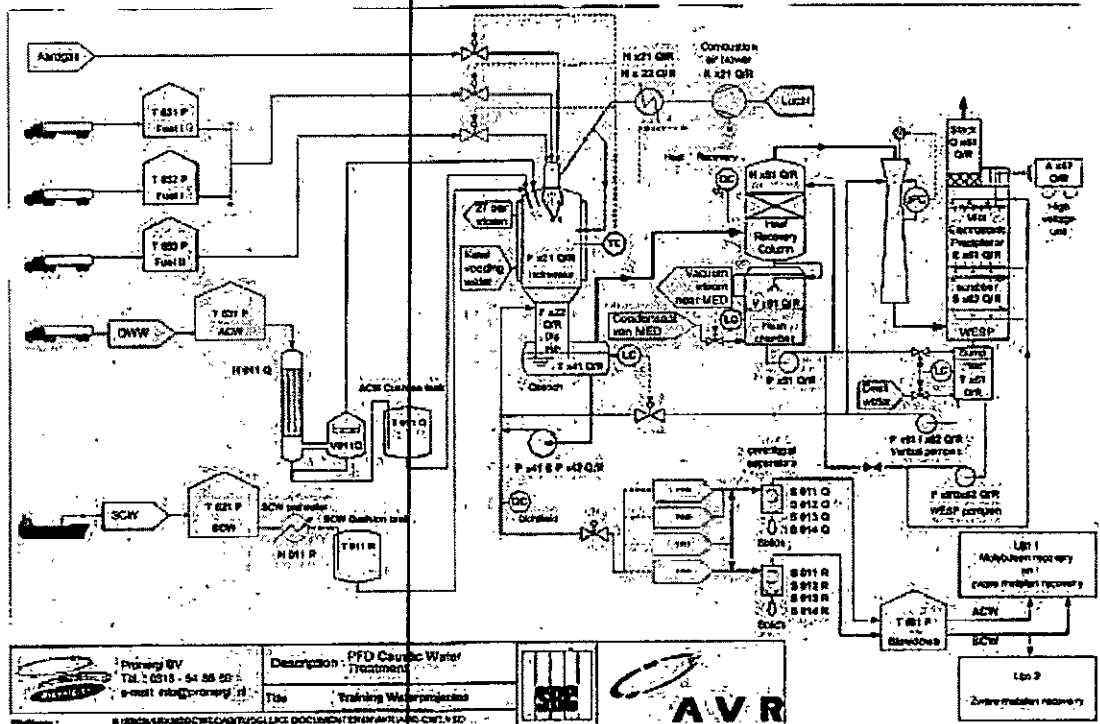


Figure 2.18: Process scheme of AVR's caustic water treatment plant

2.3.4 Co-incineration of hazardous wastes

Depending on composition and characteristics, various categories of hazardous waste can be incinerated in less specific incineration plants. Examples are:

- polishing cloths, polluted with oil;
- other oil related wastes;
- equipment and packaging materials for paints;
- rubber waste;
- cosmetic waste;
- used filter materials;
- used jerrycans etc.

The main categories of hazardous wastes that are co-incinerated in (Dutch) cement kilns (see also section 2.6.4) are:

- sludges with a relatively low halogen content;
- various pasty organic materials.

Whether or not co-incineration of hazardous wastes is (environmentally) acceptable depends on the specific incineration characteristics of the waste type and on its composition. It should not have a negative influence on the incineration process itself, as well as on the quality of the residues (bottom ash, fly ash, cement).

Therefore, if individual municipal waste incineration plants, coal power plants and cement kilns plan to treat these categories of hazardous waste, they must specifically apply for this in their environmental permits. Examples are the municipal waste incineration plants AVR Botlek and AVI Amsterdam (see section 2.1.1), the coal power plant of E.ON Maasvlakte and the cement kiln plant ENCI in Maastricht.

In the Netherlands the Regulations for incineration of Hazardous Waste (in Dutch 'Regeling verbranden gevaarlijke afvalstoffen') is applicable for the emissions to air when hazardous wastes are co-incinerated. Furthermore it is noted, that a substantial amount of combustible Dutch hazardous waste (approx. 40%) is exported to other European countries.

For reference literature on sections 2.3 – 2.3.4, see chapter 7, references [78] – [86].

Short summary on incineration of hazardous wastes

rotary kiln incineration

- Rotary kiln incineration has proven to be a flexible and reliable technology for incineration of a wide variety of hazardous wastes
- Related boiler and flue gas treatment technology are comparable with the technologies, used for municipal waste, though input loads of pollutants may be higher. This should be taken into account during design.
- The operation of a rotary kiln incineration plant for hazardous wastes requires specific operational attention and waste management provisions, such as specific acceptance procedures, storage provisions, health and safety regulations and provisions, application of specific recipes etc.

incineration of hazardous waste in dedicated units

- Incineration of specific categories of hazardous wastes in "dedicated" units is an interesting option in case sufficient waste amounts of these specific categories are available (economy of scale).
- As these dedicated units are "tailor made"-solutions, a general definition of BAT cannot be given. Applied technology strongly depends on specific circumstances.

co-incineration of hazardous waste

- Co-incineration of hazardous wastes in municipal waste incineration plants and in cement kilns is limited to a number of specific hazardous waste types. It requires specific conditions in the permits of these plants, including specific acceptance procedures, insurance of adequate process conditions during incineration, quantity restrictions, safety and health conditions etc.

2.4

Incineration of specific clinical waste

General

A waste category that requires special attention is specific clinical waste. The required special attention is related to the specific risks of these wastes (e.g. infectious contamination, needles etc.), the aesthetic standards (residues of operations etc.) and the incineration behaviour, as indicated in section 1.5.2.

Specific clinical waste contains materials with very high LHV's (plastics etc.), but also residues with a very high water content (blood etc.) and therefore requires long incineration times. As for hazardous wastes, the composition of specific clinical wastes varies so strongly that a typical composition cannot be given.

The total amount of specific clinical waste in the Netherlands is approx. 8,000 ton/year. This is relatively little for a waste incineration plant. Therefore one centralised plant has been realised, for treatment of the total amount. This plant (ZAVIN, see section 2.1.3) is located at the same site as a municipal waste incineration plant (GEVUDO, see section 2.1.1) and a sewage sludge incineration plant (DRSH, see section 2.1.4). ZAVIN is an independent company, but co-operates in various technical and operational aspects with its neighbours. This causes some compensation for its relatively small economy of scale.

The applied incineration technique of the ZAVIN-plant is two stage pyrolysis-incineration (see below). Rotary kiln incineration (see section 2.3.2) can be considered as an alternative technique.

Short description of the ZAVIN plant (see figure 2.19)

The specific clinical waste is collected regularly from hospitals and other health care institutes, including doctors, dentists and veterinarians. The waste is collected in special 30 or 60 litre bins, which have been filled at the institutions and do not need to be opened again. The waste is then incinerated, including the bins, which also act as an auxiliary fuel.

As indicated in section 1.5.2, only specific clinical waste is collected and treated in this way. The non-specific waste from hospitals and health care institutions is collected and treated as normal municipal waste.

The collected waste is stored in closed transport containers on site. The bins are collected and transported semi-automatically to the incineration unit, which is located in a closed building. Feeding the incinerator occurs through an air lock, in order to prevent the introduction of false incineration air.

Incineration takes place in a 2-stage process. In the lower incineration room, a controlled pyrolysis occurs, followed by incineration with primary air as the waste progresses through the room. Finally, the waste ends in a water-filled ash-discharger, from which the ash is removed by a chain conveyer system.

The formed flue gases are incinerated with secondary air and, if required, with auxiliary fuel at a temperature level of approx. 1000 °C. Subsequently, they are cooled in a saturated steam boiler (steam temperature 225 °C, pressure 10 bar), a heat exchanger, and a scrubber. Steam is supplied to the adjacent municipal waste incineration plant of GEVUDO (see section 2.2.1), which uses the steam for various purposes and returns the related boiler feed water to ZAVIN.

The scrubber of ZAVIN is a two stage system for removing acid compounds, as described in more detail in section 4.4. The treated flue gas is heated up (in the previously mentioned heat-exchanger and in a steam-flue gas heat exchanger) before passing a dust bag filter with adsorbens injection (activated carbon and lime), for removal of dioxins, and a SCR-DeNOx-unit, which is also described in more detail in section 4.4. Emission concentrations of the emitted flue gases are analysed according to Dutch standards (see section 4.4.8). The flue gas is emitted through a 55-meter high stack.

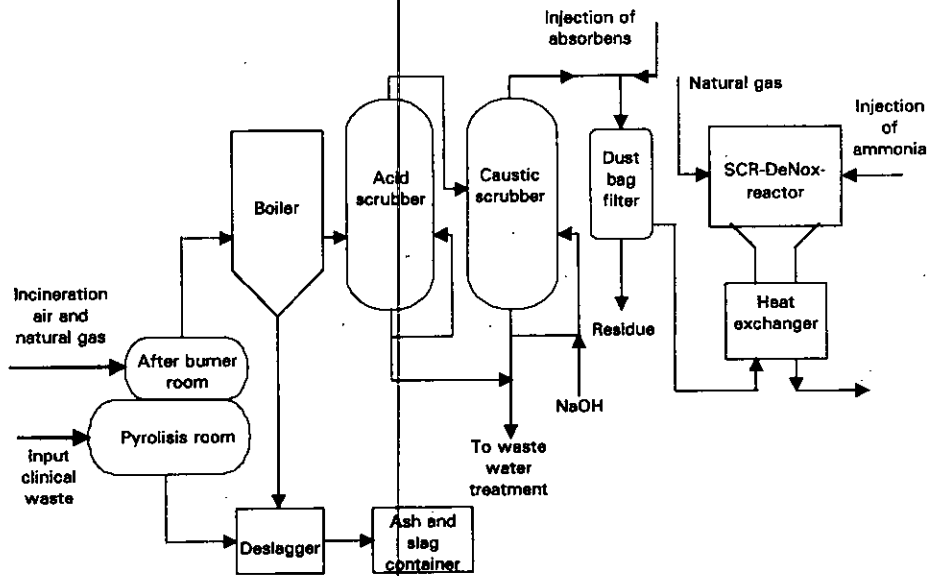


Figure 2.19: ZAVIN specific clinical waste incineration plant

Short summary

incineration of specific clinical waste

- In the Netherlands, specific clinical waste is collected and treated in a centralised incineration unit. This system was preferred over decentralised treatment, as it ensures compliance with high environmental standards; by the realised economy of scale, an acceptable cost level can be achieved.
- Taking into account the specific characteristics of this type of waste, the applied incineration system is a two stage (pyrolysis/afterburner) system, with recovery of energy (steam) and adequate flue gas treatment.
- The incineration unit is located on the same site as a municipal waste and a sludge incineration plant, resulting in synergy effects.

For reference literature on section 2.4, see chapter 7, references [87] – [88].

2.5 Incineration of sewage sludge

2.5.1 General

Sewage sludge production in the Netherlands

In the Netherlands, the annual production of sewage sludge from waste water treatment plants (WWTP's) amounts to approx. 650,000 tons/year, based on dry solids. As sludge normally has a dry solids content of 20 – 25 % after mechanical dewatering, this amount is the equivalent of 2.5 – 3.0 million tons/year of (mechanically dewatered) sludge. Of this amount, approx. 400,000 tons d.s./year (nearly 2.0 million tons of sludge material) results from communal WWTP's. One of the main (final) disposal routes for this waste category is incineration.

A typical composition of Dutch communal sewage sludge is given in table 2.2

Table 2.2: Average composition of Dutch communal sewage sludge after dewatering

Component	range	average	standard for agricultural use	unit
dry solids	15 – 35	20 – 25		%
organic material	50 – 70	60		% of dry solids
heavy metals:				
Cr	20 – 60	35	75	mg/kg d.s.
Cu	200 – 600	375	75	mg/kg d.s.
Pb	100 – 400	175	100	mg/kg d.s.
Ni	15 – 50	30	30	mg/kg d.s.
Sb	1 – 5	3	--	mg/kg d.s.
Zn	500 – 1500	900	300	mg/kg d.s.
As	5 – 20	12	15	mg/kg d.s.
Hg	0.5 – 3	1.4	0.75	mg/kg d.s.
Cd	1 – 5	2	1.25	mg/kg d.s.
Mo	4 – 20	8	--	mg/kg d.s.

Table 2.2 shows that the average heavy metal content of Dutch communal sewage sludge does not allow agricultural use.

Sludge incineration

As indicated in section 2.1, there are two large scale incineration plants in the Netherlands (DRSH Dordrecht and SNB Moerdijk). They are both using bubbling fluidised bed technology. This technology was selected because of its specific suitability for sludge incineration.

The capacity of the DRSH sludge incineration plant is approximately 85,000 tons d.s./y (375,000 t/y of sludge material). SNB has a capacity of 100,000 tons d.s./y (400,000 t/y of sludge material). The design of these plants is described in more detail in sections 2.5.2 and 2.5.3.

A third plant (V.I.T. Hengelo), based on complete pre-drying and grate incineration, has a much smaller capacity of 25,000 tons d.s./y (approx. 100,000 t/y sludge material). The plant had severe operational problems and is closed down in the beginning of 2001. It is not clear, whether or not the plant will be put in operation again.

The following sections describe the general design of large scale incineration plants, including a process description of the applied incineration process and specific aspects of the flue gas treatment process. Subsequently other incineration technologies for sludge incineration are discussed.

The subject 'sewage sludge' concludes with some remarks about future developments on thermal treatment of sludge.

Other sludge treatment technologies

As indicated in section 1.5.3, agricultural use of sewage sludge is very exceptional, due to sewage sludge composition and applicable composition standards. Direct landfilling of mechanically dewatered sludge is not in accordance with national waste management policy.

Applied sludge treatment methods in the Netherlands are biological sludge drying (comparable with composting), thermal sludge drying and wet oxidation. These technologies are not discussed in this BAT-document. However the subject of the co-incineration of dried sewage sludge in electrical power plants etc. is discussed in section 2.6.3.

2.5.2 General design of a large scale sewage sludge incineration plant

The two Dutch centralised, large scale sewage sludge incineration plants are characterised by following design:

- the availability of large provisions for reception and storage of dewatered sewage sludge (a minimum storage capacity of 4 days, and preferably 7 days incineration capacity), in order to ensure sufficient continuity in acceptance and treatment. Storage takes place in a closed building with forced ventilation and air treatment systems, in order to prevent odour emissions;
- the application of an environmentally friendly and energy efficient incineration process, including partial pre-drying of the sludge (see section 2.5.3);
- the application of dust pre-removal and wet flue gas treatment, with special attention for mercury removal (based on application of activated carbon), which is also described in section 2.5.3. Air emissions comply with Dutch standards (see section 3.1.2). Special attention is given to emission reduction of mercury, as the mercury content of sewage sludge is rather high.

Sludge incineration is financially competitive with other sludge treatment methods, due to the applied large scale of the operations.

2.5.3 Process description of fluidised bed incineration of sewage sludge

Bubbling fluidised bed incineration is the most commonly used incineration system for sewage sludge. In this system, sewage sludge is fed into a sand bed, which is fluidised by an upward flowing air stream (see also section 2.2.4).

Other sludge incineration processes, such as multiple hearth furnaces or rotary kilns, are technically more complicated and therefore less appropriate for the stand-alone incineration of sewage sludge.

Overall process schemes of the two large Dutch sewage sludge incineration plants are given in figures 2.20.a (DRSH, fourth line) and 2.20.b (SNB).

Incineration takes place at temperature levels of 850 - 950 °C. In order to reach this temperature without excessive amounts of supporting fuel, the sludge material needs to have a minimum d.s.-contents of 35 – 40%. For this reason, disc driers are used to dry the dewatered sludge in a first process step.

For this drying process, steam is produced by a boiler (which is positioned behind the fluidised bed furnace) and is used as a heating medium. There is no direct contact between the steam and the sludge material. Sludge vapours are extracted from the dryer and condensed. The resulting water has a high COD (approx. 2000 mg/l) and N-content (approx. 600 – 1000 mg/l). It also contains certain amounts of pollutants (heavy metals, PAH, EOX), present in the treated sewage sludge. Therefore the water has to be treated before final discharge to the surface water. The remaining non-condensables are incinerated.

After incineration, the flue gases are cooled down in a heat exchanger in order to preheat the incineration air to temperatures of approximately 300 °C, and in some cases to over 500 °C. The remaining heat in the steam boiler is recovered and used for the production of saturated steam (pressure level approx. 10 bar), which, in turn, is used (as previously mentioned) for the partial pre-drying of sludge.

The option to produce high-pressure steam, followed by electricity production in a counter-pressure steam turbine was not selected for the design of the Dutch sludge incineration plants, because this option requires a more complicated design and operation for a relatively small power generation capacity.

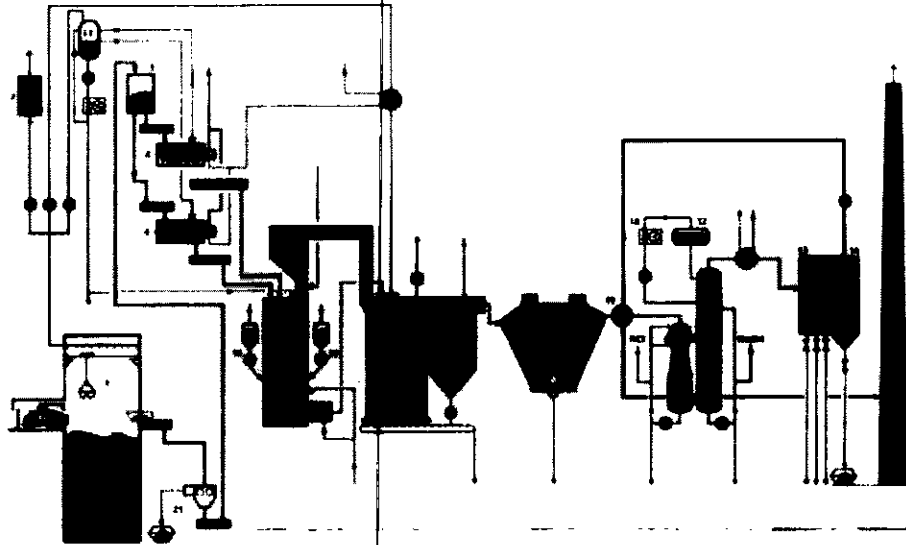
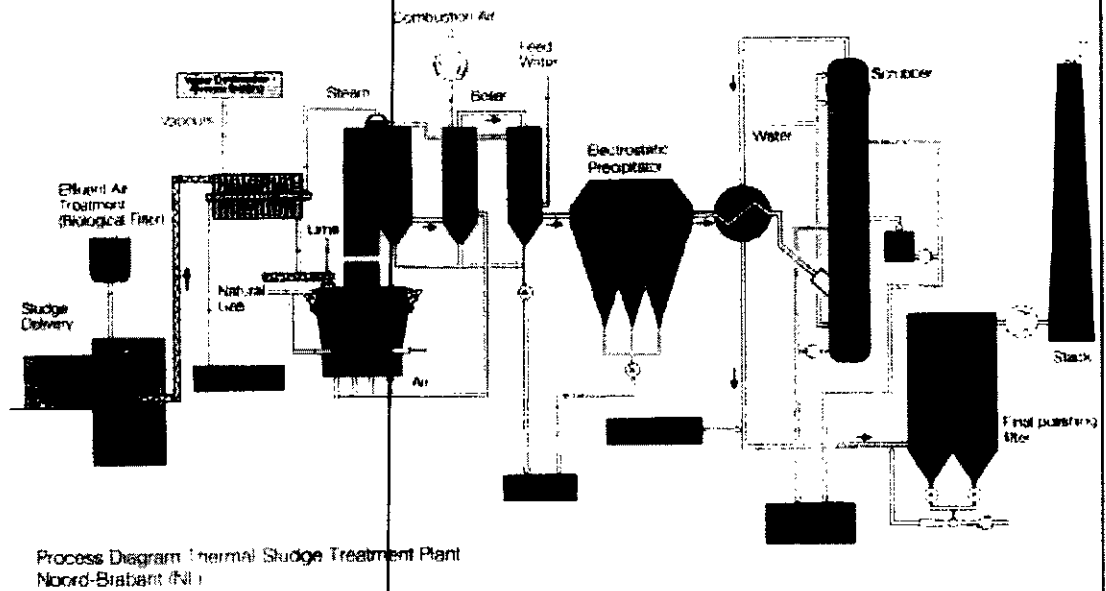


Figure 2.20a: Sludge incineration DRSH (fourth line)



Process Diagram Thermal Sludge Treatment Plant
Noord-Brabant (NB)

Figure 2.20.b: Sludge incineration SNB

The configuration with air preheating, in combination with steam production for pre-drying of sludge, enables a very energy-efficient overall set-up of the incineration process. This design allows the use of a maximum part of the produced heat for the overall process. On the other hand, flue gases are not in direct contact with hot dewatered sludge after passing the high-temperature incineration zone. They therefore do not pick up organic, unburned compounds, which should cause smell problems and the emission of polluting agents.

Finally, flue gases are treated in a flue gas treatment system that is comparable with the systems used for municipal waste incineration (see section 4.4). However, special attention is required for removing nitrogen oxides (NO_x) and mercury.

In the two Dutch fluidised bed incineration plants NO_x-emissions are reduced by injection of ammonia during the incineration process (SNCR, see section 4.4.6). By using this system, it is possible to reduce a normal emission concentration level of 100 – 200 mg/m³ to less than 70 mg/m³.

During the sludge incineration process, mercury is mainly released in the metallic state. In municipal waste incineration, mercury remains in an ion state (mainly chlorides). This is due to the larger concentration of chlorides in municipal waste. Metallic mercury is more difficult to remove from the flue gases than mercury in an ion state. The technology to remove mercury includes the following options:

- the use of complex-building chemicals in a wet scrubber. By adding these chemicals, a substantial increase in mercury removal efficiency can be realised in the scrubber;
- the application of activated carbon in fixed bed reactors. The fixed bed material can be used for the recovery of mercury;
- application of entrained bed technology, where adsorbents is injected in the flue gas stream and removed in a dust bag filter. The adsorbents is normally a mixture of lime and activated carbon. The used adsorbents can be landfilled, but incineration is also an option, provided a sufficient overall removal of mercury is ensured.

With this technology, mercury emissions can be reduced below prevailing emission standards. For further details on flue gas treatment technology see section 4.4.

Re-use and disposal of incineration ash is discussed in section 3.3.6.

2.5.4 Other sludge incineration technologies

Other incineration technologies for sewage sludge are:

- *rotary kiln incineration*, as described in section 2.3.2;
- *multiple hearth incineration*. In the Netherlands, this type of sludge incineration was used by GEVUDO (see section 2.1) from 1973 until 1992, in combination with a municipal waste incineration plant. However, for the new large scale sewage sludge incineration plants, bubbling fluidised bed technology was preferred (see above).

Multiple hearth furnaces have advantages over fluidised bed systems for sludge types with a low melting point of the ash (high potash and/or salt contents). In a fluidised bed furnace, these types of sludge (mainly from industrial origin) may lead to the

clogging of ash in the bed. The clogged ash will form 'stones' and so will create operational problems. Multiple hearth furnaces are less sensitive for clogging, but their construction is more complicated and the incineration process is more difficult to control. This results in higher CO and/or NO_x-emissions than with bubbling fluidised bed incineration.

2.5.5 Future developments in thermal sludge treatment

As indicated in section 2.5.1, a substantial part of the sewage sludge in the Netherlands is, or will be, biologically or thermally dried. A rough estimate of the related amounts is approximately 125,000 t.d.s/year. Presently, a large part of the dried sludge is landfilled. However, tests have been carried out and plans have been developed for **co-incineration of dried sludge in coal power plants**. This can result in a reduction of coal consumption, replacing coal with a non-fossil fuel. Attention is, however, required for related emissions, especially of mercury. This subject is discussed in section 2.6.

Also, co-incineration of sewage sludge in cement kilns is an option which can be considered (see section 2.6).

Another development is the **co-incineration of (dewatered) sludge in municipal waste incineration plants**. Due to its pasty consistency and low heating value, only limited amounts of sewage sludge can be incinerated together with municipal waste in grate incineration plants. Important determining conditions are:

- a fine division of the sludge throughout the other waste;
- a maximum amount of 10% and in some cases up to 20%;
- additionally, the municipal waste should have a sufficiently high LHV in order to enable the co-incineration of dewatered sludge with its low LHV.

