

THE RETROFIT OF THE MWC ROTEB IN ROTTERDAM, HOLLAND WITH A MODERN FLUE GAS CLEANING SYSTEM INCLUDING AN ACTIVATED CHAR ADSORPTION UNIT

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ABSTRACT

The municipal solid waste combustion (MWC) plant, Reiniging, Outsmetting, Transporten Bedrijfswerkplaatsen (ROTEB) in Rotterdam, Holland consists of 4 units with a total capacity of 1200 tpd. The MWC plant started operation in 1964 and was equipped only with an electrostatic precipitator (ESP) for flue gas cleaning.

In 1989 new Dutch legislation required a major retrofit for extensive flue gas cleaning. The paper describes in detail the new five stage gas cleaning system which consists of an ESP, two wet scrubbers, an activated char reactor (ACR) and a selective catalytic reduction (SCR) system. The preceding ACR allows for the SCR to be operated at temperatures below 200°C (400°F). This installation represents the first full scale application of this new technology in Europe.

The start-up for the new flue gas cleaning plant was in 1993. The paper will also review the emission values obtained with this new technology. This is of special interest to the public since the actual emission values for acid gases, heavy metals and halogenated organic compounds such as polychlorinated dibenzodioxins and -furans (PCDD, PCDF), polychlorinated biphenols (PCB), polychlorinated phenols (PCP) etc. are around or below the detection limit of even the most sophisticated analyzers.

The paper concludes with an outlook into further applications of this technology in Europe.

INTRODUCTION

Already in the early to mid 60's municipal waste combustion (MWC) was considered an adequate technology for disposing of large quantities of household refuse and municipal waste in Holland. Especially in large ports such as Rotterdam and others, landfilling was not suitable due to the fact that most of the land had been reclaimed from the sea, thus lying as much as 10 meters (30 feet) below sea level. Most MWC plants in the sixties and seventies were only equipped with an ESP for flue gas cleaning. As environmental awareness grew in central Europe in the mideighties and it became evident that the flue gases of MWCs contained significant amounts of air toxics such as PCDD/Fs, the pressure on the legislatures to react built up [1]. Here in 1989 Holland, as one of the first countries in Europe, implemented the RV 89, the guideline for combustion. As can be seen in Table I the new emission values for MWCs in Holland required major steps of retrofitting all existing MWCs.

The city of Rotterdam and Europort Rotterdam, one of the largest ports in the world, dispose of their waste of almost 2 million metric tons per year primarily in two MWC plants. The newer Afvalverwerking Rijnmond (AVR) plant consists of 6 units with a capacity of 600 tpd per unit; a 7th unit of the same size is under construction.

The older Reiniging, Outsmetting, Transporten en Bedrijfswerkplaatsen (ROTEB) plant consists of 4 units with a total capacity of 1200 tpd. It started operation in

**TABLE I THE DUTCH EMISSION LEGISLATION
RV 89 FOR MWC'S IMPLEMENTED IN 1989**

SO ₂	40 mg/m ³	one-hour-average
HCl	10 mg/m ³	one-hour-average
HF	1 mg/m ³	one-hour-average
NO _x	70 mg/m ³	one-hour-average
Co ₂	10 mg/m ³	one-hour-average
CO	50 mg/m ³	one-hour-average
Hg	0.05 mg/m ³	eight-hour-average
Cd + Tl	0.05 mg/m ³	eight-hour-average
Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn	0.5 mg/m ³	eight-hour-average
Toxic Equivalents (TEQ) PCDD/PCDF (according to NATO- CCMS)	0.1 ng/m ³	eight-hour-average
particulate matter	5 mg/m ³	eight-hour-average

**TABLE II THE DUTCH WASTE
WATER DISCHARGE STANDARDS**

TEQ PCDD/PCDF	< 1 ng/l
Ni	1 mg/l
Mo	1 mg/l
Zn	0.5 mg/l
Cu	0.5 mg/l
Cr	0.1 mg/l
Pb	0.1 mg/l
Cd	0.05 mg/l
As	0.01 mg/l
extractable organic chloride (EOCl)	0.005 mg/l
total suspended solids (TSS)	10 mg/l
SO ₄ ²⁻	300 mg/l (in effluent of HCl- scrubber)
NO ₃ ⁻	940 mg/l (in effluent of SO ₂ - scrubber)
pH	> 6.5 < 10
temperature	< 30°C (86°F)

(all values represent 24-hour averages)

1964 and was equipped only with an ESP for about 30 years of operation [2]. In 1990 the L. & C. Steinmüller GmbH in Gummersbach, Germany and its 50% subsidiary NEM boilers B.V. in Leiden, Holland were awarded the contract to retrofit the ROTEB plant with a state-of-the-art flue gas cleaning system in order to meet the required emission values of the RV 89. In fall 1993 the new flue gas cleaning plant went into operation; representing a milestone of modern MWC-technology.

The Process Technology

In order to meet the RV 89 standards it was necessary to employ process technologies capable of achieving removal efficiencies in excess of 95% for all major pollutants, in some cases even in excess of 99%. Therefore it was decided to compile the new flue gas treatment system using the following steps.

- (1) upgrade and refurbish the existing ESP
- (2) install a wet scrubber for the removal of HCl and HF
- (3) install a second wet scrubber to remove SO₂ and residual HCl and HF
- (4) install an activated char reactor (ACR) for the control of PCDD/F, residual heavy metals (mainly mercury) and acid gases
- (5) install a selective catalytic reduction (SCR)-DeNO_x reactor to reduce NO_x to a level below 70 mg/dscm.

Besides concentrating on these five major steps of flue gas treatment several other facts and considerations had to be taken into account. The flue gas temperature at the outlet of the boiler ranges between 250°C and 290°C (480 and 550°F), with peak temperatures of up to 320°C (610°F). This was no problem for the ESP but posed a serious problem for the first scrubber material. Especially critical is the transition zone of quenching the hot flue gas down to saturation, due to high temperatures combined with acidic conditions.

Another factor to be considered was the residential area in which the plant is located, with major housing complexes across the street. Therefore it was desirable to avoid a visible plume for most of the time.

Combined with the fact that the two existing stacks were not equipped for handling wet flue gas, the flue gas temperature at the inlet of the stack had to be maintained well above the dew point of the gas. Both prerequisites led to the decision to keep the flue gas temperature above 130°C (265°F) to insure at least 60°K above the expected dew point of the flue gas so that no condensation in the stack would occur and the plume would be visible only on cold days.

Since in Holland the plants are not required to operate waste water free, unlike in other European countries where no waste water discharge is permissible [3], the neutral salts can be discharged to the sea. Therefore any precipitation of chloride, fluoride and sulfate salts had to be avoided. In order to keep all salts in solution the use of sodium hydroxide was mandatory as a scrubbing solution and neutralizing agent respectively. Prior to that, however, an extensive waste water treatment system was required in order to meet the strict standards for the effluents. Table II gives the concentrations to be met for the discharge water, making the complexity of the necessary waste water treatment system evident.

The legal situation in Holland, like in most central European countries, created yet another problem concerning a residue. The spent activated char would become a hazardous waste by law as soon as it would cross the plant's fence line. Thus it was mandatory to find a way of properly disposing of this residue on site.