Several systems have been developed in order to enable co-incineration of sewage sludge with municipal waste. The systems can be divided in:

- indirect systems, where the sludge is spread in the bunker and/or mixed with municipal waste by the bunker crane;
- direct systems, where the sludge is injected on the grate or in the furnace. Injection provisions should ensure an adequate division of the sludge.

Proper operation depends on grate and furnace design, as well as on adequate flue gas treatment systems. It is important to carry out tests before starting large scale operation of the co-incineration system.

Provided that the above mentioned limitations are taken into consideration, the system is a good alternative for a stand-alone incineration plant, especially in cases where sludge amounts do not allow for a large scale sludge incineration plant, as described in sections 2.5.2 and 2.5.3.

For reference literature on sections 2.5, see chapter 7, references [89] – [115].

Short summary

sewage sludge incineration

- A very substantial part (nearly 50%) of the Dutch municipal sewage sludge is incinerated in two large scale incineration plants;
- Applied technology is bubbling fluidised bed incineration with partial pre-drying and adequate flue gas treatment, including SNCR-DeNOx and special provisions for mercury removal;
- Though LowerHeatingValue (LHV) of sludge is low, incineration can take place without supporting fuel, due to an energy efficient design;
- Other incineration technologies, such as multiple hearth and rotary kiln furnaces are not applied in the Netherlands;
- There exists a growing interest in the co-incineration of dried sewage sludge in coal power plants and in the Dutch cement kiln, though especially efficient mercury removal can be a problem;
- Co-incineration of dewatered sewage sludge with municipal waste is considered to be an option in the Netherlands.

2.6 **(Co-)incineration of biomass and waste**

According to the Dutch Environmental Protection Act, it is forbidden to landfill combustible waste without special permission. Furthermore, Dutch policy is focussed on a substantial increase of the production of sustainable energy from biomass and waste (see sections 1.5.4 and 1.5.5). This has resulted in the development of a large number of initiatives and projects for incineration of biomass and waste, both as stand-alone projects and as co-incineration projects. In this section, an overview is given of the most relevant projects and developments.

2.6.1 Medium and small scale incineration of wood

In the Dutch wood and furniture production sectors a very large number of small-scale incineration plants are being operated with capacities varying from 0.1 - 5 MWth. The larger plants are usually equipped with provisions for energy recovery, such as process or room heating purposes. Electricity production is too expensive.

Flue gas treatment provisions are normally restricted to the use of (multi)-cyclones for dust removal. Present emission standards for this category of incineration units are substantially less severe than BLA (see sections 1.6 and 3.1.2). The Ministry of VROM, however, has announced plans to introduce stricter emission standards, amongst others for NO_x -removal.

This will result in a reduction of this activity, though present installations will not be affected, as there will probably be a transitional period.

2.6.2 Large scale incineration of wood in a fluidised bed incineration plant

As already indicated in section 2.2.7 there are various projects in the Netherlands for the realisation of incineration plants for specific wastes ('monostreams') and biomass. Capacities, waste and biomass types and technology selection show a large variation. The selected design strongly depends on local circumstances. Examples of recently realised units are

- the Schijndel project, a wood incineration plant with a capacity of 10,000 t/y of clean wood;
- the NUON Lelystad project: a grate system for wood incineration (30,000 t/y of clean wood chips), including electricity production (1 MWe) and heat supply (5 MWth), using co-generation technology;
- the Cuijk project: a large scale wood incineration project has been realised by a Dutch energy company (Essent). As an example a short description of this plant is given below.

The Cuijk project

The applied technology of the Cuijk project is bubbling fluidised bed incineration. The plant is operational since 1999. Incineration capacity is 110,000 t/y of non-polluted wood, with an average LHV of 18.7 MJ/kg. The produced steam (pressure 100 bar, maximum temperature approx. 500 °C) is used for electricity production. Gross power generation capacity is 27 MWe. Flue gas treatment is based on SCR-DeNOx (see section 4.4.7) and dust removal by electrostatic precipitators (see section 4.4.2).

The set-up of the plant is indicated in figure 2.21.

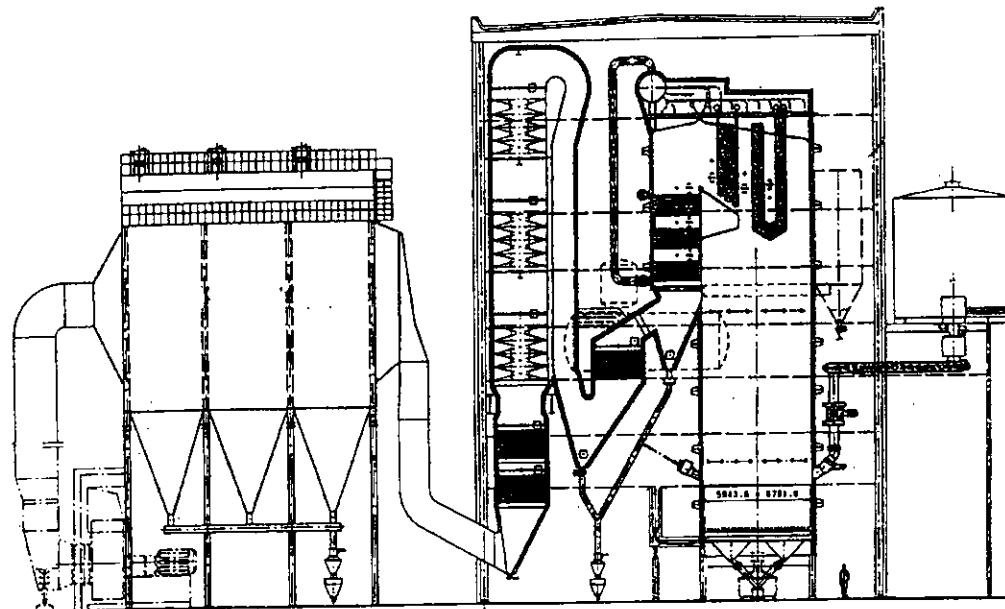


Figure 2.21: Fluidised bed wood incineration plant in Cuijk

2.6.3 Co-incineration of wood and other biomass in coal power plants

For the thermal conversion of relatively clean wood and other comparable biomass, including paper sludge, various coal power plants have been granted or have applied for revisions of their environmental permits. These coal power plants are Centrale Nijmegen, operated by Electrabel (formerly EPON), Amercentrale, operated by EEP (formerly EPZ), Centrale Borssele, operated by EPZ, Hemwegcentrale, operated by Reliant (formerly UNA) and Maasvlaktecentrale, operated by E.ON (formerly EZH). Some have adapted their plants accordingly.

Until now, this development has had a limited impact. However, following discussions between the Ministry of VROM, Economic Affairs and the Dutch energy production companies about further reducing fossil fuel input, significant growth in this sector may occur in the near future. Realisation of the present plans would replace 10% or more of the fossil fuel input.

Technical concepts for large scale co-incineration are still under consideration. Potential options vary from:

- common feeding of coal storage provisions, resulting in simultaneous processing of coal and biomass;

via:

- installation of separate storage and feeding systems for biomass, for co-firing of biomass in the coal furnace;

to:

- realisation of separate incineration units, including flue gas treatment provisions. In this case, only the steam/water cycles of the coal power plant and the biomass incineration unit are integrated;

and:

- realisation of separate biomass gassification units. The synthesis gas, produced by these units is fired in the coal power plant.

Biomass and waste types for co-incineration include following categories:

- residues of the foodstuff and luxury food industry;
- non-polluted and slightly polluted wood waste;
- used wood;
- agricultural waste and manure;
- paper and plastic wastes, including refuse derived fuel (RDF);
- meat and bone meal;
- sludge from the paper industry;
- sewage sludge (for this category and other mercury containing biomass types a restriction concerning mercury content exists, see below)
- etc.

In the Netherlands, the emission standards to air for the incineration of fossil fuels in coal power plants are different from those for the incineration of waste. This causes complications in case of a combined incineration of biomass (including wastes) and coal. At present new emission standards for co-incineration of fossil fuels, biomass and waste are in development, including a so-called "mixing rule" for various compounds. According to this mixing rule, emission standards to air in case of co-incineration of biomass are a weighted average of emission standards for fossil fuel and waste. For more details see section 3.1.2.

For biomass and/or waste types, containing mercury an input limit is proposed. The limit amounts to 0.4 mg/kg dry solids in case of a fuel input of 10% (on mass base). For higher fuel input percentages the limit value is reduced. For further information see section 3.1.2.

2.6.4 Co-incineration in cement kilns

In the Netherlands, there is one cement kiln in operation (ENCI, Maastricht). This plant has completed a permit procedure for the use of certain categories of waste and biomass as secondary fuels.

Figure 2.22 provides an overview of the cement kiln plant. During co-incineration of biomass and waste in cement kilns, it is important that these secondary fuels are fed on the lower side of the kiln (the right side in figure 2.19), in order to ensure sufficient residence time of the flue gases in the incineration zone. The cement in the kiln acts as an absorbing medium for various pollutants, but adsorption is less effective than in specific flue gas treatment systems, resulting in higher emission concentrations. Emission levels of pollutants in the solid state may depend on emission levels of dust.

As for co-incineration in coal power plants, also for cement kilns new emission standards to air are in development in the Netherlands, including application of a "mixing rule", see section 3.1.2.

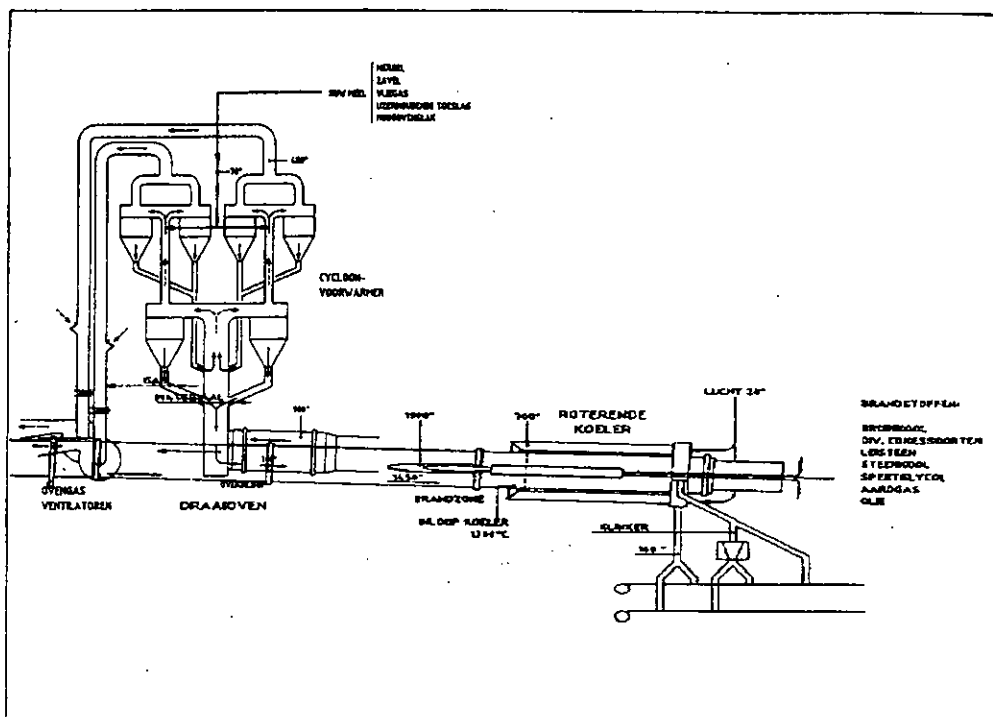


Figure 2.22: Cement kiln plant

2.6.5 Co-incineration of hazardous wastes and/or sewage sludge in municipal waste incineration plants

These subjects have already been discussed in sections 2.3 and 2.5, respectively.

For reference literature on sections 2.6 – 2.6.5, see chapter 7, references [116] – [125].

Short summary

co-incineration of biomass and waste

- The incineration of waste wood in small incineration units in the wood industry is expected to be declining, because of the introduction of more strict emission standards;
- on the other hand, middle and large scale wood incineration plants with adequate energy recovery and flue gas treatment will be of increasing importance;
- wood will also increasingly be used for co-incineration in large coal power plants, together with other biomass and waste types from agriculture, the food industry, the paper industry etc.;
- emission standards for co-incineration of biomass and waste are presently in development;
- the Dutch cement kiln plant has a permit which allows the co-incineration of various types and amounts of non-hazardous and hazardous wastes.

3. EMISSIONS, RESIDUES AND ENERGY ASPECTS

In the past decades, the subject of (reduction of) emissions to air was of main importance for the municipal waste incineration sector. In recent years also the other environmental aspects of waste incineration have gained increasing interest, including the influence of cross-media effects. Chapter 3 gives a description of the developments in these fields, as follows:

- emission to air are discussed in section 3.1. Main emphasis is directed towards emission standards in the Netherlands, Germany and in the EU;
- emissions to water are discussed in section 3.2. The main interest goes to emissions related to wet flue gas systems, but also other emissions to water are covered;
- environmental aspects of residues of the incineration process (bottom-ash, fly ash etc.) are discussed in section 3.3 and of solid residues of flue gas treatment systems are discussed in section 4.6.5.
- energy aspects are discussed in section 3.4;
- noise aspects, including the noise aspects of waste transportation, are discussed in section 3.5;
- operational and safety aspects are discussed in section 3.6.

The descriptions in this chapter are based on the incineration of **municipal waste**, as this is the main subject of this report. Only in cases where aspects differ substantially from municipal waste, other incineration sectors (hazardous waste, specific clinical waste, sewage sludge etc.) are discussed.

3.1 Emissions to air

3.1.1 General

Following activities, related to waste incineration cause emissions to air:

- traffic for transport of waste;
- waste acceptance and storage;
- waste pre-treatment;
- waste incineration;
- treatment and transport of residues.

The emissions to air, related to the waste incineration process are the most important of these emissions. As the incineration process takes place under a slight underpressure, its emissions to air exclusively take place through the stack. Therefore, discussion of BAT-aspects of the emission to air will be concentrated on stack emissions.

The other emissions will be discussed in section 3.1.3.

3.1.2

Stack emissions

Stack emission amounts depend on the flue gas amount and on the concentrations of the various emitted compounds.

Flue gas amount depends on the amount of waste, its composition (with the LHV as most important parameter), on the amount of excess air and on the water content (various flue gas treatment technologies have influence on the water content of the flue gas). In order to avoid presentation of lower emission concentrations by adding additional excess air and/or additional water vapour, concentrations are calculated on a normalised basis: 11% O₂ (comparable with an excess air factor of 2,05) and 0% H₂O ("dry"). See also section 1.7.

Standards for stand-alone incineration

Dutch municipal waste incineration plants comply fully with present Dutch emission standards, as introduced in 1989 as Dutch Directive for Waste Incineration ("Richtlijn Verbranden 1989") and as confirmed in the Decree on air emission for Waste incineration (Besluit Luchtemissies Afvalverbranding, BLA), in force since 1993.

Dutch hazardous waste incineration plants comply with the emission standards in the Dutch 'Regulations for Incineration of Hazardous Waste' ("Regeling Verbranden Gevaarlijk Afval", RVGA), which is in force since 1998.

The permitted emission concentrations of sewage sludge incineration is based, in general, on the standards of the Dutch Directive for Waste Incineration 1989, comparable with the standards in the Decree on air emission for Waste incineration (BLA, 1993).

Table 3.1 gives typical concentrations of pollutants in the flue gas before and after flue gas treatment, as well as relevant emission standards.

Table 3.1: Flue gas concentrations and Dutch and European emission standards to air for waste incineration plants

	Unit	Typical composition of raw flue gas (mun. waste)	Dutch municipal waste standard (BLA)	Dutch hazardous waste standard (RVGA)	Typical values realised in the Netherlands	Old EU standard	EU standard per 4.12.2000
Dust	mg/m ³	3000	5	10	0.5 - 3	30	10
Acid gases							
HCl	mg/m ³	750	10	10	0.5 - 5	50	10
HF	mg/m ³	5	1	1	0.1 - 0.5	2	1
SO ₂	mg/m ³	300	40	50	2 - 30	300	50
NO _x	mg/m ³	350	70	-	40 - 70	-	200/400
NH ₃	mg/m ³	-	-	-	0 - 3	-	-
Heavy metals							
Hg	mg/m ³	0.25	0.05	0.05	0.005 - 0.02	} 0.2	0.05
Cd+Pb	mg/m ³	1.0	0.05	0.05	0.001 - 0.01		0.05
Others ¹	mg/m ³	35	1	0.5	0.01 - 0.1	5	0.5
Non combusted carbon/organics							
CO	mg/m ³	25	50	50	5 - 50	-	50
C _x H _y	mg/m ³	5	10	10	0 - 10	-	10
PCDD/F's as TEQ	ng/m ³	1 - 5	0.1	0.1	0.01 - 0.05	-	0.1

1) for municipal waste incineration

2) Sb, Pb, Cr, Cu, Mn, V, Co, Ni, Se en Te

Following remarks can be made on the typical composition of untreated flue gases (column 1):

- the indicated concentrations of 'raw' flue gas are related to municipal waste incineration with grate technology. For other waste types and/or incineration technologies figures may differ;
- dust concentrations depend on the character of the waste as well as on the design of grate and furnace;
- HCl, HF and SO₂ concentrations depend on waste composition. Design of the incineration part of the plant has little influence on this value;
- NO_x-concentration mainly depends on process conditions (temperature, homogeneity, O₂-concentrations, division between primary and secondary air);
- concentrations of heavy metals strongly depend on waste composition. Solid components are attached to dust particles. Heavy metals with a relatively low boiling point (Hg, Cd, Pb) cause (also) emissions in gaseous form. This is especially the case for mercury (Hg);
- concentrations of CO and C_xH_y mainly depend on grate and furnace design. Especially the optimal division of incineration air, control of temperature, residence time and homogeneity is important;

- concentrations of PCDD and PCDF depend on boiler design ("de-novo-synthesis"), but also on grate and furnace design and on the use of an electrostatic precipitator.

In Table 3.2 a survey is given of the emissions of the waste incineration plants in the Netherlands (for the year 1999). In section 4.4 the various flue gas treatment systems are presented.

Specific note for table 3.2

The data in table 3.2 are not collected specifically for this BAT-document but are based on figures, collected out of the various Environmental Annual Reports. In some cases, figures are influenced by specific circumstances (start-up, technical problems etc.) or by factors, such as other (waste treatment or industrial) activities, executed by the incineration companies, such as:

- mechanical sorting and landfill activities (ARN Beuningen and AVI Wijster);
- waste type and composition. As an example, specific emissions to air per ton of waste are influenced by the LHV of the waste proportionally
- combinations of the incineration of municipal waste with hazardous waste (AVR Botlek), sludge and specific hospital waste (GEVUDO, ZAVIN, DRSH);
- additional sludge drying (by AVI Roosendaal) etc.

The figures should therefore not be considered as absolute values but as indications.

Emission standards for co-incineration

Emission standards for co-incineration of biomass and waste together with fossil fuels are still in development in the Netherlands. According to the present proposals, following principles will apply:

- The emission standards will be comparable with the emission limit values of the EU-directive
- Emission standards of heavy metals, HF and HCl will be more strict.

Table 3.2
DUTCH WASTE INCINERATION PLANTS

1999 EMISSIONS TO AIR

Table 3.2 : Specific emission loads to air of the Dutch waste incineration plants (see section 2.1.1);
Calculated out of the yearly emission loads and the incinerated amounts of wastes in 1999 [176]-[190] and [201].

Company (*)	Incinerated (kton/year)	CO2 (ton/ton)	Dust (kg/ton)	HCl (kg/ton)	HF (g/ton)	NH3 (kg/ton)	SO2 (kg/ton)	NOx (kg/ton)	Hg (g/ton)	Cd (g/ton)	heavy metals (g/ton)	CO (kg/ton)	CxHy (kg/ton)	Diox/Fur (10E-6 g/ton)
Municipal Waste Incineration														
Gevudo	171	1,090	0,007	0,003	1,558	0,001	0,028	0,402	0,088	0,043	0,48	0,134	0,013	0,13
AVR R'dam	386	0,885	0,001	0,013	0,371	n.a.	0,008	0,278	0,005	0,002	1,04	0,086	0,004	0,11
AVR-Bollek	1.106	0,898	0,002	0,005	0,127	0,025	0,003	0,320	0,011	0,003	0,16	0,188	0,007	0,39
AVR AVIRA	301	1,170	0,001	0,019	1,311	5,4	0,058	0,219	0,015	0,004	0,35	0,098	0,003	0,52
AVI Roosendaal	55	0,805	0,001	0,039	0,603	0,008	0,063	0,381	0,007	0,004	0,37	0,116	0,037	0,09
ARN	250	1,069	0,004	0,004	1,495	0,002	0,004	0,432	0,006	0,047	0,05	0,100	0,005	0,08
AVI Amsterdam	789	0,891	0,003	0,001	0,020	0,000	0,015	0,324	0,010	0,002	0,13	0,058	0,002	0,25
AVI Noord-Holland	452	0,918	0,008	0,006	0,252	0,008	0,013	0,303	0,006	0,023	0,02	0,062	0,002	0,12
AVI Wijster	433	1,164	0,006	0,001	1,335	0,001	0,025	0,231	0,074	0,005	0,32	0,042	0,006	0,06
AZN	603	1,000	0,003	0,015	0,332	0,017	0,008	0,342	0,006	0,000	0,11	0,046	0,001	0,33
AVI Twente	285	1,053	0,006	0,009	0,674	0,002	0,012	0,324	0,007	0,007	0,54	0,055	0,015	0,00
Hazardous Waste Incineration														
AVR-Chemie DT-08	44	1,182	0,016	0,041	0,913	n.a.	0,012	1,629	0,020	0,004	0,64	0,455	0,012	0,11
AVR-Chemie DT-09	51	1,181	0,006	0,006	0,392	n.a.	0,005	1,666	0,030	0,003	0,19	0,360	0,011	0,61
Clinical Waste Incineration														
ZAVIN	7	n.a.	0,002	0,003	4,750	n.a.	0,101	0,870	0,042	0,048	0,09	0,047	0,009	0,23
Sewage Sludge Incineration														
DRSH	371	0,291	0,001	0,001	0,094	0,000	0,004	0,089	0,003	0,003	0,01	0,009	0,002	0,01
V.I.T.	89	0,293	0,003	0,002	0,005	0,002	0,008	0,065	0,007	0,003	0,05	0,108	0,004	0,01
SNB	406	0,301	0,002	0,002	0,000	0,028	0,012	0,085	0,010	0,002	0,02	0,017	0,001	0,02

3.1.3

Other emissions to air

Air emissions due to traffic

These emissions are caused by the heavy transport trucks or other means of transport. Main bulk truck emissions are dust, CO, C_xH_y, NO_x and SO₂. Typical figures for transport emissions per ton of material for trucks with a capacity of 30 tons are indicated in table 3.3.

Table 3.3: Emission factors of diesel driven lorries

Compound	Emission factor, (gram/km)
Dust	1,0
CO	3,3
C _x H _y	2,2
NO _x	14
SO ₂	0,95

It can be calculated that the contribution of these emissions to the total emission load, related to waste incineration is relatively very limited, as long as transport distances are not over 100 – 200 km, with NO_x as an exception.

Air emissions of acceptance and storage of waste

Acceptance and storage of municipal waste takes place in a closed bunker. So no significant direct air emissions take place. Ventilation air is used as incineration air. Polluting components are therefore incinerated and included in the stack emissions.

Only in special cases, air emissions (including odour emission) may occur:

- if plants are equipped with only one line. There will be periods for maintenance and other stops, during which no incineration air is required. This situation should be taken into account in the design of the plant, depending also on environmental conditions;
- in case of accidents (fire in the bunker). Adequate fire detection, prevention and abatement measures in the bunker area are required.

Air emissions due to arrival, storage and use of chemicals

Normally chemicals are arriving in closed systems and stored under comparable conditions. Exhaust air of silos or tanks can be lead to the incineration or flue gas treatment process or treated in small treatment units, according to valid regulations.