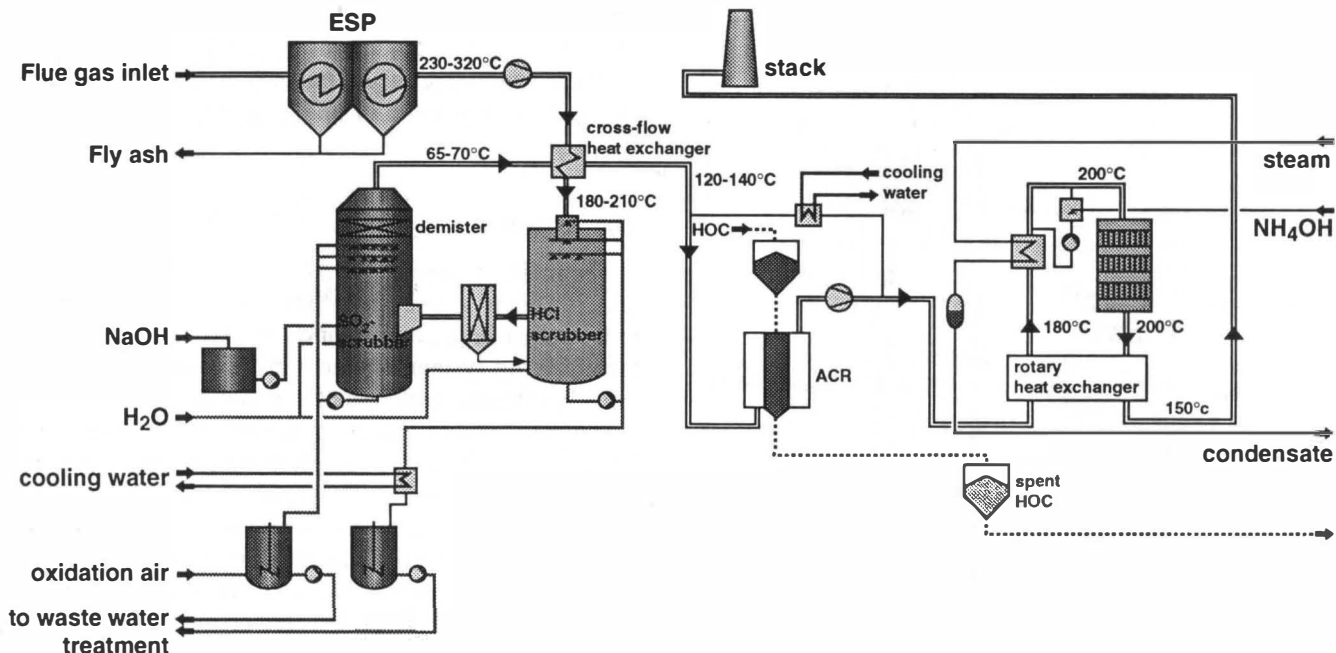


FIG. 1 PROCESS FLOW SCHEME OF THE FLUE GAS CLEANING SYSTEM OF THE MWC-PLANT ROTEB, ROTTERDAM

All these circumstances and requirements led to the creation of a process flow scheme, which is optimized for this particular plant to ideally fit its specific needs. The process flow scheme tailored to these needs is presented in Figure 1.

The Wet Absorption Stages

The wet scrubbers act as a main sink for acid gases and condensable pollutants such as heavy metals by removing 95–99% of these incoming constituents from the flue gas. Figure 2 shows the arrangement of the scrubbers with the cross-flow gas/gas heat exchanger.

Because the ESP as a first stage for the removal of particulate matter was already installed and was to be kept in place, the inlet conditions for the next stage were fixed. As described above, the temperature of 250°C to 290°C (480–550°F) with a peak maximum of 320°C required special attention. The temperature before the inlet of the first wet scrubber had to be lowered to a level which is acceptable for the scrubber material.

The high content of the HCl and HF in the flue gas combined with water as scrubbing liquid, immediately forms an extremely acidic solution. On the other hand, the very low pH is advantageous for scrubbing out heavy metals. These are predominantly present in an ionic form, hence their solubility increases with decreasing pH. These extremely acidic conditions require a scrubber material especially resistant to corrosion. The ideal material for these conditions is glass fiber reinforced plastic (GRP).

The only problem with GRP is its limited resistance to higher temperatures. About 160°C (320°F) must be considered the maximum permissible temperature, already requiring a special resin. Because the flue gas had to be reheated after the scrubbers in order to prevent condensation in the following stages a cross-flow gas/gas heat exchanger was chosen for simultaneously cooling the flue gas before the first scrubber and reheating it after the second scrubber to around 130°C (270°F). Even though the flue gas temperature is reduced by 70–80°K the resulting operational maximum of 210°C (410°F) is still too high for regular GRP. Therefore in conjunction with the supplier of the resin, BASF AG, Germany, a complicated fabrication process was used to make the inlet section of the first scrubber suitable for this temperature range.

The special resin, BASF Palatal 460, was artificially aged by heat tempering. This baking process removes the remaining gases and volatiles from the resin and hardens the material to such an extent that continuous operation temperatures of up to 210°C (410°F) can be handled.

The cross-flow gas/gas heat exchanger consists of Teflon tubes applicable to continuous operation temperatures at the inlet of 290°C (550°F). In order to account for temperatures of 320°C (610°F) dual fluid spray nozzles were installed prior to the heat exchanger inlet. When the temperature exceeds 290°C (550°F) water is injected as a fine mist to quench the flue gas temperature down to a maximum of 290°C (550°F).

The Teflon tubes in the heat exchanger are arranged vertically as hanging columns with the flue gas flowing

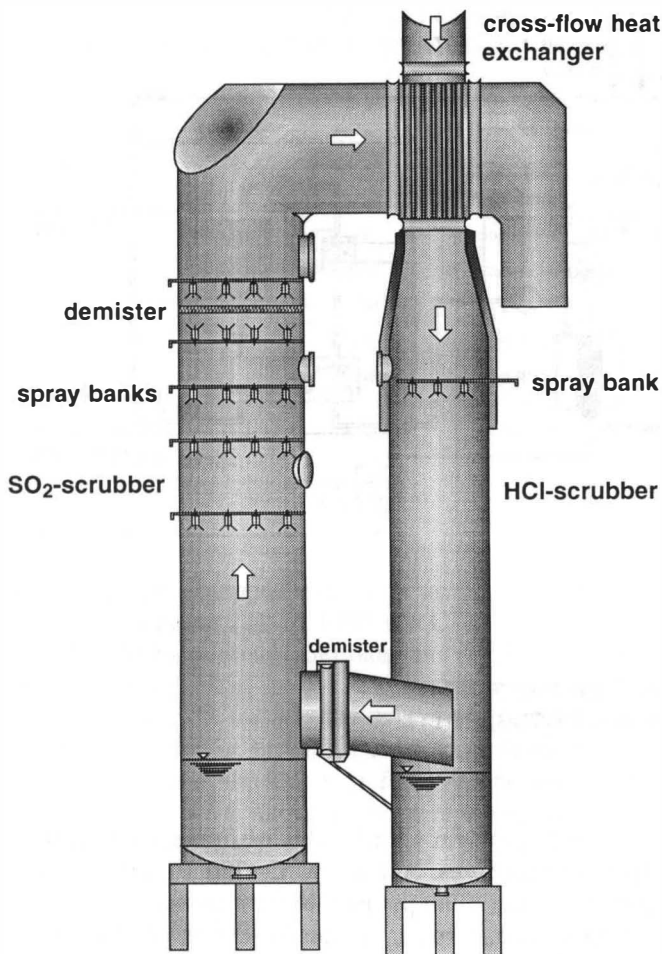


FIG. 2 THE TWO-STAGE SCRUBBING SYSTEM WITH A CROSS-FLOW HEAT EXCHANGER OF THE MWC-PLANT ROTEB, ROTTERDAM

through the tubes from top to bottom. Thus condensing acid runs directly into the first scrubber and the particulate matter remaining in the flue gas after the ESP cannot collect in the tubes and cause plugging. The heat exchanger is located on top of the first scrubber.

The supporting housing of the heat exchanger consists of stainless steel coated with Teflon. The saturated flue gas leaving the demister after the second scrubber flows around the outside of the Teflon tubes for reheating to approximately 130°C to 140°C (265–285°F).

Droplets containing neutral salts, primarily sodium sulfate can collect by means of inertial impaction on the tubes. The evaporating water then leaves a salt crust on the outside surface of the Teflon tubes. Due to the very smooth surface of the Teflon and the constant vibration and pulsations of the tubes, the forming crust is broken up and flakes off, keeping the flexible Teflon tubes clean. Because this self-cleaning effect is sufficient, no cleaning installations are required.