Air emissions of pre-treatment of waste

The potential air emissions of (mechanical) pre-treatment of waste are dust and odour. Dust emission can be prevented by application of cyclones or bag filters. Odour nuisance normally can be prevented by an adequate ventilation system. Only in specific cases (e.g sludge incineration plants), additional odour reduction provisions (biofilters, scrubbers) are required. An interesting option, in case of mechanical pre-treatment and

incineration on the same site is the use of ventilation air of the mechanical pre-treatment department as (part of the) required incineration air.

Air emissions due to treatment of residues

Emissions to air, due to incineration residues and residues of the flue gas treatment system can be prevented completely. In case of a proper incineration process, remaining contents of bio-degradable material are low and odour emissions are very limited. Dust emission may occur, due to blowing out small particles, but can be prevented by adequate measures.

Applicable measures are closed reception and treatment of fresh bottom ash. Storage can take place in open air, in case bottom-ash has a sufficient moisture content. If required, water should be sprayed.

Fly ash is to be stored and transported in closed systems (silos, tank trucks). Aspiration air of the silos has to pass bag filters.

3.2 Emissions to water

3.2.1 Introduction

(Potential) emissions to water, related to waste incineration plants can be categorised as follows:

- process waste water, resulting from a wet flue gas treatment system, including cleaning water from related departments. During the selection of a wet flue gas treatment system, the effects of emissions through this waste water stream have to be considered (cross media effects). Wet flue gas treatment systems are discussed in section 4.4.4 and the treatment technology for the related waste water in section 4.5;
- waste water from collection, treatment and (open air-)storage of bottom ash. This type of waste water can be used as water supply for wet deslagger systems (see section 2.2.2) and therefore normally does not need to be discharged. It is however important to have sufficient storage capacity, in order to be able to cope with fluctuations, caused by heavy rainfall. Incidentally this waste water has to be discharged. Options are an available process waste water treatment system, discharge to the local sewerage system and/or special disposal;
- other less specific process waste water streams, such as waste water from the water/steam cycle (resulting from the preparation of boiler feed water and from boiler drainage). In many practical situations, these water flows can be reused in the incineration and flue gas treatment process (e.g. as make-up water) and therefore do not lead to emissions to the environment. And in case they are still discharged, they are not specific for waste incineration and therefore are not discussed in detail in this BAT-document;
- sanitary waste water, resulting from toilets, kitchen and cleaning of non-specific installations departments. It is normally discharged to the sewage system, for treat-

ment in a communal waste water treatment plant. As this category of waste water is not specific for waste incineration, it is not further discussed in this BAT-document;

- clean rain water, coming from non-polluted surfaces, such as roofs, service roads and parking places etc. Normally this water is discharged by a "clean" water collection system and discharged directly to the local surface water;
- polluted rain water, from polluted surfaces (unloading activities etc.) is normally very little amounts and discharged to the polluted sewerage system;
- used cooling water. By far, the largest cooling capacity is required for condenser cooling, in case of electricity production with a steam turbine. Depending on the design of the plant, various types of cooling water streams have to be disposed of, such as:
 - * cooling water from convection cooling of the condenser, connected with the steam turbine;
 - * cooling water, drained off from a evaporation cooling water system, used for a.o. condenser cooling;
 - * cooling water from various other equipment parts which require cooling (waste chute, hydraulic systems, strippers etc.).

Because these cooling water streams are not very specific for waste incineration, they are discussed in the European "Reference document on the application of Best Available Techniques to Industrial Cooling" (see also section 1.3). It is remarked here that cooling systems have an important impact on optimisation of the energy efficiency of waste incineration.

- a specific waste water stream for sewage sludge incineration is the condensated waste water, resulting from the partial pre-drying step (see section 2.5.3). Though this waste water is not resulting from the incineration process itself, the pre-drying is considered as an integral part of the sludge incineration process. This waste water contains substantial concentrations of COD and N (mainly ammonia), as well as other pollutants which were present in the treated sludge. It therefore has to be treated in a biological waste water treatment plant before being discharged to surface water. The technology of this biological waste water treatment is out of the scope of this document. It is however noted, that especially the high nitrogen content can form a bottleneck for adequate treatment. In that case stripping of nitrogen is an option, which is applied at one of the two Dutch sewage sludge incineration plants (SNB, see section 2.1.4). The recovered ammonia-solution (concentration approx. 10%) is used for SNCR-DeNOx in the fluidised bed system.

A survey of the emissions to surface water of the various Dutch waste incineration plants is included in Table 3.4.

Specific note for table 3.4

As already indicated for table 3.2, the data in table 3.4 are not collected specifically for this BAT-document but are based on figures, collected out of the various Environmental Annual Reports. In some cases, figures are influenced by specific circumstances (start-up, technical problems etc.) or by factors, such as other (waste treatment or industrial) activities, executed by the incineration companies, such as:

- mechanical sorting and landfill activities (ARN Beuningen and AVI Wijster);
- waste type and composition.;
- combinations of the incineration of municipal waste with hazardous waste (AVR Botlek), sludge and specific hospital waste (GEVUDO, ZAVIN, DRSH);
- additional sludge drying (by AVI Roosendaal) etc.

The figures should therefore not be considered as absolute values but as indications.

Table 3.4
DUTCH WASTE INCINERATION PLANTS
EMISSIONS TO WATER 1999

Tabel 3.4 : Specific emission loads to water (surface water and/or municipal sewerage system)
Calculated out of the yearly emission loads and the incinerated amounts of wastes in 1999 [176]-[190].

Company (*)	Incinerated (kton/year)	As (mg/ton)	Cd (mg/ton)	Cr (mg/ton)	Cu (mg/ton)	Hg (mg/ton)	Pb (mg/ton)	Ni (mg/ton)	Zn (mg/ton)	Chlorides (g/ton)	Sulfates (g/ton)	CZV (g/ton)	N-Kjeldahl (g/ton)
Municipal Waste Incineration													
Gevudo	171	23,2	9,1	17	115	3,04	72	39,9	552	4990	2070	298	46
AVR R'dam	386	0,5	0,3	5	6	0,10	9	8,6	4	n.a.	n.a.	15	1
AVR-Botlek	1.106	0,6	2,7	2	4	0,72	5	2,1	20	n.a.	n.a.	34	4
AVR AVIRA	301	0,0	2,0	2	6	0,07	2	1,6	26		0	133	10
AVI Roosendaal	55	4,4	0,1	7	62	0,02	16	4,9	45	0	0	24	1
ARN	250	3,7	1,3	43	25	0,71	23	44,4	101	708	111	207	131
AVI Amsterdam	789	0,0	0,0	0	0	0	0	0	0		0	0	0
AVI Noord-Holland	452	0,1	0,1	1	3	0,02	4	0,4	27	1	n.a.	n.a.	n.a.
AVI Wijster	433	23,1	0,0	30	58	0,16	53	36,9	226	335	84	380	44
AZN	603	0,2	0,2	0	2	0,17	0	0,3	23	4602	254	18	4
AVI Twente	285	n.a.	0,0	0	0	n.a.	0	0,0	1	2	n.a.	12	1
Hazardous Waste Incineration													
AVR-Chemie DT's	44	4,6	4,6	14	25	6,84	23	18,3	228	n.a.	n.a.	319	26
Clinical Waste Incineration													
ZAVIN	7	191,1	632,1	658	2694	4391,27	11676	459,0	72832	n.a.	n.a.	658	16
Sewage Sludge Incineration													
DRSH	368	21,4	3,5	5	79	5,97	15	3,0	92	1561	4560	1829	n.a.
SNB	406	5,8	0,6	18	17	1,23	8	12,3	51	725	31	816	768
V.I.T.	89	1,9	1,5	3	14	0,51	19	6,0	56	n.a.	56083	155	30

(*) For a description of the companies is referred to section 2.1.1.

3.2.2 Basic design principles for waste water aspects

Following basic principles form the basis for the assessment of BAT concerning the (waste) water aspects of waste incineration in the Netherlands:

1. Application of optimal incineration technology. An optimal incineration process is an important condition for an effective control of emissions to water. Incomplete incineration has a negative effect on flue gas and fly ash composition, by increased presence of organic compounds with a polluting and/or toxic character. The design of an optimal incineration process is mainly discussed in sections 2.2.2, 2.2.3 and 2.2.4.
2. Minimal water consumption and minimal discharge of waste water. This principle is to be kept in mind in the various parts of a waste incineration plant, but also in the overall design. Examples of the elaboration of this principle are:
 - maximum recirculation of polluted waste water in the wet flue gas treatment system (the scrubber), including effective control of process parameters, in order to minimise the amount of waste water for discharge;
 - additional cooling of polluted waste water of the wet flue gas treatment system, resulting in a lower water content of the emitted flue gases and therefore in less water consumption. This design can even result in no water consumption at all for this purpose. Additional advantage is a better efficiency of the wet flue gas treatment system for compounds as PCDD/F and Hg etc. (AVI Amsterdam, DRSH Dordrecht);
 - application of waste water free flue gas treatment technology in case local surface water conditions prohibit discharge of treated waste water;
 - use of boiler drain water as water supply for the scrubber;
 - treatment of laboratory waste water in the scrubber;
 - application of waste water free deslaggers;
 - use of leachate of open-air bottom ash storage areas for supply of water to the deslaggers;
 - direct discharge of clean rain water from roofs and other clean surfaces;
 - etc.
3. Compliance with relevant water emission standards. This aspect is particularly of interest for the waste water from a wet flue gas treatment system. If discharge of waste water can't be avoided treatment of the waste water is necessary. The discharges should be in compliance with the relevant emissions standards and can only be permitted, provided that no adverse effects to the receiving surface water occur. Therefore the emission standards can differ per location (especially for anorganic salts, see section 3.2.3)
4. Optimal operation of the water treatment systems. Operational attention should not only be focussed on the incineration and flue gas treatment processes, but also on the operation of the (waste) water systems. Related operational personnel should be qualified in the field of waste water treatment. Plant management has to pay attention to the proper operation of water systems. Sufficient storage capacity for buffering of waste water should be

available, in order to be able to react on disturbances in the process conditions.

3.2.3 Process waste water from the wet flue gas treatment system

The production of this category of waste water depends on the selected type of flue gas treatment system. It is essential that the selection of flue gas treatment systems (dry, semi-dry or wet, see sections 4.4.3 – 4.4.4) is based on an integral evaluation of air and water emissions, including the effects on produced residues.

As described more in detail in section 4.5, three main principles for treatment of the waste water of wet flue gas treatment systems exist:

- physical-chemical treatment, based on pH-correction and sedimentation, as described in section 4.5.2. With this system, a treated waste water stream containing dissolved salts has to be discharged;
- evaporation in the waste incineration process line, by means of a semi-dry system, as described in section 4.4.3. In this case, the dissolved salts are incorporated in the residue of the flue gas treatment system. There is no emission of waste water;
- separate evaporation of waste water, as described in section 4.5.3. In this case, the evaporated water is condensed, but can be discharged (or reused) without special measures.

The integrated evaluation therefore includes following options:

1. Dry flue gas treatment (see section 4.4.3);
2. Semi-dry flue gas treatment (see also section 4.4.3);
3. Wet treatment with physical/chemical treatment (see 4.4.4 and 4.5.2);
4. Wet treatment with in line evaporation (see 4.4.4 and 4.5.3);
5. Wet treatment with separate evaporation (see also 4.4.4 and 4.5.3).

Of these alternatives, only alternative 3 has a waste water stream that has to be discharged.

Table 3.5 gives an indication of the emission standards that are to be complied with for discharge of this waste water. The indicated typical values can normally be reached in case of adequate waste water treatment. The second column with the normally applied range, gives an overview of normally used discharge standards in the Netherlands. One of the reasons for the relatively wide range, is that it is related to direct as well as to indirect (via a biological waste water treatment plant) discharge situations.

Table 3.5: Indication of emission standards for discharge of wet flue gas treatment waste water (direct and indirect discharges)

Compound	Typical value for discharge to surface water	Normally applied range, depending on circumstances	Unity
As	10	3-200	µg/l
Cd	50	5-100	µg/l
Cr	30	30-500	µg/l
Cu	20	10-100	µg/l
Hg	5	1-20	µg/l
Pb	100	50-500	µg/l
Ni	30	15-100	µg/l
Sn	50	25-100	µg/l
Mo	1000	100-1000	µg/l
Zn	200	50-500	µg/l
Suspended solids	10	10-45	mg/l
PCDD/F (TEQ)	0.1	<0.1	ng/l

In various case additional compounds are included in the permit conditions, such as phenols, EOX, VOX, PAH, N-total, sulphides, etc.

Permit conditions can vary, depending on local factors, such as local surface water quality, character etc.

Before evaluating the various flue gas treatment technologies in this document, the various options for flue gas and waste water treatment will be described in more detail in chapter 4 (see section 4.4). For further details on this integral evaluation (taking into account cross-media effects) we refer to chapter 5.

3.2.4 Cooling water

As indicated in section 3.2.1, waste incineration plants need cooling facilities. Main cooling is required for the condenser, connected with the steam turbine for electricity production.

Even if recovered energy is used for other purposes, cooling provisions may be required, in order to be able to continue the incineration process in case energy supply for recovery purposes has to be interrupted and the operation of the waste incineration process should be continued.

The most generally used cooling systems are:

- convection cooling;
- evaporative cooling;
- air cooling.

Convection cooling generally results in an optimal energy efficiency, as condenser temperature can be kept at a minimum temperature level. If cooling water is abundantly available and discharge possibilities are sufficient, convection cooling may preferably be applied.

If limited cooling water amounts are available, evaporative cooling can be considered. The efficiency of the energy recovery is somewhat lower, as the temperature level of the cooling water is higher than with convection cooling (but better than with air cooling, because wet bulb temperature is lower than ambient air temperature). The amount of water intake is substantially lower than with convection cooling. To keep water quality in the cooling water cycle on an acceptable level, part of the cooling water has to be discharged. Normally it is sufficient to drain off approximately the same amount of water as is evaporated in the system. Other effects of evaporative cooling are noise production and the presence of a water vapour plume.

Condenser cooling can also be executed with air. For this purpose an adapted condenser design is required. This cooling method results in a lower energy efficiency, as air cooling results in higher condenser temperatures than water cooling. Additionally the air cooling system requires a substantial energy consumption, due to the ventilation capacity, required to provide sufficient amounts of air. One of the environmental aspects is noise production

3.3 **Solid residues**

3.3.1 General

As described in the various sections of chapter 2 following (categories of) residues exist with municipal waste incineration:

- bottom ash, resulting directly from the incineration process on the grate (see section 2.2.2);
- boiler ash, removed out of the flue gas stream in the boiler (see section 2.2.5);
- fly ash from a specific dust removal step (see section 4.4.2)
- iron scrap, removed out of the bottom ash by magnetic separation techniques (see section 4.6.2);
- non-ferrous scrap, removed out of the bottom ash by the so-called eddy-current technique (see section 4.6.2)
- various types of residues from the flue gas treatment (see section 4.4).

Table 3.6 gives an overview of the total amount of residues of municipal waste incineration in the Netherlands and their re-use in 1999/2000.

Table 3.6: Survey of production, re-use and disposal of municipal waste incineration residues (1999/2000)

	Number of plants	1999			2000		
		Production	sale for re-use	landfill	Production	sale for re-use	landfill
Incineration residues							
Bottom ash	11	1,100,000	1,350,000	12,500	1,000,000	800,000	5,000
Fly ash	11	90,000	41,000	47,000	80,000	55,000	24,000
Boiler ash	5	8,800	--	--	7,600	3,000	4,000
Ferrous scrap	11	116,000	116,000	--	114,000	114,000	--
Non-ferrous scrap	11	6,300	6,300	--	6,200	6,200	--
Subtotal	11	1,321,100	1,391,000	59,500	1,207,800	978,200	33,000
Flue gas treatment residues							
Filter cake	9	13,300	7,000	7,000	8,700	2,600	6,000
Salts	4/5	20,300	--	20,300	27,200	--	20,600
Sludges	2	5,200	--	5,200	3,600	--	3,600
Gypsum	1	2,000	2,000	--	2,400	2,400	--
Subtotal	11	40,800	9,000	32,500	41,900	5,000	30,200

It is noted, that production, re-use and landfill figures may not fit exactly for each year, due to temporary storage.

As indicated a very large part of the residues are re-used for various purposes.

In the Dutch (general) policy on residues of waste incineration the realisation of a maximum volume of re-use of these residues, under sound environmental conditions is a very important objective. As bottom ash is the majority of the municipal waste incineration residues, this policy is further elaborated for this type of residue in the following section 3.3.2.

The other incineration residues of municipal waste are discussed in sections 3.3.3 – 3.3.5.

Incineration residues from other types of waste are:

- slag from the rotary kiln incineration of hazardous waste. This is a relatively limited amount of approx. 20,000 t/y;
- bottom ash from specific clinical waste incineration. This is a very little amount of approx. 1,000 t/y;
- incineration ash of sewage sludge. It should be noted that with fluidised bed incineration there is no bottom ash. All ash residues (with exception of the bed ash) leaves the bed with the flue gases and is removed out of the flue gases as boiler ash (a minor part) and as fly ash (the majority). These ashes show little difference in composition and therefore are normally stored and treated together.
- bed ash from fluidised bed incineration. The amount of bed ash, related with sewage sludge incineration is very limited. Fluidised bed incineration of other waste types may cause higher amounts of bed ash, especially if circulating

fluidised bed incineration will be applied. Up till now, the application of fluidised bed technique for waste incineration in the Netherlands is mainly limited to sewage sludge.

As indicated above, residues from non-municipal waste incineration are produced in relatively small amounts, with the exception of incineration ash of sewage sludge (total yearly production in the Netherlands approx. 70,000 t/y). Therefore only the situation of this incineration ash is discussed in more detail in section 3.3.6.

Finally, residues of flue gas treatment of municipal waste and other waste types are discussed in section 3.3.7.

3.3.2 Bottom ash

The main compounds of bottom ash from municipal waste are SiO₂ (approx. 55%), CaO (10%), Fe₂O₃ (6%) and Al₂O₃ (6%). Furthermore it contains some salts (especially its chlorine content is relatively high for use as a civil construction material) and a wide variety of heavy metals. An indicative, average composition (heavy metals) of bottom ash is given in table 3.7.

Table 3.7: Heavy metal contents of various waste incineration residues (indicative average values in mg/kg dry solids, actual composition can vary substantially)

Element	Municipal waste	Industrial waste	Other waste	Other waste
Aluminium		700		
Arsenic	40	70	50	30
Bismuth		275		
Cadmium	10	130	140	5
Chromium	380	300	300	90
Cobalt		40		
Copper	2400	1000	900	950
Mercury	0.1	0.3	5	<0.1
Lead	3000	9000	5500	450
Polychlorinated biphenyls	100	25	30	20
Nickel	190	100	150	75
Vanadium		300		
Zinc	3500	12,000	12,000	2250

According to existing Dutch legislation (Baga), the bottom ash from municipal waste incineration is non-hazardous waste, which under certain (environmental) conditions can be used for recycling purposes, as indicated in the Dutch Building Materials Decree ("DBMD", Bouwstoffenbesluit, see also section 1.6). This will not be influenced by introduction of the EURAL per May, 2002.

The Dutch Building Materials Decree defines two categories of civil construction materials and a sub-category. These categories are not based on the actual composition of the ash, but on the leachability of the various heavy metals. Materials complying with the first category can be used without restrictions, for cate-

gory 2 there are certain restrictions. Category 2 has a sub-category, which is specifically defined for bottom-ash from municipal waste incineration. This sub-category is planned to be cancelled per 1 January 2003.

The bottom ashes of most of the 11 Dutch municipal waste incineration plants have difficulties to comply with the DBMD. Bottlenecks are the leachability of copper and molybdene. Only two municipal waste incineration plants produce bottom ash, which complies and therefore is certified, two other plants have minor deviations. The others do not comply.

This means an important limitation for future re-use of the bottom ashes. Nevertheless, as already indicated in table 3.6, it was possible to re-use nearly all bottom ashes in the past years, in line with Dutch policy. In order to continue this situation, Dutch policy is formulated as follows:

1. Continuation of the nearly 100% re-use of bottom ash, according to the DBMD;
2. In line with the DBMD, application of bottom-ash should take place in large projects, (embankments >10,000 tons, preferably >100,000 tons per project, road foundations >1,000 tons) in the public sector;
3. Pursuit of quality improvement, by improvement of input and/or after treatment;
4. Certified bottom ash can be sold on the commercial market, but should preferably be applied in large projects;
5. The long term strategy is to comply with category 2 of the DBMD, towards category 1.

To realise this policy, bottom ash treatment techniques are under development, as described in section 4.6.2 of this BAT-document.

3.3.3 Boiler ash

In Dutch municipal waste incineration plants, boiler ash is either added to the bottom ash or to the fly ash. An indicative, average heavy metals composition is indicated in table 3.7. As the compositions of boiler ash and bottom ash do not show substantial differences, the recent trend is to add the boiler ash to the bottom ash. This offers better possibilities for re-use;

3.3.4 Fly ash

The composition of fly ash is also indicated in table 3.7. In the Netherlands, substantial amounts of fly ash of municipal waste incineration plants are recycled in bound applications, such as the asphalt industry. Another application is re-use in mortars for filling-up old mines in Germany. Unbound applications are not allowed. Remaining fly ash is landfilled as hazardous waste.

Dutch specific policy on re-use and disposal of fly ash can be described as follows (according to LAP, draft of January 2002):

1. landfill with application of cold immobilisation (separately or in combination with other waste types) and/or in big-bags (not for fly ash of hazardous waste incineration) is considered as the minimum standard;

2. if possible continuation of the existing possibilities for re-use of fly ash;
3. improvement of possibilities for re-use by immobilisation techniques and/or immobilised applications;

Treatment methods to improve fly ash quality are discussed in section 4.6.3.

3.3.5 Iron scrap and non-ferrous metals

Untreated bottom ash contains approx. 6% of iron scrap, which can be removed with magnetic separation. This scrap can easily be sold, though market prices may vary.

The content of non-ferrous metals in the bottom ash is approx. %, of which approx. 50 % aluminium, % brass, % zinc and % others. These materials can be removed by electric separation techniques (eddy-current) and offer at the moment an interesting price in the non-ferrous metal market.

3.3.6 Incineration ash of sewage sludge

The incineration ash of sewage sludge incineration is largely used as a civil construction material, in line with the minimum standard according to Dutch waste policy (LAP, version January 2002).

Main applications are:

- use as filling material in the asphalt industry;
- use as a filling material in mortars for the German mining industry. The use of this application will depend on the question, if this application will be considered as useful, according to forthcoming jurisprudence of the European Court.

According to Dutch legislation (Baga) incineration ash of the incineration of municipal sewage sludge is considered as non-hazardous waste. This will not change with the introduction of the EURAL.

3.3.7 Residues of flue gas treatment systems.

Additionally to the (direct) incineration residues, as discussed in section 3.3.1, the flue gas treatment systems, connected with waste incineration (see sections 4.4 and 4.5) produce residues. The composition of these residues can vary substantially. Their composition is not so much defined by the type of waste but much more by the type of flue gas treatment, see section 4.4.3 – 4.4.7.

Generally spoken following components can be included in these residues:

- * remaining amounts of fly ash, including heavy metals and dioxins;
- * salts, formed as a result of the reactions to remove acid compounds. Depending on the type of flue gas treatment, waste water treatment and applied chemicals, this can include soluble and/or non-soluble salts;
- * surpluses of used chemicals and adsorbents (e.g. lime, activated carbon, A-cokes);
- * (in various cases also) water.

According to Dutch waste policy (LAP, version January 2002), two main categories of flue gas treatment residues can be distinguished:

- filter cake;
- dry residues;

These residues are considered hazardous waste. Minimum standard for disposal of these waste is landfilling under special conditions (hazardous waste landfill, immobilisation and/or application of big bags).

Methods to improve (environmental) quality etc. for these residues, as well as developments to re-use (part of) these residues are discussed in sections 4.4 and 4.5 and summarised in section 4.6.5.

3.4 Energy aspects

Recovered energy from (municipal) waste incineration is mainly used for electricity production (see table 3.8). Important advantage of this application is that the produced electricity can be supplied to the local electricity grid and that no significant constraints exist with respect to time, quantity and distance. Only price level can be influenced by these constraints.