The main part of the co-current first scrubber, the connecting duct work and the second counter-current scrubber

are made of regular GRP. This includes the demister housing, the spray banks, the circulation pipes and all piping carrying aggressive media under pressure. The remaining piping is mostly made of polypropylene (PP).

The Activated Char Reactor (ACR)

The main purpose of the ACR is the removal of PCDDs and PCDFs to a level well below 0.1 ng TEQ/dscm. Due to the rather high concentration of PCDD/Fs produced by the old firing system and the high temperature ESP an extremely effective technique for removal had to be chosen.

Outlet concentrations at the ESP of over 40 ng TEQ/dscm have to be handled without the concern of possible breakthrough. The process technology and the function of the patented Steinmüller/Hugo Petersen cross-flow ACR-system has been described extensively in numerous previous papers [4, 5, 6]. Besides removing not only PCDD/Fs but all halogenated organic compounds like polychlorinated biphenols (PCB's), polychlorinated phenols (PCPs), polychlorinated benzenes (PCB₂s) etc. extremely effectively [7, 8], activated char also adsorbs all of the other pollutants remaining in the flue gas after the scrubber. Thus heavy metals, especially mercury, and acid gases are removed to levels at or below the detection limits of even the most sophisticated analyzers. The ACR acts as a gas mask for flue gas polishing by means of adsorption by activated char made from hearth oven coke (HOC).

ACRs have to be operated on the suction side of the I.D. fan to prevent any outleakage of untreated flue gas. Figure 3 provides a schematic of the employed ACR-system. The actual emission values obtained will be measured by the Dutch regulatory agency in spring 1994 and published as soon as available. Table III gives an overview of emission values obtained at a full scale ACR installation after a 120 tpd hazardous waste incinerator [7, 8].

The Low Temperature SCR-DeNO_x

The I.D. fan is located directly after the ACR and therefore upstream of the SCR unit. At this point the composition of the flue gas is almost ideal, containing virtually only H₂O, O₂, CO₂, CO and NO_x and is well above its dew point. This high purity of the flue gas can be attributed to the extraordinary efficiency of the ACR. For the SCR unit this feature provides a distinct advantage.

The SCR-catalysts commonly used consist of a ceramic base material with an active substance for catalysis incorporated. The homogeneous ceramic titanium dioxide (TiO₂) is usually activated with 2-3% vanadium pentoxide (V₂O₅) and extruded into a honeycomb structured block. This type of catalyst provides high efficiencies for the reduction of NO_x to N₂ and H₂O in the presence of NH₃. Unfortunately it also catalyzes the oxidation of SO₂ to SO₃

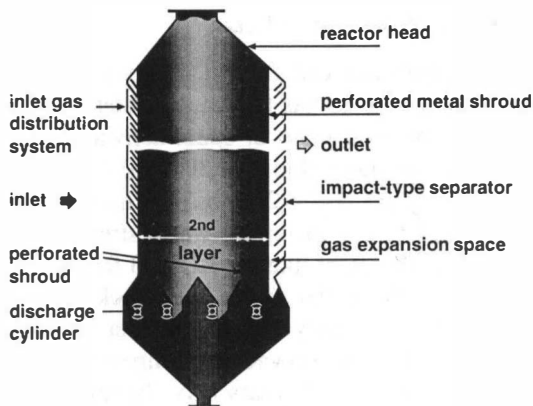


FIG. 3 SCHEMATIC OF THE STEINMÜLLER ACR ADSORBER

TABLE III STACK EMISSIONS AFTER AN ACR-ADSORBER

SO ₂	0.22 mg/m ³	(0.2)
HCl	0.68 mg/m ³	(0.6)
HF	n. d. mg/m ³	(0.1)
Co _{org}	n. d. mg/m ³	(1.0)
Hg	0.90 µm/m ³	(0.7)
Cd+Tl	0.38 µm/m ³	(0.3)
∑ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn	52 µm/m ³	(34)
TEQ PCDD/PCDF according to NATO-CCMS)	0.001 ng/m ³	(0.0003)
particulate matter	n. d. mg/m ³	(1.1)
PCB (Ballschmitter)	9.4 ng/m ³	(3.0)
PCP _h	10.7 ng/m ³	(2.4)
PCB ₂ (Di-Hexa)	2.5 ng/m ³	(0.7)

all values represent the average of several test results obtained at a hazardous waste incinerator in west-central-Germany as published earlier [7, 8]. The values given in parenthesis () represent the detection limits of the test method used. The removal efficiency for all stated pollutants exceeds 99.9 %.

very effectively, thus raising the dew point of sulfuric acid in the flue gas.

A high SO₃ content also leads to the formation of ammonia hydrogen sulfate (NH₄HSO₄), which condenses at a temperature of around 200°C (390°F) to form a sticky coating on the catalyst, thus greatly reducing the NO_x removal efficiency. The higher the content of V₂O₅ in the catalyst, the higher the conversion rate of SO₂ to SO₃. A second undesired feature is the decreasing NO_x-reduction efficiency with decreasing temperature. As shown in Figure 4, this effect can be completely compensated for by an increased concentration of V₂O₅ in the catalyst combined with a larger volume of catalyst.

Unfortunately the catalyst is also susceptible to poisoning, namely by heavy metals such as cadmium, mercury, lead, arsenic and others. The poisoning limits the lifetime of the catalyst to a range of 3 to 5 years, depending on

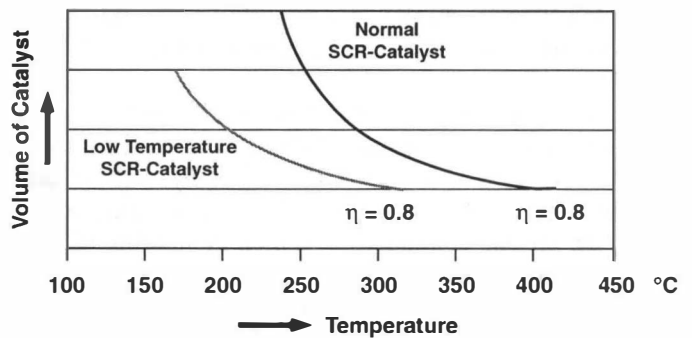


FIG. 4 REQUIRED CATALYST VOLUME DEPENDING ON THE FLUE GAS TEMPERATURE FOR NORMAL AND LTSCR CATALYSTS

the concentration and the array of heavy metals present. Thus, large volumes of catalyst are undesirable when significant amounts of heavy metals are present in flue gases, as is the case in MWC plants. The use of SCR catalysts in untreated flue gas of MWC's would lead to high replacement costs every 3 to 5 years, not accounting for the downtime.

Both problems, the SO₂/SO₃ conversion and the heavy metal poisoning are practically unknown to catalyst exposed to flue gas coming from an ACR. The gas after the activated char adsorber is virtually free of SO₂, so no significant SO₂/SO₃ conversion occurs, regardless of the volume of catalyst and its activity. Therefore large volumes are not a disadvantage any more, since the virtual absence of heavy metals avoids poisoning of the catalyst.

Even though SCR-catalysts after ACR-units in power plants have been in operation for only about 50,000 hours without a measurable decrease in efficiency, a lifetime of the catalyst of far more than 10 years must be expected and spent catalyst can be recycled.

This knowledge led to the development of the Low Temperature SCR-DeNO_x (LTSCR). Operation of an SCR-DeNO_x in MWC plants at temperatures below 200°C (390°F) bears several advantages over the conventional operating temperature of 300–350°C (570–660°F). These are:

(1) instead of natural gas or oil, steam (usually 400°C, 40 bar) produced by the MWC plant can be used for reheating, thus reducing the cost of reheating significantly

(2) the lower temperature itself requires less energy for reheating

(3) the heat exchanger, if employed at all, is significantly smaller due to a much smaller heat transfer surface area necessary

(4) if the SCR unit is operated at a temperature of 170°C (340°F) the heat exchanger becomes completely obsolete

(5) less costly materials can be used for the SCR reactor and the duct work due to the lower temperature

All these advantages can be summarized in one. The LTSCR-technology becomes an interesting alternative to the commonly employed thermal selective non-catalytic

reduction (SNCR)-DeNO_x due to higher achievable NO_x-removal efficiencies at lower stoichiometric ratios of NO_x to NH₃.