As can be seen from table 3.8, all Dutch municipal waste incineration plants are equipped with steam boilers and produce electricity, with the exception of AVI Roosendaal (SITA ReEnergy), which has hot water boilers and is producing heat for various purposes (see below).

Municipal waste consists for a substantial part of renewable materials (paper, wood etc), but also contains materials from fossil origin, such as plastics. Electricity recovered from municipal waste incineration is considered in the Netherlands as 50% sustainable energy.

As indicated in section 2.2.4, steam temperatures are normally limited to approx. 400°C and therefore electricity production has a limited efficiency. Technological developments to improve efficiency of energy recovery and electricity production have been discussed in section 2.2.6.

As indicated in section 1.6, the preparation of the new National Waste Management Plan (Landelijk Afvalbeheers Plan, LAP) includes the planning of the Dutch waste incineration sector. For the planning of the waste incineration sector there is much emphasis on an optimal efficiency of the production of (partly sustainable) electricity from waste. Thus in the Netherlands there is much interest in the new developments on furnace and boiler technology, as indicated in sections 2.2.4 and 2.2.6.

Additionally, supply of heat (preferably using co-generation technology) is an important method to improve overall energy efficiency of waste incineration. This development also attracts much attention. Begin 2001, a report has been published with a proposal for a method to determine the overall energy efficiency of waste incineration with or without co-generation technology (KEMATNO) [192, 193].

Specific note for table 3.8

The data in table 3.2 are not collected specifically for this BAT-document but are based on figures, collected out of the various Environmental Annual Reports. In some cases, figures are influenced by specific circumstances (start-up, technical problems etc.) or by factors, such as other (waste treatment or industrial) activities, executed by the incineration companies, such as:

- mechanical sorting and landfill activities (ARN Beuningen and AVI Wijster);
- waste type and composition. As an example, specific energy indicators per ton of waste are influenced by the LHV of the waste proportionally
- combinations of the incineration of municipal waste with hazardous waste (AVR Botlek), sludge and specific hospital waste (GEVUDO, ZAVIN, DRSH);
- additional sludge drying (by AVI Roosendaal) etc.

The figures should therefore not be considered as absolute values but as indications.

Table 3.8

**Table 3.8 DUTCH WASTE INCINERATION PLANTS
1999 ENERGY DATA**

Company	Incinerated (kton/year)	Installed electric Power (Mwe)	Installed thermal power (MWth)	Generated Electricity (Gwhe)	Generated Electricity (kWhe/tonne)	Steam Production (kton)	Steam Production (kton/tonne)	Steam Pressure (bar)	Steam temperature (C)	Application/remarks
Gevudo	171	9,9	69,8	56	0,328	290	1,70	40	400	Only 2 lines with boiler, electricity, supply of steam to neighbours
AVR Roteb	386	25,5	126	169	0,438	946,9	2,46	30	350	Electricity, process steam
AVR-Botlek	1.106	108	387	598	0,541	2969	2,68	27	370	Electricity, production of distilled water
AVR AVIRA	301	25	75	124	0,412	626	2,08	40	400	Electricity, hot water for district heating
AVI Roosen- daal	55	0	18	0	0,000	hot water				Hot water for heating of greenhouses and sludge drying
ARN	250	28	120	161	0,644	930	3,72	40	400	Electricity
AVI Amster- dam	789	80	225	534	0,676	2418,5	3,06	40	415	Electricity
AVI Noord- Holland	452	51,4	154	345	0,763	1392	3,08	40	400	Electricity
AVI Wijster	433	54	180	369	0,852	1142	2,64	40	400	Electricity
AZN	603	0	240	0	see application	2035	3,37	100	400	Steam: to nearby Combined-Cycle plant (see section 2.2.6)
AVI Twente	285	30	100	180	0,632	890	3,12	40	415	Electricity
AVR-Chemie	44				See AVR-Botlek					
AVR-Chemie	51				See AVR-Botlek					
ZAVIN	7	0,5	45	0		36,6	5,51	12	200	Saturated steam to GEVUDO
DRSH	83	0						10	200	Saturated steam for own sewage sludge partial pre-drying
V.I.T.	20	0								Direct drying
SNB	91	0						10	200	Saturated steam for own sewage sludge partial pre-drying

For the supply of heat, following possibilities are relevant (see also section 2.1):

- supply of heat to district heating systems. A Dutch waste incineration plant is applying this system (AVR AVIRA see section 2.1) and others are planning to do so in the near future. Limitation is, that seasonal effects reduce the average utilisation factor and that economic viability is normally rather poor;
- supply of heat to gardening centres and greenhouse areas. This option is also applied in the Netherlands (AVI Roosendaal, see below);
- supply of heat to industries and/or energy demanding activities. These are quite "tailor-made" solutions. Examples in the Netherlands are application of waste heat for production of distilled water (AVR Botlek), for thermal treatment (pre drying) of sludge (GEVUDO and AVI Roosendaal) and for improvement of biological waste water treatment (ARN Nijmegen and planned for AVI Amsterdam). In other cases, heat is supplied to (chemical) industries (AVI Moerdijk, in combination with a combined cycle power plant), actually in execution (AVI Amsterdam, industrial district heating) or in the planning phase (AVI Alkmaar).

As indicated above, AVI Roosendaal is the only Dutch waste incineration plant, which is not producing electricity. Total available heat production of AVI Roosendaal is approx. 450,000 GJ/year (2000). Heat supply to a adjacent gardening centre amounts to approx. 80,000 GJ/y, for sludge drying 36,000 GJ/y and for internal use (spray absorber) 100,000 GJ/y (figures for the year 2000).

Energy recovery is an important issue in the municipal waste incineration sector. This issue also plays a role in the incineration of hazardous waste, specific clinical waste, sewage sludge and biomass:

- the rotary kiln units of AVR Chemie are provided with boilers that are integrated in the energy system of AVR Botlek;
- various dedicated units for incineration of hazardous waste are integrated in the energy systems of the related chemical plants;
- the centralised clinical waste incineration plant of ZAVIN is provided with a boiler that supplies its steam to the energy system of the adjacent GEVUDO municipal waste incineration plant;
- the LHV of sewage sludge is so low, that electricity production is not considered as a feasible option. The design of the Dutch sewage sludge incineration plants is however as energy-efficient as possible;
- production of (sustainable) energy is the main aspect of the incineration of biomass.

3.5 **Noise aspects (including effects of waste transport)**

Noise aspects of waste incineration are comparable with other heavy industries and with power generation plants. In the Netherlands it is common practice that municipal waste incineration plants are installed in (a) completely closed building(s), as far as possible. This normally includes reception and unloading of waste, mechanical pre-treatment, flue gas treatment, treatment of residues etc. Only cooling facilities and long-time storage of bottom-ash are executed in open air.

Most important sources of external noise are:

- trucks for transport of waste, chemicals and residues;
- mechanical pre-treatment of waste;
- exhaust fans, extracting flue gases from the incineration process and resulting in noise from the outlet of the stack;
- noise, related to the cooling system (in case of evaporation cooling and especially in case of air cooling);
- noise related to transport and treatment of bottom-ash (if on the same site).

Other installation parts are not significant for external noise production but may contribute to a general external noise production by the plant buildings.

Noise is considered as a local aspect and therefore it is not discussed in detail in this BAT-document.

3.6 **Operational and safety aspects**

These aspects are comparable with similar industries and with the power generation sector. Important elements to ensure internal and external safety are:

- adequate procedures for acceptance of waste;
- adequate provisions for detection of fire and fire fighting in the waste bunker area;
- approval of boiler design by a competent authority;
- approval of the electrical design by a competent authority;
- design of the flue gas treatment department according to relevant safety regulations for storage and use of chemicals;
- application of modern control technology, in order to ensure proper process operation, including execution of a HAZOP-study (hazardous & operability);
- approval of the total plant set-up by the fire brigade;
- adequate training of operating personnel;
- adequate maintenance during plant operation;
- availability of adequate calamity procedures;
- application of a certified quality systems for process, environment, health and safety.

These elements have a general character and therefore are not discussed in detail in this BAT-document.

For reference literature on sections 3.1 – 3.6, see chapter 7, references [126] – [143].

4. REDUCTION OF EMISSIONS (AVAILABLE TECHNIQUES)

4.1 Introduction

In this chapter, technologies for pre-treatment of wastes, process-integrated measures, flue gas treatment technologies and residue treatment systems are discussed, comparable with the set-up of chapter 2 for waste incineration and boiler technology.

4.2 Pre-treatment of municipal waste

Pre-treatment of wastes is a very diversified subject and lies formally out of the scope of this document. As pre-treatment affects waste incineration, this report includes a general overview of this subject, according to the Dutch waste management policy as laid down in the LAP-version of January 2002 (Chapter 14).

The following aspects are discussed:

- segregated collection of waste;
- the status of mechanical sorting systems for treatment of municipal and industrial waste;
- pre-treatment of waste, as far as normally included in a municipal waste incineration plant.

4.2.1 Segregated collection of waste

In Dutch national waste management policy, segregated collection of waste (at source) is an important issue.

This includes in the first place **the segregated collection of useful materials and equipment**, such as paper, glass, metals, textiles, used household equipment etc. According to the Environmental Protection Act, this activity has priority over other waste treatment methods. There exists a wide variety of additional recycling activities, which are however out of the scope of this document.

A second important category is **the segregated collection of organic household waste (v.g.f.-waste)**. In the Netherlands in 1999 approx. 1,500,000 tons of v.g.f.-waste has been collected separately.

Standard treatment method for this material is *composting*. The resulting compost is used for agricultural purposes, including public gardens and sport accommodations. Since the large scale introduction of segregated collection of v.g.f.-waste in the 1990-ies, approx. 25 composting plants have been realised in the Netherlands, with capacities, varying from 10,000 up to 400,000 t/y.

Additionally two *digestion plants for v.g.f.-waste* have been realised in the Netherlands. The first plant was started up in 1994 and has a capacity of approx. 50,000 t/y (SMB, Tilburg). It produces a compost-like material, but additionally biogas is produced, which is upgraded into natural gas quality.

The second plant (Lelystad) is operational since 1999 and with a capacity of originally 35,000 t/y, to be extended till 50,000 t/y.

Furthermore there exists in the Netherlands a system for **segregated collection of (small amounts) of hazardous household wastes** (to be considered as BAT). Incineration of this waste takes place with AVR Chemie (see section 2.1.2), but also under specific conditions in municipal waste incineration plants (AVR Botlek, AVI Amsterdam, see section 2.2.1)

4.2.2 Mechanical sorting systems

Mechanical sorting of municipal waste has been developed in the Netherlands since the 1970-ies. Original main purpose was the production of secondary raw materials from municipal waste. Experiments and demonstration projects have shown, that the quality of the derived secondary materials (especially paper and plastics) was not sufficient for recycling purposes. Material qualities that could be obtained with segregated collection of various waste compounds were substantially better. This resulted in the following developments:

- an increased interest in the segregated collection of waste (see section 4.2.1);
- mechanical sorting systems for municipal waste aimed at the production of Refuse Derived Fuel (RDF, the relatively dry fraction) and OWF (organic wet fraction, the relatively wet fraction) as main sorting products;
- mechanical sorting technology was applied for treatment of industrial waste. Because of the possibility to make a pre-selection of industrial waste types, it is possible to reach better secondary material qualities as is the case with municipal waste;
- more recently mechanical sorting activities of industrial waste and also of building and construction waste are more directed towards the production of secondary fuels in stead of secondary materials. For these fuels, the expression "solid recovered fuel (SRF)" was introduced in the LAP-planning procedure, according to CEN (Commission European de Normalisation).

Present situation in the Netherlands is, that two municipal waste incineration plants (ARN Beuningen and AVI Wijster, see section 2.1.1) are equipped with mechanical sorting units. Main sorting products are RDF, OWF and metals. RDF is incinerated in the municipal waste incineration plants themselves. For this purpose the incineration plants are adapted to the relatively high LHV of the RDF (in comparison with normal municipal waste), amongst others by the use of water cooled grates. Additionally AVI Wijster produces a light RDF-fraction consisting of paper and plastic sheets, which are blown out of the RDF in wind-zifters. This fraction (SRF) is meant for sale to third parties, but applications in the Netherlands are unclear.

Final disposal of the OWF has been complicated by the fact that this fraction is also considered as combustible waste, as it is not complying with composition standards for agricultural use and because of its content of combustible materials. It is however remarked here, that incineration of OWF is not possible without drying/sorting, since OWF has a LHV of approx. 4 – 5 MJ/kg.

The incineration of RDF in these municipal waste incineration plants is complying with the same emission standards as "normal" municipal waste incineration.

Therefore emission concentrations of pollutants are on comparable levels. The amounts of emitted compounds per ton of incinerated waste increase (because of the higher average LHV). On the other hand, the amount of incinerated waste is reduced by the mechanical sorting operation, so the yearly emission loads are also reduced. This will end in case OWF will also be incinerated.

One mechanical sorting plant (VAGRON, Groningen, 2000) is producing a RDF for external use, while the OWF is washed, for removal of sand and other inert materials and subsequently digested [194]. The capacity of the sorting plant is 230,000 t/y, with an RDF production of 130,000 t/y. There are plans for additional sorting activities for paper and plastic out of the RDF, for a total of 35,000 t/y. Total amount of OWF is 92,000 t/y, out of which approx. 32,000 t/y sand and inert materials are removed. The remaining organic fraction (60,000 t/y) is digested. The sorting operation includes separation of iron scrap (7000 t/y) and non-ferrous metals (<2000 t/y).

Other former mechanical sorting plants for municipal waste have adapted their activities and now concentrate on treatment of industrial waste. This is in line with present development, that industrial waste is increasingly treated in mechanical separation lines. By an adequate combination of acceptance policies and mechanical sorting, these units produce RDF-types of improved quality.

Most applied mechanical sorting technologies are:

- rotary sieves and flat sieves, for separation of RDF and OWF;
- magnetic systems for removal of iron scrap;
- eddy current systems for removal of non-ferrous scrap;
- air zifters, for separation of light fractions;
- handpicking, for removal of specific materials;
- pelletising, for improving product handling properties.

4.2.3 Pre-treatment of waste in the municipal waste incineration plant

Mixing of waste in the bunker

An adequate mixing of waste before incineration has a favourable effects on the waste incineration process. The operation of process control systems, as discussed in section 2.2.4, is facilitated substantially if waste quality is more constant. For this purpose the waste bunker should have sufficient capacity and crane personnel should use available crane and bunker capacity.

The importance of an adequate mixing of waste in the bunker should not be under-estimated. It is one of the reasons why bunker volume should be sufficiently large.

Size reduction of bulky waste

Bulky wastes have dimensions that are not acceptable for waste incineration. They may cause problems in the hopper and chute as well as in the deslagger and during bottom ash treatment. Additionally they may lead to a less efficient incineration process on the grate. For size reduction of bulky wastes various technical systems are applied, of which the most important are:

- guillotine shears, capable of handling a very wide variety of bulky wastes;
- rotary shears, with a more limited scope of treatable materials but a substantially higher hourly capacity.

These units are normally installed in the unloading hall of the municipal waste incineration plants. A separate bunker compartment is used for storage of bulky waste.

For reference literature on sections 4.1 – 4.2.3, see chapter 7, references [144] – [148].

4.3 Process integrated measures

In this NL BAT-document process integrated measures are not discussed in a separate section. Various process integrated measures are indicated in the sections which describe the related process parts.

In this respect it can be mentioned that process integrated measures are preferred over end-of-pipe techniques, according to the Dutch Environmental Management Act and the IPPC-directive.

4.4 Flue gas treatment

4.4.1 General

As indicated in section 3.1.2, a wide variety of polluting components has to be removed from the flue gases of waste incineration.

For this purpose following main systems are identified:

- dust removal systems, in order to remove the main part of the fly ash, including polluting solid compounds, such as heavy metals and various organic micropollutants (see section 4.4.2);
- removal systems for acid compounds, such as HCl, HF and SO₂. Applied systems can be divided in dry and semi-dry systems (section 4.4.3) and wet systems (section 4.4.4) with related waste water treatment (section 4.5);
- DeNO_x-systems, for removal of NO_x. Main systems are so-called selective non-catalytic reduction (SNCR) and selective catalytic reduction (SCR), see sections 4.4.6 and 4.4.7 respectively;
- polishing systems, in order to remove remaining polluting microcomponents, such as dioxins and mercury (see section 4.4.8).

4.4.2

Dust removal systems

Description

Dust removal techniques can be divided between pre-dedusting and end-dedusting. Whereas the main purpose of pre-dedusting is to collect residues of different composition separately and to avoid operational problems in downstream equipment, the main purpose of end-dedusting is to reduce final dust emissions. Furthermore it is noted here that, in case of pre-dedusting, downstream equipment such as scrubbers may additionally reduce dust emissions.

Following dust removal systems are used for waste incineration:

- Cyclones and multi-cyclones;
- Electrostatic precipitators (ESPs);
- Bag filters (BFs).

Cyclones and multi-cyclones

In cyclones dust removal takes place due to centrifugal forces. The removal efficiency of a cyclone is related to the angular velocity achieved in the vertical flow zone within the cyclone separator. As the rotational velocity within the device increases, progressively smaller particles reach the collection area at the outer wall and are captured. Cyclone collection efficiency increases directly as a function of the dust load, flue gas flow rate, particle size and density. As the fly ash particles are fine, the density is low and the dust load and flue gas flow rate changes, dust removal efficiency of cyclones is rather limited. Normally no lower dust concentration values than 200 – 300 mg/m³ can be reached.

Multi-cyclones, which are based on the same removal principle can reach somewhat lower values, but lower values than 100 – 150 mg/m³ are very difficult to achieve.

For these reasons, in modern flue gas treatment systems cyclones and multi-cyclones can only be used as a pre-removal step.

It should be noted that cyclones are a relatively simple design without moving parts (except transport systems for removal of fly ash from the bottom) and therefore can have a good availability at relatively low costs. However, pressure drop of the flue gas stream is relatively high, resulting in an increased required power of the flue gas fan and therefore in additional energy consumption.

Electrostatic precipitators (ESP, dry and wet).

Dust removal with ESP's is based on electrostatic charging of particles, which are attracted to metals plates. The plates are cleaned periodically by a mechanical knocking system.

An ESP can reach substantially lower dust concentration values than (multi-) cyclones. Depending on the design and the place in the flue gas treatment system (pre- or end-dedusting), dust emission concentration values of 15 to 25 mg/m³ can be realised. For lower values, the required volume of the ESP increases very rapidly. Pre-dedusting with ESP's is used for reduction of the dust load to downstream equipment (avoiding deposition and/or clogging problems).

ESP's are equipped with an electrical system, which maintains a high electrical voltage between wire and plate systems. For the proper functioning of an ESP it is important that the flue gas stream is evenly distributed over its total surface. The pressure drop of the flue gas over an ESP is low, reducing energy consumption.

ESP's can be divided in more compartments (fields), each with their own electrical system. This has the advantage, that even during a break-down of one of the electrical systems, a relatively large part of the dust removal capacity is still available.

Because of their good availability and efficient dust removal, ESP's are nowadays a very common system for dust removal for waste incineration plants. This despite the fact that they have problems to reach modern low dust emission standards on their own and despite the fact that it has been reported that flue gas PCDD/F-concentrations may increase during their residence time in the ESP.

A specific version of the ESP is the *wet* ESP. This type is also based on electrostatic charging of particles, which are attracted to metals plates. In this case the cleaning takes place continuously by a water flow. The version is applied as end-dedusting after a wet scrubber. It is able to reach very low dust emission concentrations (<5 mg/m³).

Bag filters (BF)

These filters consist of various compartments, in each of which a number of dust bags is installed. The flue gas passes through the fabric material of the bags (from outside to inside), including a thin layer of dust on the bag filter material, which itself acts also as a filter.

If the dust layer on the bags in a compartment is too thick, operation for this compartment is interrupted and the bags are cleaned. Reflecting the method of bag cleaning, BF's can be divided into three classes. These include mechanical shaking, reverse flow and pulsed jet cleaning. Mechanical shaking is reliable and often has the lowest capital cost of the three bag cleaning methods. In reverse flow cleaned systems, the filtered gas flow is gently and intermittently reversed. The gentle cleaning process extends bag life. This is particularly important for fibreglass bags. In pulse-jet cleaning, a solenoid valve is electronically opened

and a short burst of air is discharged into the open end of the cylindrical bag, resulting in a short countercurrent air flow. The dust is collected and the compartment is put in operation again.

With bag filters, very low dust emission concentrations can be reached (<5 mg/m³). This makes them very applicable for flue gas polishing systems (entrained bed system and catalytic filter systems, see section 4.4.7).

It should be noted that bag filter systems are normally designed and constructed with a recirculation system. In order to avoid condensation of moisture on the fabric material during start-ups, pre-heated air can be circulated in this system, before actually starting-up the incineration process. The recirculation pipeline can however also be used as a by-pass.

The key characteristics of fabrics for use in gas filtration include maximum operational temperature and resistance to acids, alkalis and flexing (due to bag cleaning). Also gas humidity can affect the strength and dimensional stability of the fabrics, due to hydrolysis. Several basic fibre properties are summarised in Table 4.1

Table 4.1: Fabric Filter Characteristics.

Fabric	Maximum Temperature (°C)	Resistance		
		Acid	Alkali	Flex
Cotton	80	Poor	Good	Very good
Polypropylene	95	Excellent	Excellent	Very good
Wool	100	Fair	Poor	Very good
Polyester	135	Good	Good	Very good
Nomex (nylon)	205	Poor to fair	Excellent	Excellent
Teflon	235	Excellent	Excellent	Fair
Fiberglass	260	Fair to good	Fair to good	Fair

The most important criteria of performance for filtration devices are collection efficiency and pressure drop, which are determined by the specific filter area.

Application and comparison of dust removal systems

Table 4.2 gives an overview of applied dust removal systems in the Dutch waste incineration sector and table 4.3 gives a summarised comparison of the applied dust removal systems.

Table 4.2: Dutch plants (see also section 2.1) equipped with (multi)cyclones, electrostatic precipitators and bag filter systems

Name/place	(Multi)cyclones	Electrostatic precipitators	Bag filter systems	Dust emission to air [g/ton-waste]
Dutch municipal waste incineration plants				
ARN Beuningen	--	(dry) + (pre)	(ad,2) + (end)	3.7
AVI Akmaar	--	(dry) + (pre)	(ad,1) + (end)	8.2
AVI Amsterdam	--	(dry) + (pre)	--	3.0
AVI Moerdijk	--	(dry) + (pre)	(ad,3) + (end)	3.3
AVI Roosendaal	--	(dry) + (pre)	--	1.4 (end)
AVI Twente	--	(dry) + (pre)	(ad,2) + (end)	5.9
AVI Wijster	--	(dry) + (pre)	--	5.6
AVR AVIRA	--	(dry) + (pre)	--	0.8
AVR Botlek	--	(dry) + (pre)	--	1.7
AVR Rotterdam	--	(dry) + (pre)	--	1.0
GEVUDO	--	(wet) + (end)	(ad,2) + (pre)	6.7
Dutch specific clinical waste incineration plants				
ZAVIN Dordrecht	--	--	(ad,2) + (end)	1.6
Dutch sewage sludge incineration plants				
DRSH Dordrecht	--	(dry) + (pre)	+ (end)	1.4
SNB Moerdijk	--	(dry) + (pre)	(ad,2) + (end)	1.5

- (dry) = Dry electrostatic precipitator.
(wet) = Wet electrostatic precipitator.
(pre) = As pre-dedusting unit
(end) = As end-dedusting unit
(ad,1) = With adsorbens injection (activated carbon)
(ad,2) = With adsorbens injection (activated carbon & slaked lime)
(ad,3) = With adsorbens injection ('Hoogoven-cokes')
-- = not present

As can be seen from table 4.2 there is no direct relationship between the applied dedusting system and the realised dust emission figure per ton of waste. This is caused by the fact, that also other equipment (the scrubber) has an influence on dust emissions.

All emission values are clear below the level according to the Dutch dust emission standard, which is approx. $6000 \times 5 \text{ mg} = 30 \text{ g/ton waste input}$.

Table 4.3: Comparison of dust removal systems.

Dust removal systems	Emission concentrations	Advantages	Disadvantages
Cyclone and multicyclone	- cyclones: 200 – 300 mg/m ³ ; - multicyclones: 100 – 150 mg/m ³	- robust, relatively simple and reliable. - applied in waste incineration.	- only for pre-dedusting - relatively high energy consumption (compared to ESP).
- dry Electrostatic precipitator	<25 mg/m ³ .	- relatively low power requirements. - ability to accommodate gas temperatures in the range of 150 - 350°C. - widely applied in waste incineration.	- formation of PCDD/F
- wet	< 5mg/m ³	- able to reach low emission concentrations	- little experience in waste incineration - generation of process waste water
Bag filter	<5 mg/m ³ .	- increasingly applied in waste incineration. - the layer of residue acts as an additional filter, including an adsorption reaction.	- relatively high energy consumption (compared to ESP). - sensitive to condensation of water and to corrosion.

Short summary

dust removal systems

- **Cyclones and multicyclones** cannot reach the required dust removal efficiency to comply with prevailing emission standards.
- Because of this, cyclones are now used only as pre-treatment step before another flue gas treatment unit, such as a wet scrubber, in order to reduce the dust load of these equipment parts. For reaching low dust emission concentrations, additional dust removal steps are required.
- **Electrostatic precipitators (ESPs)** are commonly applied in the waste incineration sector, normally as pre-treatment step, because it is difficult to realise sufficient dust removal efficiency with ESP's alone.
- Operational availability is increased by application of ESP's with more than one electrical system (field) in series.
- **Bag filters (BFs)** are also commonly applied for removing the fly ash from the flue gas.
- If compared with electrostatic precipitators, a bag filter can reach lower dust emission concentrations, but it is somewhat more sensitive in operation, with respect to temperatures, condensation and corrosion problems and also with the risk of leakage of bags.
- Due to the water vapour, present in the flue gas, the temperature must be kept appropriately high in order to avoid condensation (above 125°C).
- A specific application of bag filters is flue gas polishing, see section 4.4.7.

4.4.3 Dry and semi-dry flue gas treatment

Dry flue gas treatment

With dry flue gas treatment the gaseous acid components (HF, HCl and SO_x) are adsorbed by an alkaline chemical. Normally slaked lime (Ca(OH)₂) is used. In order to realise an adequate reaction a reactor is used, which ensures sufficient homogeneous distribution of the adsorbent in the flue gas stream and sufficient reaction time. Hereto, the powdery additive is injected into the flue gas via nozzles at suitable points.

Due to process conditions (dry), the efficiency of the adsorbent reaction is rather limited. In order to improve the efficiency of the used adsorbent, recirculation of adsorbent is normally applied. Nevertheless, adsorbent consumption in general exceeds the stoichiometric quantity with a factor 2, resulting in a relatively large adsorbent consumption and as a consequence a larger residue production.

Additionally, the surplus of adsorbent and the reaction products are removed out of the flue gas stream by a dust removal system. For this purpose dust bag filters are preferred, as:

- this system enables an adequate removal of adsorbent, including remaining fly ash;
- it ensures an additional effective contact between the flue gas stream and a layer of adsorbent on the dust bag filter surface.

The separated dust is a mixture of surplus (slaked) lime, remaining fly ash and salts (such as CaF_2 , CaCl_2 , CaSO_4).

Semi-dry flue gas treatment.

Basic principle and chemical reactions of semi-dry flue gas treatment are comparable with dry flue gas treatment. Main difference is the fact, that the adsorbent is suspended in water to obtain a liquid absorbent. The slurry is sprayed in the flue gas stream at a temperature of normally 200-240°C, by means of nozzles and/or a rotating disc system (i.e. a spray absorber). This results in extremely fine water droplets to be evaporated. Simultaneously the gas is cooled down to about 130-180°C.

Solid powdery lime (CaO), slaked lime (Ca(OH)_2) or soda ash (NaHCO_3) can be used as chemicals. CaO is economically most attractive (lower costs of chemicals and transport cost) but requires some more operational attention. Soda ash is more effective but relatively expensive and therefore only used in special circumstances.

In the process the absorbent reacts with the acid gases (HF , HCl and SO_x) to form solid reaction products (CaF_2 , CaCl_2 and CaSO_4). The wet environment increases the effectivity of the reaction between acid components and absorbent. This results in a lower consumption of chemicals in comparison with dry flue gas treatment. In combination with the effect of residue recycling and the desired emission concentrations, the stoichiometric factor is normally approx. 1.5.

The resulting dust is collected in a downstream dust removal system, normally an electrostatic precipitator or (preferably) a bag filter. The separated dust is a mixture of surplus (slaked) lime and afore mentioned reaction products. A bag filter is somewhat more sensitive in operation than an ESP, but the filter layer on the bag is supporting the effectivity of the absorbent reaction, as indicated above.

A semi-dry flue gas treatment system can also be used for another purpose than just for flue gas cleaning. It can be used for evaporation of process waste water from a wet flue gas treatment system. This application is discussed in section 4.5.2 ("in-line evaporation"). In this case the system can be indicated as *spray-dryer* in stead of *spray-adsorber*. Evaporation of the neutralised waste water stream in the flue gas can have a certain cleaning effect. Compliance with the emission standards is however achieved in the following scrubber system (see section 4.4).

Application and comparison of dry and semi-dry flue gas treatment systems

Table 4.4 shows a not-limitative list of present available dry and semi-dry processes, which are applicable to reduce the emissions of HF, HCl and SO_x.

Table 4.4: Commercially available dry and semi-dry flue gas treatment processes.

No.	Process Name / Trade names	Neutralising agent / reagent		End product / residue	
		Name	Formula	Name	Formula
DRY PROCESSES					
1.	Dry alkali	Lime/lime stone	CaO/CaCO ₃	Calcium chloride Calcium sulphite/sulphate Calcium oxide Calcium carbonate	CaCl ₂ CaSO ₃ /SO ₄ CaO CaCO ₃
2.	Various trade names	Slaked lime	Ca(OH) ₂	Calcium chloride Calcium sulphite/sulphate Slaked lime	CaCl ₂ CaSO ₃ /SO ₄ Ca(OH) ₂
SEMIDRY PROCESSES					
3.	Slaked lime	Slaked lime	Ca(OH) ₂	Calcium chloride Calcium sulphite/sulphate Slaked lime	CaCl ₂ CaSO ₃ /SO ₄ Ca(OH) ₂
4.	Aqueous carbonate	Soda ash	NaHCO ₃	Sodium chloride Sodium sulphite/sulphate Soda ash	NaCl Na ₂ SO ₃ /SO ₄ NaHCO ₃
5.	Various trade names	Lime/slaked lime	CaO/Ca(OH) ₂	Calcium chloride Calcium sulphite/sulphate Slaked lime	CaCl ₂ CaSO ₃ /SO ₄ Ca(OH) ₂
6.	Various trade names	Slaked lime	Ca(OH) ₂	Calcium chloride Calcium sulphite/sulphate Slaked lime	CaCl ₂ CaSO ₃ /SO ₄ Ca(OH) ₂
7.	Various trade names	Ammonia	NH ₃ (aq)	Ammonium chloride Ammonium sulphate	NH ₄ Cl (NH ₄) ₂ SO ₄

Table 4.5 gives an overview of Dutch plants that use semi-dry flue gas treatment. As indicated, most plants use the system as an intermediate system for the evaporation of process waste water, i.e. as spray dryer and not as spray adsorber.

Dry systems are not applied in Dutch waste incineration plants

Table 4.5. : Dutch plants equipped with semi-dry flue gas treatment

Name/place	Reagent	Location of spray dryer/absorber in flue gas line	Fluoride emission [g/ton-waste]	Chloride emission [g/t-waste]	SO _x emission [g/t-waste]
ARN Beuningen	Slaked lime	intermediate	1.5	4	4
AVI Alkmaar	Lime / Active carbon	intermediate	0.3	6	13
AVI Amsterdam	Slaked lime / Blast-furnace cokes	intermediate	0.02	1	15
AVI Roosendaal (incl sludge drying)	Lime / active carbon / soda ash	End-step	0.6	39	63
AVI Twente	Slaked lime	intermediate	0.7	9	12
AVI Wijster	Slaked lime	intermediate	1.3	2	28

Table 4.6 gives a summarised comparison between dry and semi-dry flue gas treatment systems.

Table 4.6: Comparison of dry and semi-dry flue gas treatment systems

Process type	Emission concentrations	Advantages	Disadvantages
Dry	HF: <1 mg/m ³ . HCl: <10 mg/m ³ . SO _x : <40 mg/m ³ .	most simple design	- lower efficiency (compared to semi dry) - difficult to comply with emission standards, - high consumption of chemicals and large amounts of residue, - dust bag filter required
Semi-dry	HF: <1 mg/m ³ . HCl: <10 mg/m ³ . SO _x : <40 mg/m ³ .	relatively simple design, less complicated than wet scrubbers	- lower efficiency (compared to wet scrubbers), - higher consumption of chemicals than wet scrubbing, more residues, - dust filter recommended

Short summary

dry and semi-dry flue gas treatment systems

- main advantage of dry and semi-dry flue gas treatment systems is, that there is no polluted process waste water stream which needs treatment before discharge;
- investment costs are lower than for wet flue gas treatment systems, especially for relatively small capacities;
- it is not possible to reach the same very low emission concentrations as with wet flue gas treatment;
- consumption of chemicals is larger, especially for dry flue gas treatment;
- also production of residues is larger than with wet flue gas treatment.
- dry flue gas treatment is not used in the Netherlands. Its application is mainly restricted to units with small incineration capacities.
- semi-dry flue gas treatment alone is used in one relatively small incineration plant.
- various municipal waste plants in the Netherlands use semi-dry spray dryer technique in combination with wet scrubbing, in order to avoid discharge of waste water (see section 4.5.3)

4.4.4 Wet flue gas treatment

Description

There exists a wide variety of elements and designs for wet flue gas treatment systems. The basic principle of wet scrubbing is an intensive contact between flue gas and liquid (water) during which pollutants are absorbed in the liquid.

Wet flue gas treatment is technically applicable in waste incineration. However, set-up in of wet systems with waste incineration is normally a two or three stage process.

In the first stage, part of the water used for scrubbing is evaporated, under simultaneously cooling of the flue gases until saturation temperature. In the first one or two stages, an acid pH (approx. 1) is maintained. At this process condition, removal of strong acids, such as HCl is possible. SO₂ is hardly or not removed, as it forms a weak acid. Additionally, the removal of (volatile) heavy metals is here effective, as they are in ionic state.

In the last stage, a more neutral pH is maintained, by dosing of alkaline chemicals (soda or sometimes lime), in order to realise sufficient removal of SO₂. Part of the remaining dust (after the preceding dust removal) is absorbed by the scrubber liquid.

It is noted that NO_x is hardly or not removed in wet scrubber systems.

There is a wide variety of elements and designs for wet flue gas treatment systems, showing large differences in costs, reliability, availability, removal efficiency etc. The application of a wet scrubber system is a dedicated study in itself.

Examples of applied designs are:

- venturi scrubbers; liquid and gas are brought into contact in a venturi, in which the liquid is flowing with high radial speed;
- open scrubbers; the liquid is injected in the reactor with nozzles;
- fixed bed scrubbers; the contact surface between gas and liquid is increased by bed elements;
- tray scrubbers, where the gases have to pass through a number of trays, which contain a layer of liquid;
- radial scrubbers, where the gases have to pass through a radial layer of liquid;
- multi-venturi scrubbers, based on the same intensive contact principle as venturi scrubbers. Multi venturi scrubbers have a higher dust separation efficiency, due to the relative smaller radius (larger centrifugal forces). With this type of scrubbers, very low dust emissions can be archived.

The liquid, used in the scrubber is collected in the bottom and can be recirculated. As during scrubbing the concentrations of contaminants in the liquid increase, part of the liquid has to be drained off and replaced by fresh water. This water is preferably used in the last step of the scrubber, resulting in a cleaner liquid in this last step and therefore in lower flue gas emission concentrations (countercurrent effect). Recirculation of the scrubber water results in a substantial reduction of the amount of water that has to be drained off. The polluted waste water from the scrubber needs treatment, as discussed in section 4.5.

For further improvement of wet scrubbing systems following technical measures have been developed by different suppliers:

1. High voltage electrodes (EDV);
 2. Dosing of activated carbon in the scrubber;
 3. Further reduction of scrubbing temperature;
 4. Application of gas/gas heat exchangers
 5. Double alkali systems.
-
1. High voltage electrodes. By installation of high voltage electrodes in the scrubber, removal of very small dust particles (aerosols) is improved.
 2. Dosing of activated carbon or detergents in the scrubber. Dosing of activated carbon or detergents in (or just before) the scrubber also leads to an improved removal of micropollutants (dioxins, mercury) in wet flue gas systems (adsorption on activated carbon). Activated carbon particles are removed during waste water treatment.
 3. Further reduction of scrubbing temperature. Operational temperature of scrubbing systems depends on flue gas temperatures and water vapour content, together determining saturation temperature. Most scrubbers operate at temperatures of somewhat over 60°C. It is possible to reduce the operational temperature by application of gas/gas heat exchangers (see below) or by application of cooling of the circulating waste water. Most important effect of reduced water temperature is an increase of the efficiency of mercury removal. Therefore this option is to be considered especially in situations where mercury- and/or PCDD/F-removal is critical (see sludge incineration).

An additional advantage is the potential improvement of overall energy efficiency, as already indicated in section 2.2.6.

4. Application of gas/gas heat exchangers. A regularly used technique in wet waste water treatment is the application of gas/gas heat exchangers. They are used to reduce flue gas temperature before the scrubbing process. This results in a somewhat lower scrubbing temperature, which has a slightly favourable effect on removal efficiency, as discussed above. Simultaneously, treated flue gases are heated up. This sometimes is necessary for a following polishing step and/or may reduce plume formation at the stack. These heat exchangers operate in rather critical conditions (corrosion risks because of temperatures below dew point, presence of many pollutants in the untreated flue gases). Applied materials are therefore glass and carbon. Finally, it can be noted, that it is an option to recover low-temperature heat (approx. 60°C) from the waste water. By application of heat pumps, this temperature level could be increased for more effective heating purposes, but financial feasibility is low under Dutch circumstances (in comparison with e.g. Scandinavia, where a similar system is operational in Göteborg).

5. Double alkali systems. In the first step(s) of the scrubber system, a very low pH is maintained. Neutralisation of the waste water of this step can take place with lime. As calcium salts of sulphite and sulphate are well soluble at a low pH, recirculation of the waste water stays possible and the calcium in this recirculated waste water will not cause any sticking problems. In the final step of the scrubber a neutral pH has to be maintained, in order to realise sufficient removal of SO₂. For this purpose the use of lime may cause problems, as this can cause substantial sticking problems (depending on scrubber design). In such cases, caustic soda is applied, which is a much more expensive chemical than lime.
The double alkali system enables the use of lime also for neutralisation in the last step of the scrubber. The waste water from the second step is mixed with lime. The sulphites and sulphates are precipitated as gypsum. The resulting liquid, a mixture of (mainly) caustic soda and (some) lime is treated with soda ash in order to remove the remaining calcium ions (in the form of calcium carbonate) and can be recirculated to the scrubber without causing sticking problems. Main advantage of the double alkali system is the reduction in cost of chemicals, not a higher removal efficiency of pollutants. For a process scheme of the double alkali system see figure 4.1.

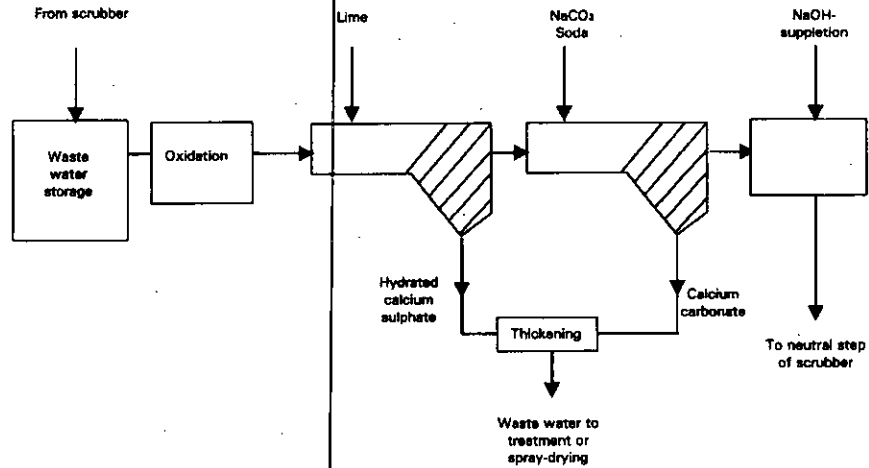


Figure 4.1: Process scheme of a double alkali system

As a final remark, it should be noted that scrubbers remove also part of the dust in the flue gases.

Application and comparison of wet flue gas treatment systems

Table 4.7 gives an overview of the applied wet flue gas treatment systems in Dutch municipal waste incineration plants.

Table 4.7: Dutch plants equipped with wet flue gas treatment, the effective reagents and achieved reduced emission concentrations

Name/place	Reagents	Fluoride Emission [g/ton-waste]	Chloride Emission [g/ton-waste]	SO _x Emission [g/ton-waste]
Municipal Waste Incineration				
ARN Beuningen	Caustic soda / slaked lime	1.5	4	4
AVI Akmaar	Caustic soda / slaked lime	0.3	6	13
AVI Amsterdam	Caustic soda / slaked lime / detergent	0.02	1	15
AVI Moerdijk	Caustic soda / slaked lime	0.3	15	8
AVI Twente	Slaked lime	0.7	9	12
AVI Wijster	Caustic soda / slaked lime	1.3	2	28
AVR AVIRA	Caustic soda / slaked lime (*)	1.3	19	58
AVR Botlek	Caustic soda / slaked lime	0.1	5	3
AVR Rotterdam	Caustic soda / slaked lime	0.4	13	8
GEVUDO	Caustic soda	1.6	3	28
Specific Clinical Waste Incineration				
ZAVIN Dordrecht	Caustic soda	4.8	3	101
Sewage Sludge Incineration				
DRSH Dordrecht	Caustic soda	0.1	1.1	4.0
SNB Moerdijk	Slaked lime	0.04	1.8	12

(*) Including activated carbon

It should be noted here, that realised emission concentrations are relatively little dependent on used chemicals. Especially process conditions (pH) determine the level of the emission concentrations.

Table 4.8 gives a summary of advantages and disadvantages of wet flue gas treatment systems.

Table 4.8: Advantages & disadvantages of wet flue gas treatment

Emissions	Advantages	Disadvantages
HF: <1 mg/m ³ HCl: <10 mg/m ³ SO _x : <40 mg/m ³ .	- relatively simple. - reliable. - proven.	- waste water treatment required - discharges to water.

Short summary

wet flue gas treatment systems

- According to the Dutch experience, wet flue gas treatment is an effective system to reach low emission standards for dust (in combination with pre-dusting and polishing systems), HF, HCl and SO₂. The system is also effective for heavy metals removal.
- Wet flue gas treatment is used in the vast majority of Dutch waste incineration plants.
- Consumption of chemicals and production of residues is limited in comparison with dry and semi-dry flue gas treatment
- NO_x is hardly or not removed in wet flue gas treatment systems and requires additional DeNO_x-provisions.
- There exists a wide variety of technical designs for wet flue gas treatment.
- Wet flue gas treatment results in waste water stream which requires treatment (see section 4.5)

4.4.5 Selective Non Catalytic Reduction (SNCR)

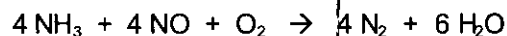
Introduction

NO_x-emissions can be reduced during the combustion process or can be treated by 'end-of-pipe' technologies. Process-integrated measures during the combustion process can reduce NO_x-levels to a certain extent (recirculation of flue gas etc. see section 2.2.4), but emission standards cannot be reached with grate incineration. Therefore application of an 'end-of-pipe' technique is required.

The commercially available 'end-of-pipe' techniques to reduce NO_x emissions, are Selective Non-Catalytic Reduction (SNCR) and Selective Catalytic Reduction (SCR). SNCR as well as SCR are based on the same mechanism in which the SCR differs from SNCR by using a catalyst and another temperature level. This section will focus on the SNCR-process. The SCR-process is further elaborated in section 4.4.6.

Description

Selective Non-Catalytic Reduction (SNCR) is a commercially available process for the reduction of NO_x-emissions. In the SNCR process, ammonia (NH₃) is used as the chemical to reduce NO_x-emissions. The basic reaction between the NH₃ and NO_x is shown below.



Aforementioned chemical reaction is fast, normally less than 0.1 seconds. However, in practice longer residence times (up to seconds) are taken. The range of temperatures at which the reaction takes place is called the temperature window. The NH₃ reacts most effectively with NO_x between 850°C and 950°C. If the temperature is too high, a competing oxidation reaction generates unwanted NO_x. If the temperature is too low, or the residence time for the reaction between NH₃ and NO_x is insufficient, the efficiency of NO_x-reduction decreases, and emission

of residual ammonia can occur (NH_3 slip). NH_3 slip is also caused by excess injection.

Emission of NH_3 is to be prevented. In the Dutch situation, with nearly always application of wet flue gas treatment including an acid step, the NH_3 is absorbed in the (acid) scrubbing water. By steam stripping of the scrubbing water, the ammonia can be removed and recovered for re-use in the SNCR-process.

Another side effect, which should be mentioned, is the formation of N_2O . N_2O has a very high Global Warming Potential (310 x the GWP of CO_2). Experiments, executed with the fluidised bed sewage sludge incineration plant of DRSB (see section 2.1.4) show that:

- N_2O -formation decreases with higher incineration temperatures, whereas NO_x -formation increases with higher temperatures;
- N_2O -formation increases with increasing injection of ammonia.

Generally spoken, N_2O -concentrations increase in case NO_x -concentrations decrease. Under unfavourable conditions, levels of over 50 mg/m_o^3 can be reached, whereas under favourable conditions, emission concentration levels are below 10 mg/m_o^3 . For a reduction of N_2O formation it is therefore important to optimise and control process conditions.

The results of the experiments with DRSB cannot be directly translated to other plants. They are to be considered as indicative, but emphasise the importance of an optimal process control.

The amount of injected NH_3 depends on the NO_x -concentration, as well as on the required NO_x -reduction. The NH_3 can be introduced into the flue gas either by injection of an aqueous solution or by direct injection of gaseous ammonia. If injection of an aqueous solution is the chosen method, the most commonly used solutions are (concentrated or diluted) caustic ammonia (NH_4OH) or urea ($\text{CO}(\text{NH}_2)_2$). The use of urea is effective for relatively small units, as urea can be stored in solid state (in bags) and storage of ammonia (including the related safety provisions) is not required. For larger unit, use of ammonia is more effective. There is no application of gaseous ammonia in the Netherlands. This is mainly related to the required safety provisions, which are rather complicated.

It is noted that good mixing of reagents and NO_x in the flue gas at the optimum temperature is essential to reach a high NO_x removal efficiency. In order to meet optimum temperature and to compensate for fluctuations in temperature, several sets of injector nozzles can be installed at different levels.

In principle, SNCR can be applied where a temperature window is available in the range of 850°C to 1150°C . In waste incineration plants, this window occurs in the upper part of the furnace.

Furthermore, SNCR systems are performing best under steady operating conditions (equal ammonia-distribution and NO_x -concentration), by process control. When operating conditions are not steady, ammonia slip (excessive ammonia emission), inadequate NO_x treatment or N_2O formation can occur.

Table 4.9 gives an overview of the application of SNCR with Dutch municipal waste and sludge incineration plants.

Table 4.9: Dutch plants equipped with SNCR

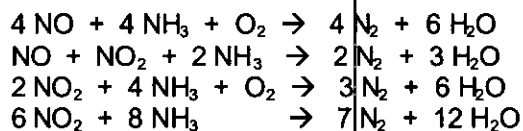
Name/place	Reagent	Location	Distribution	NOx-emission [g/ton-waste]
Municipal Waste Incineration				
AVI Amsterdam	25% ammonia	In furnace	1 level 12 nozzles/level 3 boiler sides	324
AVI Moerdijk	25% ammonia	In furnace	3 levels 2 x 8 nozzles/level 2 boiler sides	342
AVR AVIRA	10 - 25% ammonia	In furnace	3 levels 12 nozzles/level 2 boiler sides	319
Sewage Sludge Incineration				
DRSH Dordrecht	25% ammonia			89
SNB Moerdijk	(*) ammonia		1 injection point (**)	84

* concentration unknown as (partly) a waste stream is used ** in the furnace.

4.4.6 Selective Catalytic Reduction (SCR)

General

Selective Catalytic Reduction (SCR) is a commercially available process for the reduction of NO_x-emissions. In the SCR-method the NO_x concentration in the flue gas is reduced through injection of ammonia (NH₃) in the presence of a catalyst. For the ammonia injection methods see the description in section 4.4.5 (SNCR). The most common SCR reactions, which are catalysed, are:



The temperature at the catalyst has an important effect on the (relative speed of) the reactions. The optimum temperature range for catalytic reduction is usually between 300°C and 400°C; however, use of other, new types of catalysts has extended the temperature range downwards in some applications.

Generally spoken, a lower temperature results in a slower reaction rate and possible ammonia slippage. A higher temperature results in a shortened catalyst life-time and can lead to the oxidation of NH₃, actually forming additional NO₂.

Present experience with SCR in the Dutch waste incineration sector is limited to application of SCR as a tail-end system, because flue gases before flue gas treatment contain too much pollutants which would poison the catalyst.

As in tail-end applications the temperature of the flue gases is below the optimum temperature window, heating of the flue gases is required. For this reason a heat exchanger is installed, followed by additional heating by an outside source (i.e. high pressure steam or natural gas). The ammonia is injected in a stoichiometric amount, just before the catalyst.

Catalysts

The catalyst material generally consists of the carrier (TiO_2) with added active substances (V_2O_5 and WO_3). It has been reported too, that activated carbon or cokes can act as a catalyst, but there is no experience with this system in the Netherlands

Criteria for determining the type of catalyst to be used are: flue gas temperature, NO_x reduction required, permissible ammonia slip, and permissible oxidation of sulphur dioxide, concentration of pollutants and lifetime of the catalyst.

The following types of degradation limit the lifetime of catalysts:

- Poisoning: the active site of the catalyst is blocked by a strongly bound compound;
- Deposition: pores are blocked by small particles or condensed salts, such as ammonium bisulphate (NH_4HSO_4);
- Sintering: at too high temperatures the microstructure of the catalyst is destroyed;. Furthermore it is noted here that CO is converted to CO_2 and this exothermic reaction can cause additional sintering;
- Erosion, due to physical damage caused by solids and particles.

Guaranteed lifetimes of 3 to 4 years are reported for catalysts.

Furthermore, it can be remarked that there is no experience available in the Netherlands about formation of N_2O with SCR-systems, due to a bad condition of the catalyst, as has been reported from the nitric acid production industry.

Comparison with SNCR

In the first half of the 1990-ies, the majority of the Dutch waste incineration plants have decided to use SCR to reduce NO_x -emissions (see table 4.10). An important argument for that decision was the fact that chemical process conditions within SCR-systems are better controlled than with SNCR, so there was more certainty that emission standards could be met. Also side effects such as ammonia slippage and N_2O formation are less.

On the other hand SCR requires additional consumption of natural gas (or high-pressure steam) and relatively high additional investment costs. Price-effectiveness is therefore lower than with SNCR.

High-dust SCR

As indicated above, in the Dutch waste incineration sector SCR is applied as a tail-end solution. In coal power plants, SCR is also applied as an intermediate process step. In such cases, the SCR-unit is located in the boiler area, before the economiser and without a preceding dedusting-step. At that position flue gasses have still sufficient temperature level. A similar configuration is under development with waste incineration. It is however expected that in that case a pre-dedusting step will be required, as the fly ash of waste incineration is more polluted than the fly ash from coal incineration.

Table 4.10: Dutch reference plants equipped with SCR.

Name/place	Reagent	Catalyst	NO _x -emission [g/ton waste]
Municipal waste incineration			
ARN Beuningen	25% ammonia		432
AVI Alkmaar	25% ammonia		303
AVI Roosendaal (incl sludge drying)	25% ammonia	V ₂ O ₅ /TiO ₂	381
AVI Twente	25% ammonia		324
AVI Wijster	25% ammonia		218
AVR Botlek	liquefied NH ₃	V ₂ O ₅ /WO ₃	320
AVR Rotterdam	25% ammonia	V ₂ O ₅ /WO ₃	278
GEVUDO	25% ammonia		402
Specific clinical waste incineration			
ZAVIN Dordrecht	25% ammonia		870

Economics:

The operating costs of removing 1 ton of NO_x ranges between € 3,500 and € 4,500. If this cost is allocated to the processing costs per ton of waste, this corresponds to € 5 to € 7.7 [1]. Originally it was reported that removal cost for SNCR and SCR were on the same level. More recent experience shows that removal cost of SNCR can be substantially lower than those of SCR.

Short summary (DeNOx-systems)

Selective non-catalytic reduction (SNCR)

- With application of SNCR NO_x-emission concentrations of 70 mg/m³ are feasible;
- SNCR requires less capital costs compared to SCR (no specific reactor and catalyst are required).
- SNCR is associated with a certain amount of ammonia slip. However, the ammonia emission concentration will be low, due to downstream gasscrubbing. General practice shows that under steady conditions, this slip can be kept below 5 mg/m³;
- Below 280°C and in presence of SO_x, ammonia slip can form deposits of ammonium bisulphate (NH₄HSO₄) and/or ammonium sulphate ((NH₄)₂SO₄) on the downstream equipment (can cause operational problems);
- In case of application of SNCR, nitrous oxide (N₂O) can be formed as a side effect. N₂O has a very high Global Warming Potential. To keep formation of N₂O on a low level it is important to adequately control process conditions (temperature, amount of injected ammonia)
- The handling, storage and use of gaseous or liquefied ammonia implies an increased safety risk. The complication and costs involved with handling and storing according to safety rules that exist in most countries, makes it favourable to use aqueous ammonia solutions or other chemicals, such as urea solutions. However, the use of urea may lead to the formation of nitrous oxide (N₂O) as a by-product. Therefore most waste incineration plants with SNCR use ammonia solutions

Selective catalytic reduction (SCR)

- With SCR NO_x emission concentrations of 30 to 50 mg/Nm³ are realised. However, actual NO_x reduction depends on the initial NO_x concentration, the temperature and the number of catalyst layers, the minimum level of residue NO_x obtainable being limited in practice by the risk of unreacted ammonia and allowed ammonia emission concentrations.
- As additional pre-treatment (dust removal) is needed to avoid excessive deposition of particulate on the catalyst bed, SCR can only be applied in a tail-end position in the flue gas treatment;
- SCR requires additional consumption of natural gas (or high pressure steam) and relatively high additional investment costs. Price-effectiveness is therefore lower than with SNCR;
- SCR is associated with some ammonia slip. General practice shows that under steady conditions, this slip can be kept below 5 mg/ m³;
- As for SNCR, handling of gaseous or liquefied ammonia, implies an increased safety risk. The complication and costs involved with handling and storing according to prevailing safety rules, make it favourable to use ammonia solutions. Therefore all Dutch waste incineration plants, equipped with SCR use ammonia solutions.

4.4.7

Polishing systems

Description

Following flue gas polishing systems are applied with waste incineration:

- **fixed bed reactors.** In these systems, the flue gas stream passes a fixed bed reactor, consisting of activated carbon particles. Also Herdofencokes is applied. Remaining polluting components are adsorbed in the material. Removal of microcomponents, such as dioxins and mercury can be realised to values substantially below emission standards. Additional advantage is, that in case of reduced removal efficiency of the preceding flue gas systems, remaining components are removed ("Police filter"). It is important to realise an equal distribution of flue gases through the filter. An operational risk of these fixed bed filters may be the formation of so-called "hot spots". Therefore temperature control is required, as well as control on CO-levels after the filter. "Hot spots" can also be reduced by mixing the active carbon with inert material in which the latter material has the function to release heat. In case the filter is used after a wet flue gas system, flue gas is to be heated up somewhat, in order to prevent condensation phenomena in the filter. The residue can be incinerated in the waste incineration plant, if following conditions are fulfilled: an adequate collection and transport system and sufficient removal efficiencies in the remaining flue gas system in order to prevent accumulation of polluting components;
- **entrained bed systems**, using adsorbens injection and dust bag filters. Adsorbens is injected in the flue gas stream before the dust bag filter. After sufficient residence time, the adsorbens, including remaining dust and other pollutants are removed from the flue gas by a dust bag filter. The system is specifically used for removal of micro-pollutants such as mercury and dioxins, as well as for ensuring that dust emissions are below emission standard values. Entrained bed systems are used with various types of adsorbens, such as active carbon only, herdofencokes and with mixtures of lime and active carbon;
- in special cases, alternative adsorbens materials are applied, such as **zeolite**, a material from mineral origin. Advantage of these materials is that they are not combustible (better safety). Their effectivity is however somewhat lower than that of activated carbon and experience is limited;
- a rather new development is the application of **catalytic dust bag filters**. These filters consist of a teflon membrane with an additional layer of catalytic felt substrate on the "clean" side of the membrane. The substrate is a needlepunched felt made from teflon fibres, containing a dioxin-destroying catalyst. PCDD/F molecules diffuse on the catalyst surface and react to form insignificant amounts of CO₂, H₂O and HCl. Operational temperature is >180 °C. This system is not applied in the Netherlands. It has been reported to be applied in municipal waste incineration plants in Belgium (a.o. Roesselare) to operate according to expectations, but the combination with SNCR-DeNOx (resulting in a certain NH₃-slippage, which might poison the catalytic function) is not yet proven. More information on this technique is available in the Ref-

erence document on Best Available Techniques in common waste water and waste gas treatment/management systems in the chemical sector.

Application and comparison of flue gas polishing systems

Table 4.11 gives an overview of polishing systems, applied by Dutch waste incineration plants.

Table 4.11: Dutch waste incineration plants, with specific CO, CxHy and dioxin emissions.

Name/place	Polishing system	CO-emission [kg/ton-waste]	CxHy-emission [kg/ton-waste]	PCDD/F-emission [µg/ton-waste]
Municipal Waste Incineration				
GEVUDO	--	0.134	0.013	0.13
AVR Rotterdam	fixed bed reactor	0.086	0.004	0.11
AVR Botlek	fixed bed reactor	0.188	0.007	0.39
AVR AVIRA	--	0.098	0.003	0.52
AVI Roosendaal (incl. sludge drying)	--	0.116	0.037	0.09
ARN Beuningen		0.100	0.005	0.08
AVI Amsterdam	--	0.058	0.002	0.25
AVI Alkmaar	entrained bed/bag filter	0.062	0.002	0.12
AVI Wijster		0.050	0.006	0.08
AVI Moerdijk	entrained bed/bag filter	0.046	0.001	0.33
AVI Twente	entrained bed/bag filter	0.055	0.015	0.10
Hazardous waste incineration				
AVR Chemie I		0.455	0.012	0.11
AVR Chemie II		0.360	0.011	0.61
Specific Clinical Waste Incineration				
ZAVIN Dordrecht	entrained bed/bag filter	0.047	0.009	0.23
Sewage Sludge Incineration				
DRSH Dordrecht	fixed bed/bag filter	0.009	0.002	0.004
SNB Moerdijk	entrained bed/bag filter	0.016	0.001	0.020

Short summary

polishing systems

- In the Netherlands there are used two flue gas polishing systems. The entrained bed system, using active carbon or other adsorbents, and or lime, including as bag filter is the most commonly used system. Various plants also use a fixed bed system with activated carbon or Herdofencokes
- There is some experience with zeolite as adsorbents, but results have shown, that this material is less effective than activated carbon.
- There is no large scale experience with catalytic dust bag filters in the Netherlands

4.4.8 Measurement systems for emission concentrations

The recent EU regulations for emission standards to air for waste incineration include regulations on measurements systems for emission concentrations.

Following emission compounds are to be measured on a continuous base:

- dust;
- HCl;
- SO₂;
- CO;
- C_xH_y;
- NO_x (if emission standards apply);
- HF (but not if the process ensures adequate HCl- removal).

Continuous measurements are not imperative for HCl, HF an SO₂, in case the process design makes it impossible that emission standards are exceeded. In that case regular measurements satisfy. A specific example hereof is the sludge incineration plant DRSH, where continuous measurements are not required according to the environmental permit.

Additionally following process parameters are to be monitored on a continuously:

- furnace temperature;
- O₂;
- pressure;
- flue gas outlet temperature;
- water vapour content (unless emission measurements are executed in dried flue gas).

Other emission compounds are to be measured on a regular base (2-4 x per year):

- heavy metals
- PCDD/F's

Mercury (Hg) and dioxins (PCDD/F's) are considered as most critical emission compounds, as measurement techniques are relatively complicated and expensive:

Measurements of mercury are more complicated than measurements of other heavy metals, as a substantial part of the emitted mercury is in the gaseous state. In the last decade measurement systems for mercury have become more sophisticated. Older measurements often were unreliable, as the gaseous part of the mercury emission was neglected. Recently a continuous system for Hg-measurements was introduced in the European market. In the Netherlands there is no operational experience yet with this system.

Nowadays there is no continuous measurement system for dioxins, but since several years a continuous sampling system is available. This system is operational in different waste incineration plants in Austria and Belgium and has been operational for half a year in a Dutch hazardous waste incineration plant. Samples can be analysed as frequent as necessary or desirable. This system can be applied in plants with critical PCDD/F emission concentration levels.

For reference literature on sections 4.3 – 4.4.8, see chapter 7, references [149] – [169].

4.5 **Waste water treatment related to scrubbing of flue gases**

4.5.1 General

The process waste water, resulting from wet flue gas treatment contains a wide variety of polluting components. Amounts of waste water and concentrations depend on the composition of the waste and on the design of the wet flue gas system. An important aspect is, that the wet system should use recirculation of waste water, resulting in a substantial reduction of the amount of waste water and as a consequence in higher concentrations of pollutants.

As indicated in section 4.4.4, following options exist for treatment of this waste water:

- Physical/chemical treatment, principally based on neutralisation of the waste water, flocculation of pollutants, removal by gravitation and dewatering (see section 4.5.2);
- In-line evaporation and separate evaporation (see section 4.5.3).

4.5.2 Physical/chemical treatment

A typical set-up of a physical/chemical treatment unit for process waste water is given in figure 4.2.

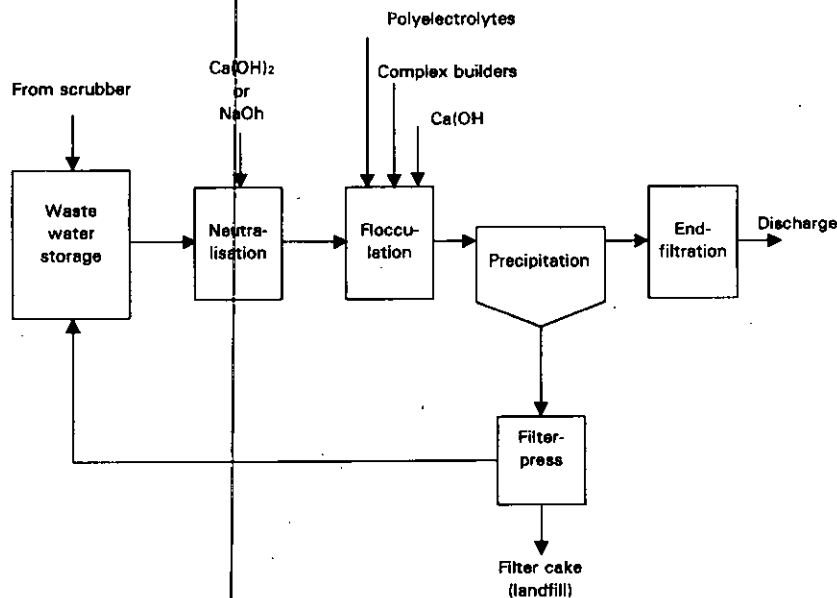


Figure 4.2: Process scheme for physical/chemical treatment of waste water from a wet flue gas treatment system

The process consists of following process steps:

- neutralisation of the polluted waste water;
- flocculation of pollutants;
- gravitation (precipitation) of the formed sludge;
- dewatering of the sludge;
- filtration of the effluent ("polishing").

For neutralisation normally lime is used, resulting in the precipitation of sulphites and sulphates (gypsum). In situations where discharging of sulphites/sulphates to surface water is allowed (maritime environments), caustic soda (NaOH) can be used, resulting in a substantially lower production of flue gas treatment residue.

Removal of heavy metal compounds is based on flocculation, followed by precipitation. Heavy metal compounds have a very low solubility with pH over approx. 9. From this value on, heavy metals are forming (hydro)oxides, which can be precipitated. It should be noted that the optimal pH is different for various heavy metal compounds. Especially the optimal pH for nickel deviates from other heavy metals.

As a very stable and well controlled acidity (pH) of the neutralised water is of great importance, a two-step (or even more) neutralisation is normally required.

The first step is a coarse neutralisation, especially for the waste water from the first acid step of the scrubber system. The second step is a fine neutralisation. Additionally it is recommended to provide in sufficient waste water storage capacity, in order to be able to reduce process variations in time by buffering. Flocculation of heavy metal (hydro)oxides takes place under the influence of flocculation agents (poly-electrolytes) and FeCl_3 . Additionally, for an improved removal of mercury and other heavy metals, complex-builders are to be added. Precipitation takes place in settling tanks or in lamellar separators.

The resulting sludge is normally dewatered in filter presses. Dry solids contents of 40 – 60% can be realised, depending on used chemicals and other conditions.

For filtration of the resulting effluent (“polishing”) sand filters and/or active carbon filters are used. The direct effect of sand filters is mainly a reduction of suspended solids, but this also results in a reduction of heavy metals concentrations. Filtration with active carbon is specifically effective for a reduction of PCDD/F-compounds.

With the described techniques, emission standards as indicated in section 3.2.3 (table 3.5) or lower can be reached. An additional remark is, that physical/chemical waste water treatment units require special operational attention, as they are quite sensitive systems.

In addition to the typical set-up of a physical/chemical treatment unit, following alternatives can be applied:

- Application of sulphides

For flocculation organic agents (poly-electrolites) are used. As indicated above especially for mercury removal additional complex-builders are required in order to be able to reach the required very low emission standards. Alternatively, sulphides (Na_2S) can be used in order to improve emission values of mercury, but also of other heavy metals, as sulphides of heavy metals have very low solubilities. The use of sulphides however requires special safety regulations, because of their toxic character. An advantage is the lower costs of sulphides in comparison with other complex-builders. Na_2S -systems are used by AVI Amsterdam and by AVR AVIRA.

- Application of membrane technology

One of the options for treatment of waste water, polluted with salts and micro-pollutants is membrane-filtration. The technique is especially efficient in case of large water flows with relatively low salt concentrations. With higher salt concentrations, energy consumption increases rapidly. The salt content of the process waste water of waste incineration is rather high (up to 10 w-%). Therefore this option requires too much energy consumption. Furthermore the technique is more sensitive to disturbances. The system is not used in the Netherlands.

- Stripping of ammonia

In case of application of SNCR-DeNOx-technique (see section 4.4.5), the waste water from the wet scrubber contains ammonia compounds. Ammonia concentration depends on the process conditions of the SNCR-DeNOx-unit. Depending on the actual ammonia concentration, stripping of ammonia is an option.

An ammonia stripping unit consists mainly of a heated distillation column. The vapours are condensed, resulting in an ammonia solution. Though ammonia concentration is normally below the original concentration of the trade product, the solution can be reused in the SNCR-process. The bottom product of the distillation column is to be discharged. Various Dutch municipal waste incineration plants are equipped with ammonia stripping facilities.

- Separate treatment of waste water from the first and the last steps of the scrubber system

As indicated in section 4.4.4, the first step(s) of the scrubber system are operated with a very low pH-level. Under these process conditions, specifically HCl is removed from the flue gas stream. Removal of SO₂ takes place in the final step, at a neutral pH.

Another option is to treat the waste water from the first acid step(s) separately from the waste water, produced in the final step. Purpose of this option is to produce gypsum of a quality, which allows recycling.

Figure 4.3 gives an example of a process scheme of this option. The example includes the removal of NH₃ (slippage of a SNCR-DeNOx-system) from the waste water (by ammonia-stripping), as well as an additional step for removing Ca out of the effluent, because of specific sewerage discharge conditions.

The waste water from the first step of the scrubber is neutralised with lime, followed by removal of heavy metal compounds by normal flocculation and precipitation. The treated waste water, containing mainly CaCl₂ is mixed with the waste water from the final step, mainly containing NaSO_{3/4}. This results in the formation of gypsum and a liquid, mainly consisting of NaCl.

Depending on local conditions, this waste water can be discharged or evaporated. Evaporation results in the recovery of NaCl, household salt. This option results in a very substantial reduction of hazardous flue gas treatment residues, as the precipitated sludge of heavy metal compounds is the only residue which has to be disposed of without useful application.

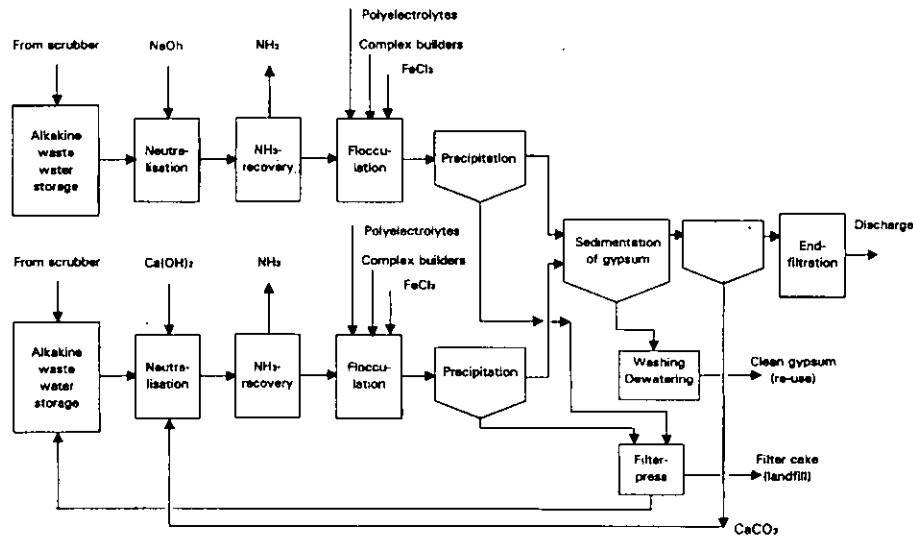


Figure 4.3 Separate treatment of the water of the acid and the neutral step

- anaerobic biological treatment (converting of sulphates into elementary sulphur)

One of the problems with discharging the treated waste water may be the remaining content of sulphates. Sulphates can affect concrete sewage systems. So the concentration of sulphates to be discharged in sewerage systems can be limited. To solve this problem a system has been developed for anaerobic biological treatment of waste water from waste incineration. The system can also be applied with waste water from desulpharisation units of coal power plants. A test unit has been operational with the coal power plant Amercentrale (Geertruidenberg).

The sulphates in the waste water are reduced to sulphides in a reactor, by the activity of anaerobic bacteria. The effluent of this reactor, with a high content of sulphides is treated in a second reactor. In this reactor, the sulphides are biologically oxidised in an aerobic atmosphere into elementary sulphur.

Subsequently the sulphur is removed out of the waste water in a laminated separator. The collected sludge is dewatered in a decanter, resulting in a sulphur cake, which can be re-used or eventually landfilled. The remaining waste water can be re-used in the scrubber and/or be discharged.

4.5.3 Evaporation systems for process waste water

General

If discharged of soluble salts (chlorides) is not acceptable, the process waste water is to be evaporated. For that purpose two main options exist:

- in-line evaporation;
- separate evaporation.

Both systems are discussed below.

In-line evaporation

In this configuration, the waste water is recycled in the process line by means of a spray dryer. Figure 4.4 gives an overview of the process configuration.

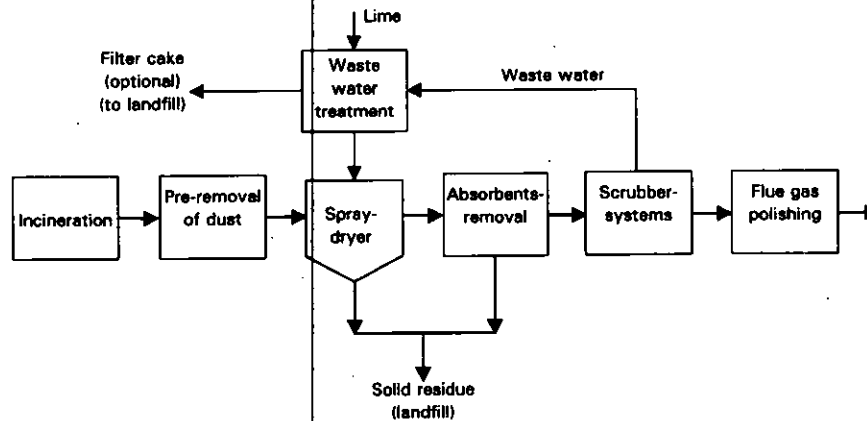


Figure 4.4: In-line evaporation of waste water

The spray dryer is comparable with the spray absorber, used in the semi-dry flue gas treatment system (see section 4.4.3). The difference is, that in case of semi-dry treatment lime is injected and in case of in-line evaporation the waste water from the scrubber is used for injection after a neutralisation step. This neutralisation step can be combined with flocculation and gravitation of pollutants, resulting in a separate residue (filter cake).

The neutralised waste water, containing soluble salts is injected in the flue gas stream. The water evaporates and the remaining salts and other solid pollutants are removed in a dust removal step (cyclone, ESP or bag filter). This flue gas treatment residue consists of a mixture of fly ash, salts and heavy metals.

Due to the application of a wet scrubbing system, consumption of chemicals is approx. stoichiometric and consequently residue production is lower than in semi-dry flue gas treatment systems.

This basic configuration is applied at several Dutch municipal waste incineration plants, such as AVI Amsterdam, AVI Alkmaar, ARN Nijmegen, AVI Twente and AVI Wijster.

Separate evaporation

Separate evaporation is based on evaporation in steam heated evaporation systems. Figure 4.5 gives an example of a process scheme.

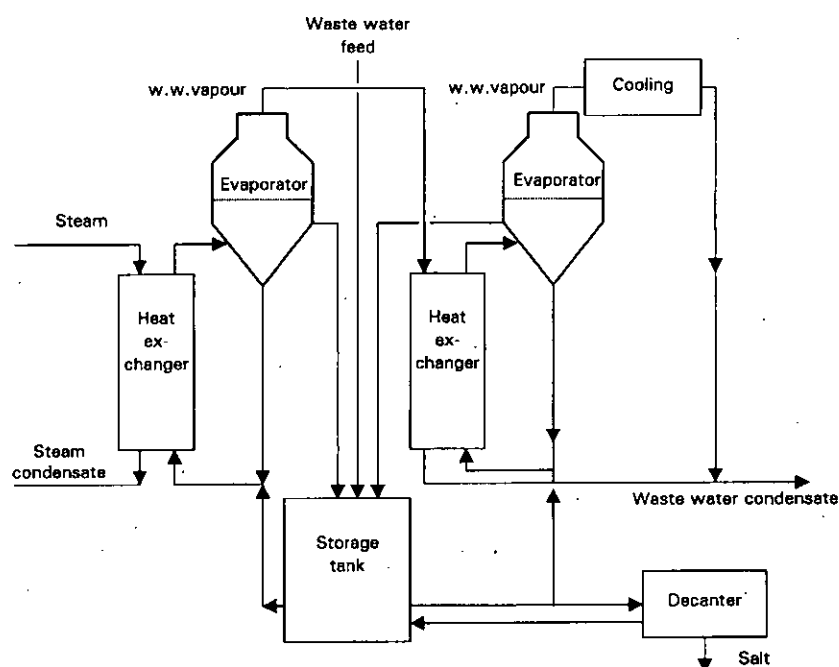


Figure 4.5: Separate evaporation

The waste water, with its soluble salts is fed into a storage tank, containing a (liquid) mixture of waste water and already partially evaporated liquid. Subsequently, water is partly evaporated out of the liquid in a reactor under low pressure. The

required heat is supplied by (low-pressure) steam and transferred to the liquid in a heat-exchanger. The surplus of liquid is flowing back to the storage tank. The vapours are cooled down, resulting in a clean condensate, which can be discharged without problems.

Due to the increasing salt concentrations in the liquid, crystallisation of salts starts. Subsequently, the salt crystals are separated in a decanter and collected in a container.

Figure 4.5 shows a two-stage process, where two evaporators are installed. The input of heat for the second evaporator is the vapour of the first evaporator, thus reducing the specific energy consumption. Additionally, effective energy consumption is reduced by the fact, that low-pressure steam can be used (with application of co-generation of electricity and heat, see section 3.4).

In the Netherlands one sewage sludge incineration plant is using separate evaporation. The required evaporation capacity of this plant is relatively very limited, due to the low chlorine content of sewage sludge in comparison with municipal waste.

For reference literature on section 4.5 – 4.5.3, see chapter 7, references [170] – [173].

4.6 **Treatment and disposal of solid residues**

4.6.1 General

As indicated in section 3.3, waste incineration can result in various types of solid residues. A distinction can be made between residues, directly resulting from the incineration process and residues, resulting from the flue gas treatment system (including an eventual waste water treatment system).

The first category (incineration residues) includes following residue types:

Municipal waste:

- bottom ash, resulting from grate incineration of municipal waste. Because of its large volume, this is an important type of residue. Treatment, recycling and disposal options are discussed in section 4.6.2;
- boiler ash, as collected in the boiler of municipal waste incineration plants. As this residue is either added to the bottom ash or to the fly ash (see section 3.3.3), its treatment and disposal is not discussed separately;
- fly ash, as collected in a dust removal step in municipal waste incineration. Treatment and disposal of this residue type is discussed in section 4.6.3;

Hazardous waste and specific clinical waste:

- slag, resulting from rotary kiln incineration of hazardous wastes. In the Netherlands, this type of residue is disposed of by landfill without further treatment. It is therefore not discussed in this section.
- the same is normally the case for the ash of dedicated units for incineration of hazardous wastes and for the incineration residue of specific clinical waste;

Sewage sludge:

- fly ash, resulting from fluidised bed incineration of sewage sludge. This type of waste is used as a filling material for bound applications in civil construction. It also finds application as a filling material for mines in Germany, both applications without further treatment. Fly ash which is not re-used, is land-filled;
- bed ash, resulting from fluidised bed incineration of sewage sludge. This is a relatively very small category, which is added to the fly ash or landfilled without further treatment and therefore not discussed in this section;

Biomass and secondary fuels:

- bed ash, resulting from fluidised bed incineration of various biomass and waste categories. Depending on the specific characteristics of the material, bed ash amounts may be substantially higher than for sewage sludge incineration. In many cases, specific re-use possibilities exist, but normally the development of these options requires a certain period of time. There is too little experience with this subject to assess the various options now;
- ash, resulting from small and medium scale incineration of wood. This concerns also relatively small quantities and is not further discussed;
- ash, resulting from the co-incineration of biomass and waste in coal power plants (see section 2.6.3). In this application the ash of the biomass and waste forms an integral part of the coal incineration ash (bottom-ash and fly ash). As co-incinerated materials are a relatively low part of the total incineration capacity (normally <10% on energy basis), the character and composition of the residues is mainly determined by the coal quality. These ashes are normally re-used as civil construction material. One of the main criteria for the selection of biomass and waste types for co-incineration is, that the quality of the resulting mixed ashes complies with the existing standards for re-use. This condition results in limitations on the composition of the biomass and waste types that are acceptable for co-incineration. Checking of the expected composition takes place by computerised calculation programs;
- the residue of co-incineration of biomass and waste in cement kilns forms an integral part of the produced cement. It is obvious, that the cement producer controls the quantities and checks the composition of co-incinerated materials in order to ensure adequate cement quality.

The second category of residues are the residues from flue gas treatment. These residues contain concentrated amounts of pollutants and therefore normally are not appropriate for recycling purposes. The main objective should be to enable an environmentally safe final disposal (normally hazardous waste landfilling) of the polluting substances. However, some recycling options exist, as indicated below. Following types of flue gas treatment residues can be distinguished:

- residues from dry and semi-dry flue gas treatment (see section 4.4.3). These closely related systems offer relatively little opportunities for recycling of residues. Main residue is a mixture of calcium and/or sodium salts, mainly chlorides and sulphites/sulphates, including some fluorides, with part of the used chemicals (lime or sodium bicarbonate). This mixture includes some fly ash that is not removed out of the flue gas in an eventual preceding dust removal step and therefore also includes polluting heavy metals and PCDD/F. The normal way of disposal is landfilling as hazardous waste in big-bags. Because of the high leachability of the material (presence of well soluble salts) the landfilling has to comply with high standards. Improvement of the properties for landfilling by cold solidification is complicated, because of the high salt content of the residue.
- filter cake from the physical/chemical treatment of waste water from wet flue gas treatment (see section 4.5.2). This material is characterised by a very high heavy metals content, but can also include insoluble salts, such as gypsum. The normal way of disposal is landfilling (hazardous waste). Landfill characteristics are better than for residues from (semi-)dry flue gas treatment;
- gypsum. Clean gypsum (see section 4.5.2 and 4.6.5) can be re-used, replacing natural gypsum;
- salts, resulting from in-line evaporation of waste water (see section 4.5.3). This residue is quite comparable with the residue from (semi-)dry flue gas treatment;
- salts, resulting from separate evaporation of waste water (see also section 4.5.3). Re-use and or disposal depends on the composition of the residue;
- residues from flue gas polishing (see section 4.4.7). As indicated there, the residue of (activated) carbon fixed bed reactors can be incinerated in the waste incineration plant itself, if certain process conditions are fulfilled. The residue of entrained bed systems can also be incinerated, if the applied adsorbens is activated carbon or herdofencokes only. If a mixture of lime and activated carbon is used, the residue is to be landfilled. If zeolite is used, there are in principle possibilities to recover the mercury, but these possibilities are not yet available in practice.

As indicated, there are some interesting developments to reduce the amount of flue gas treatment residues that need final disposal and to enable recycling of (part of) the materials. These options are discussed in section 4.6.5.

4.6.2 Treatment of bottom-ash

As indicated in section 3.3, nearly all bottom ash, produced in the 11 Dutch municipal waste incineration plants is re-used as civil construction material.

A general set-up of a treatment system for bottom ash is given in figure 4.6. Actual systems per municipal waste incineration plant may show some differences, but the principal set-up is comparable.

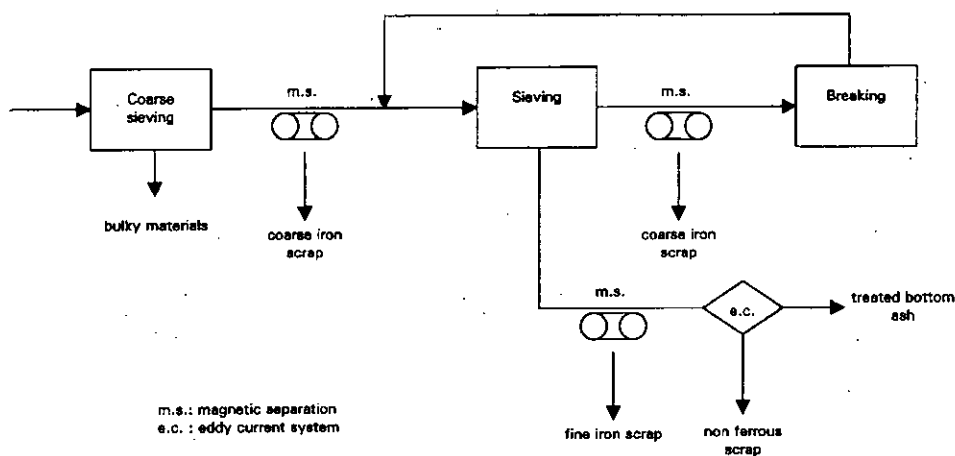


Figure 4.6: General set-up of bottom ash treatment systems

Figure 4.6 includes following operations:

- **Sieving** takes place in several steps, from a coarse sieving in order to remove bulky parts to finer sieving steps in order to produce material with well defined particle sizes. Applied sieves are rod sieves (for coarse material), rotary sieves and flat sieves.
- **Breaking** of bulky materials and/or coarse fractions is an option. For breaking shredders and hammer mills are used. The broken material is recycled to the input of the system.
- **Removal of iron** takes place in streams of coarse and fine material. Applied removal systems are magnetic rollers or overband conveyors. Recycled scrap is sold to the iron industry for (varying) market prices.
- For **removal of non-ferrous metals** eddy-current systems (based on electrical induction) are used. For non-ferrous metals interesting prices are achievable.

Reduction of leachability of the bottom ash can be achieved by various methods:

- natural ageing. It has been established, that bottom ash properties improve by ageing (reduced leachability). Storage times of several weeks lead already to improvements, but longer storage times are more effective;
- artificial ageing. This method is based on ageing with an increased speed, by the use of air or preferably CO₂. For this purpose, flue gas can be used. In the Netherlands, tests have been executed, but large scale application is still under discussion;
- cold immobilisation (solidification). In this technique, the material is mixed with additional inorganic materials, such as cement, in order to reduce leachability. The technique is not used for bottom ash in the Netherlands;
- wet treatment (washing) for removal of the more mobile heavy metals, also leading to a reduction of the leachability of the residue. An additional favourable effect is that soluble salts (chlorides) are removed, which improves re-use possibilities. The waste water of the washing process has to be treated and it should be possible to discharge the dissolved chlorides to surface water. Tests have been executed, but the technique is not used on large scale;
- thermal treatment (sintering, vitrification). By melting the ash, followed by air or water cooling the leachability can be reduced substantially. Due to high operational and energy costs, this method is not relevant for bottom ash as an additional process step. It can be noted here that various thermal treatment methods, such as rotary kiln incineration and gassification operate at temperatures that produce a molten bottom ash.

4.6.3 Treatment and disposal of fly ash (from municipal waste)

There exist two main disposal routes for fly ash in the Netherlands:

- use as filling material in bound applications for civil construction (asphalt etc.);
- use as filling material in mortars for filling up underground mines.

Remaining fly ash of municipal waste incineration is disposed of by landfilling in specific hazardous waste landfills, preferably in big bags.

The application of solidification (with cement etc., see section 4.6.2) or thermal treatment (sintering, vitrification, see also section 4.6.2) is under discussion in the Netherlands.

4.6.4 Treatment and disposal of residues of flue gas treatment

Normal disposal route for flue gas residues is specific hazardous waste landfill.

Following developments are taking place or discussed in the Netherlands to improve disposal and recycling possibilities for residues of flue gas treatment systems:

- solidification, in order to improve landfill properties;
- production of clean gypsum, as described in section 4.5.2 (separate treatment of the waste water from the first and the last steps of the scrubber system). By application of a two stage scrubber and separate treatment of the acid and neutral waste water streams, part of the residue can be transformed in gypsum of a quality which is fit for re-use;
- treatment of the residue from a spray dryer system, in combination with wet flue gas treatment. The system consists mainly of a vacuum band filtration unit, with various filtration zones, a physical chemical waste water treatment unit and an evaporation unit. A mixture of the product of the spray dryer is mixed with waste water from the scrubber and treated, resulting in following products:
 - an insoluble residue, with low leachability, fit for landfilling;
 - a waste water stream which can be recycled within the system;
 - a cleaned 40% CaCl₂-solution, which can be re-used

The system is under development (test-unit) with AVI Amsterdam (see section 2.1.1)

For reference literature on sections 4.6 – 4.6.4, see chapter 7, references [174] – [177].

5. BEST AVAILABLE TECHNIQUES

5.1 Introduction

After the general introduction in chapter 1, chapter 2 of this document gives a more detailed description of waste incineration techniques, including process integrated measures to prevent or reduce emissions and other environmental impacts. Chapter 3 gives an overview of relevant environmental aspects, to be taken into account. In chapter 4, techniques to prevent emissions (pre-treatment of waste, flue gas treatment as well as residue treatment) have been identified and discussed.

The selection of BAT of waste incineration is made in this chapter 5, based on the information provided in chapter 2, 3 and 4 and considering the following aspects:

- applicability of the techniques;
- main achieved emission levels;
- cross-media effects;
- economics.

BAT of co-incineration of waste with other incineration processes is not included in this chapter.

The selection of BAT for waste incineration represents the view of the Ministry of Housing, Spatial Planning and the Environment with regard to BAT. The achievable emission levels, as given below are not intended to be applied straightaway (e.g. for direct licensing purposes), but provide reference for the licensing authorities as what can be considered BAT in general for the sector.

The main concern (considering the environmental issues in the waste incineration sector in general) is related to the emissions to air and water, treatment and disposal of residues and energy efficiency. As a result, the techniques identified in Chapter 4 are mainly suitable to reduce these emissions.

Handling and storage, noise nuisance, cooling water emissions, good house-keeping and external safety are described in less detail in this document. Although these aspects can be very important in a specific situation, identification of BAT in a quantitative matter for these aspects is out of the scope of this document. The reader is kindly referred to existing BAT-descriptions and expected so-called "horizontal" BAT-reference documents.

In the past, Dutch waste incinerators have received a lot of public attention, especially due to the emissions of dioxins to air. This has resulted in the development of very stringent emission limit values (ELV's) since 1989. These stringent ELV's have been a driver for the development of new technology. Meeting the current ELV's within a safe margin, it will be difficult for the Dutch waste incinerators to reach even lower values from an economical point of view. Therefore, current Dutch ELV's are quite comparable with the emission levels associated with BAT.

5.2 General criteria for selection of Best Available Techniques

General criteria for the selection of BAT, related to the various environmental aspects can be summarised as follows.

5.2.1 Emissions to air

- Selection of flue gas treatment technology should be based on an optimal reduction of air emissions, but also other environmental (cross-media) aspects are to be considered, such as:
 - minimisation of emissions to water,
 - acceptability of discharging of soluble salts to local surface water,
 - production of residues,
 - consumption of chemicals and energy
 - maximum energy recovery.
- The following table gives an overview of emission concentrations to air for various polluting compounds, as normally reached for waste incineration in the Netherlands.

Table 5.1: Typical flue gas concentrations for Dutch waste incineration plants

	Unit	Typical values realised in the Netherlands
Dust	mg/m ³	0.5 – 3
HCl	mg/m ³	0.5 – 5
HF	mg/m ³	0.1 - 0.5
SO ₂	mg/m ³	2 – 30
NO _x	mg/m ³	40 – 70
NH ₃	mg/m ³	0 – 3
Hg	mg/m ³	0.005 – 0.02
Cd+Pb	mg/m ³	0.001 – 0.01
Others ¹	mg/m ³	0.01 – 0.1
CO	mg/m ³	5 – 50
C _x H _y	mg/m ³	0 – 10
PCDD/F's as TEQ	ng/m ³	0.01 – 0.05

1) As, Sb, Pb, Cr, Cu, Mn, V, Co, Ni, Se, Sn and Te

2) dry flue gas, at 273K, 101.3 kPa, 11% O₂, hourly average values based on standardised (inter)national sampling and analysis methods.

- Other emissions to air (dust, odour) should be prevented by an adequate design of the plant (adequate storage and ventilation provisions etc.).

5.2.2 Emissions to water

- 1 Process waste water, resulting from a wet flue gas treatment system is to be adequately treated before discharge, in order to substantially reduce levels of pollutants (solid particles, heavy metals, organic micro-pollutants).
- 2 The following table gives an overview of emission concentrations to water for various polluting compounds, as normally reached for waste incineration in the Netherlands.

Table 5.2: Indication of emission standards for discharge of wet flue gas treatment waste water (direct and indirect discharges)

Compound	Unity	Typical value for discharge to surface water	Normally applied range, depending on circumstances
As	µg/l	10	3-200
Cd	µg/l	50	5-100
Cr	µg/l	30	30-500
Cu	µg/l	20	10-100
Hg	µg/l	5	1-20
Pb	µg/l	100	50-500
Ni	µg/l	30	15-100
Sn	µg/l	50	25-100
Mo	µg/l	1000	100-1000
Zn	µg/l	200	50-500
Suspended solids	mg/l	10	10-45
PCDD/F (TEQ)	ng/l	0.1	<0.1

- 3 In case discharge of treated waste water, containing dissolved salts is not environmentally acceptable (depending on local circumstances), a waste water free flue gas treatment system (evaporation) should be applied.
- 4 Waste water, resulting from bottom-ash collection and storage should not be discharged without adequate treatment.
- 5 For other non-specific waste water streams an adequate set-up of provisions for storage, treatment and discharge is to be applied.

5.2.3 Residue treatment and disposal

1. The re-use of incineration residues (bottom-ash, fly ash etc.) is to be maintained on a high level.
2. Re-use of bottom-ash as civil construction material should preferably take place in large scale applications.

3. Improvement of the quality of the bottom-ash (reduction of leachability) is to be promoted in order to comply with category 2 of the Dutch Building Materials Decree (DBMD, "Bouwstoffenbesluit", see sections 1.6 and 3.3.2).
4. Increased re-use of fly ash is recommended, if required after using immobilisation techniques.
5. Further development of (on site) technologies for re-use of part of flue gas treatment residues (gypsum, salts) requires attention. Disposal of flue gas treatment residues should take place by controlled landfill (see European Directive for landfills).

5.2.4 Energy aspects

1. Use of recovered energy for production of electricity, based on maximum steam temperatures of approx. 400°C is a minimum requirement for BAT.
2. If the local situation offers this opportunity, use of heat by neighbouring activities, under application of co-generation technology is to be applied.
3. For the selection of a new site, possibilities for use of heat by neighbouring activities should be taken into account. For existing sites, possibilities for (increase of) use of heat should be investigated.
4. Possibilities to increase energy efficiency are to be investigated and if possible be applied. This includes options to reduce the own energy consumption, to increase thermal efficiency (recirculation of flue gas, improvement of incineration control systems etc.) as well as opportunities to improve thermodynamic efficiency, such as application of higher steam temperatures and/or better cooling.

5.3 **BAT for municipal waste incineration**

In this section, BAT for municipal waste incineration is defined. BAT-aspects of pre-treatment, acceptance and storage of municipal waste plants are discussed in section 5.3.1. BAT for grate, furnace, boiler and energy recovery is discussed in section 5.3.2. Subsequently, BAT for flue gas treatment is discussed in section 5.3.3.

5.3.1 BAT for pre-treatment, acceptance and storage of municipal waste

Based on the criteria, as discussed in the section 5.2, following aspects of municipal waste pre-treatment, acceptance and storage are included in BAT for incineration of municipal waste:

- an acceptance policy with maximal attention for segregated collection (at source) of specific waste categories such as organic household waste, paper and board, glass, metals, textiles, used household equipment, small amounts of hazardous wastes, industrial wastes, demolition and construction wastes etc.;

- adequate waste acceptance provisions and procedures, such as weighing bridges, administrative systems, possibilities to check contents of waste trucks etc.;
- a closed reception hall with adequate ventilation;
- a waste storage bunker of sufficient size (minimum approx. four days storage capacity), with sufficient dumping positions and with adequate fire protection provisions;
- a bunker crane system with at least two cranes. Crane personnel should have an adequate view in the bunker. Crane movements are to be controlled semi-automatically and with adequate safety provisions;
- size reduction of bulky wastes by means of guillotine and/or rotary shears;
- adequate provisions for storage and mixing of waste in the waste bunker.

5.3.2 BAT for grate, furnace, boiler and energy recovery

BAT for municipal waste incineration includes following aspects of grate incineration:

- a grate system which ensures an adequate incineration process with a low percentage of unburned material in the bottom ash;
- the distribution of primary air under the grate should be controlled;
- depending on the waste quality there should be provisions to pre-heat (part of) the primary incineration air;
- a deslagger system, which prevents the introduction of false air at the end of the grate. The deslagger should be able to operate waste-water free or with controlled discharge of waste water;
- the furnace should have a relatively low specific heat load, in order to reduce flue gas velocities and enable sufficient residence time of flue gases on a temperature level above 850 °C;
- secondary incineration air should be effective over the total cross-section of the furnace, if required by extra beams, in order to realise sufficient homogeneous presence of oxygen (a minimum of 6% is only indicative);
- part of the secondary air can be replaced by recirculated flue gases (after pre-removal of dust);
- flue gas flow patterns in the furnace should be tested in computer models or on laboratory scale;
- protection of the lower part of the furnace by refractory lining;
- application of an incineration control system. Design of the system may vary, depending on design of the grate system and experience of equipment supplier and operating company;
- water cooled grate systems are considered as BAT for waste with a relatively high LHV (above 10 MJ/kg);

BAT for the related boiler and energy recovery system includes following elements:

- a maximum flue gas temperature before the first superheater convection bundles of 650°C;
- application of additional empty boiler passes is optional;
- a first convection bundle with a relatively low temperature and with large distances between tubes;

- application of moderate steam conditions (steam temperature <math><400^{\circ}\text{C}</math>) in combination with concurrent flow in the last superheater;
- application of special boiler cleaning devices;
- application of a steam turbine with electrical generator for electricity production;
- (if applicable) heat supply to neighbouring customers and if possible with co-generation technology;
- application of special configurations for the water/steam cycle, in case local conditions enable this;
- improving of energy efficiency by application of low cooling temperatures, if possible in combination with the supply of low-temperature heat to neighbouring customers;
- application of special tube materials (inconel) for furnace walls (evaporator).

Furthermore following conditions are to be taken into account on selection of BAT for municipal waste incineration:

- the grate, furnace and boiler system should have a well-proven availability;
- a sufficient economy of scale of the plant should be realised, preferably with minimal three lines and capacities per line of minimal 15 t/h, preferably approx. 25 t/h;
- the design of the plant should prevent the risk of local soil pollution by soil protection measures, such as watertight floors;

5.3.3 BAT for flue gas treatment of municipal waste incineration plants

BAT for flue gas treatment can be described as follows:

For large municipal waste incineration plants wet flue gas treatment is considered as BAT. For municipal waste incineration plants with relatively small capacities, semi-dry flue gas treatment (including pre-removal of fly-ash) can be considered as an alternative.

In detail BAT for flue gas treatment is assessed as follows:

- application of pre-removal of dust. The resulting fly ash is to be collected separately and can be applied usefully;
- application of wet flue gas treatment. The treatment of the resulting waste water depends on local circumstances;
- if local surface water can accept the resulting load of soluble salts (mainly chloride), physical/chemical waste water treatment is considered as BAT;
- physical/chemical treatment consists of following process steps: neutralisation of acid waste water (in two stages), sedimentation, sand and/or activated carbon filtration and dewatering of sludge. The emission levels to water, as indicated in table 5.2 are to be achieved;
- the waste water treatment unit should be dimensioned sufficiently large in capacity, in order to be able to cope with process variations. Additionally provisions for storage of waste water variations should be available and operational personnel should pay attention to process control. Discharge of effluent should preferably take place on a communal waste water treatment plant;
- if local surface water cannot accept the resulting load of dissolved salts, a waste water free design of wet flue gas treatment is applicable, by evapora-

- tion of the produced waste water in a spray dryer/absorber, including bag house filter or ESP, located between pre-removal of dust and wet scrubber;
- SNCR-DeNO_x for removal of NO_x, for new plants (less energy consumption, better cost-effectivity). For existing plants a retrofit with SNCR may not be applicable. In that case SCR-DeNO_x is more appropriate.
 - flue gas polishing by means of an entrained bed system, consisting of injection of adsorbents and dust bag filters;

The indicated technology is fully capable of reaching the emission levels to air of table 5.1 and if applicable the emission levels to water of table 5.2, with safe margins.

5.3.4 BAT for solid residues

BAT for bottom-ash treatment consists of:

- treatment by sieving, breaking, removal of iron scrap (magnetic separation) and non-ferrous metals (eddy-current);
- natural ageing of the material;

Although re-use of bottom-ash, fly ash and flue gas treatment residues takes place outside the boundaries of the incineration plant and therefore is formally out of the scope of this document, the best environmental solutions for these residues are:

- for bottom ash: controlled re-use as civil construction material in large projects (for embankments >10,000, preferably >100,000 tons per project, for road foundations >1,000 tons per project);
- for fly ash: re-use as a filler in bound applications (asphalt, mortars) and re-use after solidification;
- for flue gas treatment residues: controlled landfill after solidification

These routes are according to the LAP (version January 2002).

5.4 **BAT for hazardous waste incineration**

5.4.1 General

As BAT for the incineration of hazardous waste, as far as different from municipal waste incineration, is considered:

- Rotary kiln incineration, with a kiln of sufficient size to cope with large variations in composition of the compounds. Drums of 200 l should be processable;
- The furnace (after-burning room) should be designed for an incineration temperature of $>1100^{\circ}\text{C}$, in case halogen-containing ($>1\%-\text{w}$) waste is to be incinerated (which is normally the case). Only for existing plants a lower temperature is acceptable ($>1000^{\circ}\text{C}$), with the condition that sufficient combustion efficiency can be demonstrated;
- The operation of a rotary kiln incineration plant for hazardous wastes requires specific operational attention and waste management provisions, such as specific acceptance procedures, storage provisions, health and safety regulations and provisions, application of specific recipes etc.

Related boiler and flue gas treatment technology are well comparable with the technologies as applied for municipal waste, though input loads of pollutants may be higher. This should be taken into account during the design of the plant.

5.4.2 BAT for boiler and energy recovery (hazardous waste)

Boiler technology can be described as follows

- a maximum flue gas temperature before the first superheater convection bundles of 650°C ;
- application of additional empty boiler passes is optional;
- a first convection bundle with a relatively low temperature and with large distances between tubes;
- application of moderate steam conditions (steam temperature $<400^{\circ}\text{C}$) in combination with concurrent flow in the last superheater;
- application of special boiler cleaning devices;
- application of a steam turbine with electrical generator for electricity production;
- (if applicable) heat supply to neighbouring customers and if possible with co-generation technology;
- application of special configurations for the water/steam cycle, in case local conditions enable this;
- improving of energy efficiency by application of low cooling temperatures, if possible in combination with the supply of low-temperature heat to neighbouring customers;
- application of special tube materials (inconel or comparable) for furnace walls (evaporator) and for superheaters for existing plants, in case these superheaters have a short life time, due to high-temperature corrosion effects.

5.4.3 BAT for flue gas treatment (hazardous waste)

This includes:

- application of pre-removal of dust. The resulting fly ash is to be collected separately and can be applied usefully;
- application of wet flue gas treatment. The treatment of the resulting waste water depends on local circumstances;
- if local surface water can accept the resulting load of soluble salts (mainly chloride), physical/chemical waste water treatment is considered as BAT;
- physical/chemical treatment consists of following process steps: neutralisation of acid waste water (in two stages), sedimentation, sand and/or activated carbon filtration and dewatering of sludge. The emission levels to water, as indicated in table 5.2 are to be achieved;
- the waste water treatment unit should be dimensioned sufficiently large in capacity, in order to be able to cope with process variations. Additionally provisions for storage of waste water variations should be available and operational personnel should pay attention to process control. Discharge of effluent should preferably take place on a communal waste water treatment plant;
- if local surface water cannot accept the resulting load of dissolved salts, a waste water free design of wet flue gas treatment is applicable, by evaporation of the produced waste water in a spray dryer/absorber, including bag house filter or ESP, located between pre-removal of dust and wet scrubber;
- flue gas polishing by means of an entrained bed system, consisting of injection of adsorbent and dust bag filters;

The indicated technology is fully capable of reaching the emission levels to air of table 5.1 (remark: for hazardous waste NO_x-levels do not apply yet) and if applicable the emission levels to water of table 5.2, with safe margins.

5.4.4 Treatment and disposal of residues

BAT for the disposal of the residues of hazardous waste incineration is controlled landfill.

5.4.5 Dedicated units for incineration of hazardous waste

Incineration of specific categories of hazardous wastes in "dedicated" units is a recommended option in case sufficient waste amounts of these specific categories are available (economy of scale).

As these dedicated units are "tailor made"-solutions, a general definition of BAT cannot be given. Optimal technology strongly depends on specific circumstances.

5.4.6 Co-incineration of hazardous waste in municipal waste incineration plants

Co-incineration of hazardous wastes in municipal waste incineration plants is limited to a number of specific types of hazardous waste. This requires specific conditions in the permits of these plants, including specific acceptance proce-

dures, adequate process conditions during incineration, quantity restrictions, safety and health conditions etc.

5.5 **BAT for the incineration of specific clinical waste**

BAT for the incineration of specific clinical waste is defined as follows:

- a centralised incineration unit with adequate environmental provisions, comparable with (municipal and hazardous) waste incineration. This requires the establishment of a segregated collection system for specific clinical waste;
- the applied incineration system should be designed to cope with the specific characteristics of this type of waste. Adequate options are a two stage (pyrolysis/afterburner) system or a rotary kiln system;
- The incineration unit should preferably be located on the same site with other waste incineration activities, resulting in synergy effects.

Related boiler and flue gas treatment technology are well comparable with the technologies as applied for municipal waste, as described in sections 5.3.2 and 5.3.3.

The indicated technology is fully capable of reaching the emission levels to air of table 5.1 and if applicable the emission levels to water of table 5.2, with safe margins.

BAT for the disposal of the residues of specific clinical waste incineration is land-fill (hazardous waste).

5.6 **BAT for the incineration of sewage sludge**

BAT for the incineration of dewatered sewage sludge is defined as follows:

- centralised, relatively large scale incineration in plants with adequate provisions for acceptance and storage of sludge (minimum 4 days storage);
- bubbling fluidised bed incineration with partial pre-drying of the sludge with steam or thermal oil;
- as LowerHeatingValue (LHV) of sludge is low, the incineration plant should have an optimal energy efficient design;
- a specific aspect of sludge incineration is the potential smell emission related with storage of sludge and partial pre-drying. Adequate provisions (biofilters, incineration of ventilation air) are required;
- another specific aspect of pre-drying of sludge is the formation of a waste water stream with a high nitrogen content. Treatment in an adjacent waste water treatment plant is recommended;
- for the selection of a new site, possibilities for use of heat by neighbouring activities should be taken into account. For existing sites, possibilities for (increase of) use of heat should be investigated.

Related boiler technology is in many aspects comparable with the technologies as applied for municipal waste (see also section 5.3.2). As flue gas composition is less critical than for municipal waste (less Cl) and fly ash has other characteristics, design can deviate in some technical details.

The design of the flue gas treatment system (see also section 5.3.3) should take into account the relatively high sulphur content of sludge in comparison with municipal waste. Another specific aspect is the mercury, which is for a larger part present in the volatile, metallic state, which is more difficult to remove than the ion state (mainly chlorides).

Flue gas treatment should include SNCR-DeNOx and special techniques for mercury removal (preferably by activated carbon);

The indicated technology is fully capable of reaching the emission levels to air of table 5.1 and if applicable the emission levels to water of table 5.2, with safe margins. Due to the well-controlled incineration process in the fluidised bed, process conditions are rather stable. This reduces the necessity of continuous emission measurements (see section 4.4.8).

BAT for the ash of sewage sludge incineration is re-use as civil construction material in bound applications (asphalt, mortars). The residues of the related flue gas treatment are landfilled.

6. PROMISING TECHNIQUES AND REQUIRED RESEARCH

In this chapter a survey is given of promising developments, mentioned in this document. It is recommended that operational companies, suppliers of technology, universities and scientific institutes, as well as related governmental institutions combine efforts to develop improvements.

6.1 Municipal waste incineration

6.1.1 Pre-treatment, acceptance and storage

As indicated in section 5.3.1 segregated collection (at source) of specific waste categories such as organic household waste, paper and board, glass, metals, textiles, used household equipment, small amounts of hazardous wastes, industrial wastes, demolition and construction wastes etc. is an important issue in modern Dutch waste management.

In addition, important developments are taking place concerning additional mechanical sorting activities, in order to produce specific fractions out of various waste categories (industrial wastes, demolition and construction waste etc.) which are suitable for recycling and/or incineration. With respect to incineration, one of the goals of the specific sorting activities is to produce 'monostreams', which may be incinerated more effectively than mixed waste streams e.g. in cement kilns, coal power plants or specific incineration plants.

The Dutch national waste planning procedure (LAP) enables these developments.

6.1.2 Grate, furnace, boiler and energy recovery

Following technologies are not yet BAT, but are considered as promising technical developments in relation with grate incineration technology:

- a further sophistication of incineration control systems (fuzzy logic, infrared detection systems etc);
- application of dry deslaggers with efficient false air lock;
- recirculation of flue gases for use as primary air;
- application of re-superheating of steam;
- application of specific ceramic materials for protection of the furnace walls;
- application of special tube materials for superheaters;
- cleaning of waste boilers by controlled explosions, in case this results in a substantially higher boiler efficiency;
- reduction of flue gas temperatures at the end of the boiler below 175°C.

Furthermore application of circulating fluidised bed is considered as a promising technique, in particular for monostreams with a relatively high LHV.

6.1.3 Flue gas treatment

Following technologies are not yet considered as BAT, but are considered as promising techniques that might find application within BAT:

- application of high dust SCR-DeNO_x;
- improved process control for SNCR, in order to reduce N₂O-emissions;
- application of one or more of the following options which may result in the possibility to delete the flue gas polishing system, as included in BAT (dust bag filter with active carbon injection):
 1. dosing of activated carbon or other chemicals in the scrubber;
 2. further reduction of scrubbing temperature;
 3. application of zeolite as a recoverable adsorbent;
 4. application of catalytic dust bag filters. This technique requires site-specific research. The ammonia used in a SNCR (being placed before the catalytic dust bag filter) might poison the catalytic material.
- separate treatment of acid and neutral waste water streams from the scrubber, enabling the production of clean gypsum.
- separate evaporation of treated process waste water, in order to recover salt with a quality which is suitable for recycling;

6.1.4 Treatment and disposal of solid residues

Following techniques are considered as promising in order to improve re-use possibilities of bottom ash (see section 4.6.2):

- artificial ageing;
- washing processes;
- cold solidification;
- improved non-ferrous separation;
- grain size separation;
- as well as combinations of these techniques.

These developments are described in a recent KEMA-report, see [216].

Following techniques are considered as promising in order to improve re-use possibilities of fly ash (see section 4.6.3):

- cold solidification;
- thermal treatment (sintering, vitrification).

Following techniques are considered as promising in order to improve re-use possibilities of flue gas treatment residues (see section 4.6.4):

- cold solidification;
- production of clean gypsum;
- treatment of the residue of a spray dryer in combination with wet flue gas treatment (vacuum band filter, physical-chemical water treatment, evaporation).

6.2 Hazardous waste incineration

Technology of hazardous waste incineration in rotary kilns is adequately developed. New developments are focussed on pre-treatment techniques (a.o. shredding) and on improvement of acceptance procedures, operational experience, safety, controllability, reduction of maintenance and increase of technical availability etc.

Another development is the establishment of dedicated hazardous waste incineration plants, which can operate under more favourable conditions for certain specific hazardous waste types and/or the development of co-incineration of such waste types.

In this respect it should be noted that (environmental) conditions for dedicated plants and co-incineration activities should be completely comparable with those for centralised plants, as otherwise the competitive situation of centralised plants will be damaged.

6.3 Incineration of specific clinical waste

Specific promising techniques in this field have not been identified.

6.4 Sewage sludge incineration

Techniques in fluidised bed sewage sludge incineration which require further research and/or development are:

- improvement of (partial) drying technology, directed towards less maintenance and longer equipment life time, by application of new materials, improved mechanical design etc.
- improvement of temperature control of the fluidised bed system, in order to optimise NO_x and N₂O-concentrations (without increase of CO-concentration);
- application of higher steam temperatures (approx. 400°C), in order to produce electricity with a counter-pressure steam turbine.

Other relevant developments are:

- co-incineration of sewage sludge in municipal waste incineration plants;
- integration of a sewage sludge incineration unit (with own furnace, boiler and flue gas treatment, but with combined water steam cycle) within a large scale power plant, in order to improve overall energy efficiency and operational cost.

7.

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List of expressions etc.

Abbreviations

ALARA	As Low As Reasonably Achievable
AOO	Dutch Waste Co-ordination Board
ARN	Afvalverwerking Regio Nijmegen (see below)
AVI	Municipal Waste Incineration Installation
AVR	Afvalverwerking Rijnmond (see below)
AZN	Afvalverbranding Zuid-Nederland (see below)
Baga	Dutch Decree on the Indication of Hazardous Wastes
BAT	Best Available Techniques
BF	Bag filter
BLA	Dutch Decree on Air Emissions for Waste Incineration
BOD	Biochemical Oxygen Demand
BREF	BAT Reference Documents
COD	Chemical Oxygen Demand
DBMD	Dutch Building Materials Decree
DeNO _x	Removal of nitrogen oxides
DeSO _x	Removal of sulphur oxides
DRSH	Delfland Rijnland Schieland Hollandse Eilanden en Waarden (see below)
DTO	Rotary Kiln
EC	European Commission
EDV	High voltage venturi
ESP	Electrostatic precipitator
EU	European Union
EUR	European Currency Unit
EURAL	Directive 2000/532/EC (including amendment 2001/118/EC)
EZ	Dutch Ministry of Economic Affairs
GEVUDO	Gemeenschappelijke Vuilverwerking Dordrecht en omstreken (see below)
HAZOP	Hazardous & Operability
HWI	Hazardous Waste Incinerator
IPPC	Integrated Pollution Prevention & Control
IEF	Information Exchange Forum
InfoMil	Information Centre for Environmental Licensing
LAP	Dutch National Waste Management Plan
LHV	Lower Heating Value
MJA	Dutch long-term agreement on energy efficiency
MJPA	Dutch National Program on Hazardous Waste
MWI	Municipal Waste Incinerator
NeR	Netherlands emission Regulations
N-kj	Kjeldahl Nitrogen
OWF	Organic Wet Fraction
RDF	Refuse derived fuel
RIZA	Dutch National Institute for Inland Water Management and Waste Water Treatment
RVGA	Dutch Regulations for Incineration of Hazardous Waste
SCR	Selective Catalytic Reduction
SNB	Slibverwerking Noord-Brabant (see below)
SNCR	Selective Non-Catalytic Reduction
SSI	Sewage Sludge Incinerator
V.g.f.	Organic Household Waste
VROM	Dutch Ministry of Environment
VVAV	Dutch Waste Treatment Organisation
Wm	Dutch Environmental Protection Act
WWTP	Waste water treatment plant

ZAVIN Ziekenhuisafval Verwerking in Nederland (see below)

Dutch Waste Incineration plants

<u>Municipal Waste Incinerator</u>	<u>Company name</u>	<u>Location</u>
Gevudo	Gevudo Afvalverwerking NV	Dordrecht
AVR Rotterdam	NV Afvalverwerking Rotterdam	Rotterdam
AVR Botlek	NV Afvalverwerking Rijnmond	Rozenburg
AVR AVIRA	NV Afvalverwerking Rijnmond	Duiven
AVI Roosendaal	SITA ReEnergy	Roosendaal
ARN	Afvalverwerking Regio Nijmegen BV	Beuningen
AVI Amsterdam	Gemeentelijke Dienst Afvalverwerking	Amsterdam
AVI Noord-Holland	NV Huisvuilcentrale Noord-Holland	Alkmaar
AVI Wijster (VAM)	Essent Milieu	Wijster
AZN	NV Afvalverbranding Zuid-Nederland	Moerdijk
AVI Twente	aviTwence	Hengelo

<u>Hazardous Waste Incinerator</u>	<u>Company name</u>	<u>Location</u>
AVR-Chemie	NV Afvalverwerking Rijnmond	Rijnmond

<u>Clinical Waste Incinerator</u>	<u>Company name</u>	<u>Location</u>
ZAVIN	ZAVIN C.V.	Dordrecht

<u>Sewage Sludge Incinerator</u>	<u>Company name</u>	<u>Location</u>
DRSH	DRSH Zuiveringslib NV	Dordrecht
SNB	NV Slibverwerking Noord-Brabant	Moerdijk
VIT (closed down)	Verwerkingsinstallatie Twente BV	Hengelo

Other companies mentioned

AKZO	Dutch Chemical company
ENCI	Dutch Cement Producer
E.ON/EZH	Dutch/German Power supplier
Electrabel	Dutch/Belgian Power Supplier
Essent/EPZ	Dutch Power Supplier
SMB	Dutch digestion plant for organic household waste
Reliant/UNA	Dutch/American Power Supplier
VAGRON	Dutch waste sorting plant

MINISTRY OF HOUSING, SPATIAL PLANNING AND THE ENVIRONMENT
 Dutch notes on BAT for the incineration of waste

Units

bar	bar
°C	degree Celsius
EUR	European currency unit
g	gram
GJ	Gigajoule ($1 \cdot 10^9$ J)
hr	hour
J	Joule
K	Degree Kelvin
kg	kilogram
kPa	kilo Pascal
kWh	kilowatt-hour (3,6 MJ)
l	litre
m	meter
mg	milligram
m ²	square meter
m ³	cubic meter; $1 \cdot 10^3$ l
MJ	Megajoule ($1 \cdot 10^6$ J)
Nm ³	m ³ gas at 273,15 K, 101,3 kPa; dry
ppm	parts per million
ppmv	parts per million, based on volume
s	second
t	metric tonne ($1 \cdot 10^6$ gram)
TEQ	Toxic Equivalents
V	Volt
Vol. %	Percentage of the volume
W	Watt
wt. %	Percentage of the weight
yr	year

Prefixes

η	nano	$1 \cdot 10^{-9}$
μ	micro	$1 \cdot 10^{-6}$
m	milli	$1 \cdot 10^{-3}$
c	centi	$1 \cdot 10^{-2}$
k	kilo	$1 \cdot 10^3$
M	Mega	$1 \cdot 10^6$
G	Giga	$1 \cdot 10^9$
T	Tera	$1 \cdot 10^{12}$
P	Peta	$1 \cdot 10^{15}$

Compounds, ions elements and minerals

As	Arsenic
Co	Cobalt
CO	Carbon monoxide
CO(NH ₂) ₂	Urea
CO ₂	Carbon dioxide
CO ₃ ²⁻	Carbonate
CaCO ₃	Limestone (calcium carbonate)
CaCl ₂	Calcium chloride
CaF ₂	Fluorspar (calcium flouride)
CaO	Lime (calcium oxide)
Ca(OH) ₂	Slaked lime (calcium hydroxide)
CaSO ₄	Calcium Sulphate
Cd	Cadmium
Cl ⁻	Chloride
Cl ₂	Molecular Chlorine
Cr	Chromium
Cu	Copper
C _x H _y	Hydrocarbons (volatile compounds)
EOX	Extractable organic fraction
F ⁻	Fluoride
HCO ₃ ⁻	Bicarbonate
HCl	Hydrochloric acid
HF	Hydrofluoric acid
Hg	Mercury
H ₂ O	Water
H ₂ SO ₄	Sulphuric acid
Mn	Manganese
Mo	Molybdium
N ₂	Molecular nitrogen
N ₂ O	Nitrous oxide
Ni	Nickel
NO	Nitrogen monoxide
NO ₂	Nitrogen dioxide
NO _x	Nitrogen oxides
NH ₃	Ammonia
NH ₄ OH	Caustic ammonia
NH ₄ HSO ₄	Ammonium bisulphate
(NH ₄) ₂ SO ₄	Ammonium sulphate
Na ₂ CO ₃	Soda ash (sodium carbonate)
NaHCO ₃	Sodium bi-carbonate
NaNO ₃	Sodium nitrate
Na ₂ O	Sodium oxide
Na ₂ S	Sodium sulphide
Na ₂ SO ₄	Sodium sulphate
O ₂	Molecular oxygen
P.A.K.	Poly Aromatic Hydrocarbons
Pb	Lead
PCB	Poly chlorinated biphenyls
PCDD	Poly chlorinated diphenyl dioxins
PCDF	Poly chlorinated diphenyl furanes
Sb	Antimony
Se	Selenium
Sn	Tin
SO ₂	Sulphur dioxide

SO ₃	Sulphur trioxide
SO _x	Sulphur oxides
SO ₃ ²⁻	Sulphite
SO ₄ ²⁻	Sulphate
Te	Tellurium
TiO ₂	Titanium dioxide
TOC	Toxic Organic Compounds
V	Vanadium
V ₂ O ₅	Vanadium pentoxide
VOX	Volatile organic fraction
WO ₃	Tungsten trioxide
Zn	Zinc