The LTSCR in ROTEB, as shown in Figure 5 works in an identical way as a regular SCR, just at a much lower temperature of about 200–210°C (400°F) without any problems. The NO_x reduction efficiency determined by using the on line continuous emission monitoring (CEM) system, is as expected.

A NO_x level after the LTSCR-system of less than 70 mg/dscm can be maintained at all times. Other units with an operation temperature of around 170°C (340°F) are under construction and will go into operation within the next 6 months.

The Waste Water Treatment System

As shown in Table II the required purity of the waste water to be discharged into the harbor made an extensive waste water treatment system necessary. Figure 6 presents the process flow scheme of the system.

The scrubbing liquid discharged from the first scrubber is a 2% hydrochloric acid contaminated with fly ash, heavy metals and hydrofluoric acid. In order to remove the heavy metals by means of flocculation, precipitation and sedimentation, the effluent is neutralized with calcium hydroxide to a pH of 8–10. After flocculation and precipitation by adding FeCl₃, trimercapto triazene (TMT) 15 and polyelectrolyte the waste water enters a first sedimentation tank. The overflowing waste water is led via a second flocculation and precipitation stage to a clarifier. The sludge from the clarifier is returned to the first flocculation tank to enhance flocculation.

The overflow is discharged via a sulfate precipitation stage adding calcium aluminate to a second sedimentation tank. The sludge is returned to the first sedimentation tank. The overflow is passed through a gravel filter and an activated carbon filter and discharged to the harbor.

The waste water treatment system for the effluent of the second scrubber is completely separate to avoid any mixing of the two streams. A mixing would result in an undesired instantaneous precipitation of calcium sulfate formed by the reaction of sodium sulfate with calcium chloride. Therefore the effluent from the second scrubber is neutralized with sodium hydroxide to a pH of 8–10. All other steps are identical to the treatment procedure of the effluent of the first scrubber up to the clarifier. The overflow of this clarifier is discharged to the harbor, again after treatment in a gravel filter and an activated carbon filter. Both waste water streams are treated and discharged completely separate. The only point of interaction is a thickener which receives sludge from both the first and second scrubber sedimentation tanks. Sludge from the thickener is dewatered in a filter press. The filter cake is disposed of in a special landfill.

The Disposal of Activated Char

Besides bottom ash and fly ash, the only new residue created by the new flue gas treatment system is spent activated char. The total mass of spent activated char for a whole treated flue gas volume of 300,000 scm/h amounts to approximately 100 kg/h (220 lbs/h). This residue could be easily added to the incoming waste stream of around 50 tons/h. In an old plant like the ROTEB facility the thermal capacity of the boiler is the bottleneck for the plant capacity. This is primarily due to a higher heating value of the municipal waste nowadays compared to what the plant was designed for 30 years ago. Therefore the addition of the spent activated char, which has a heating value 2 to 3 times higher than municipal waste, would reduce the capacity of the plant. This led to the decision that a separate way of disposal had to be found. For this particular problem Steinmüller developed a patented cyclonic combustion chamber (CCC).

Two of these chambers are installed in ROTEB, each of which is capable of burning the full amount of spent activated char. This 100% redundancy was chosen to insure an availability of 100%. The chamber itself has a diameter of 0.8 m (2.6 ft) and a height of 2 m (6.6 ft). Two natural gas burners are used to heat the CCC during start-up. Once operating temperatures of around 1,000°C have been reached and combustion of spent HOC has been started the burners are turned off. HOC is pneumatically injected into the CCC along with the transport air.

This transport air as well as primary combustion air and the secondary combustion air are injected in such a way that a rotating cyclonic flow is created inside the CCC. The retention time of HOC particles depends on the particle size, thus insuring complete combustion. Large particles have a residence time of up to 10 minutes, smaller ones have a shorter residence time before they are consumed. When the combustion process is completed most of the remaining ash leaves the CCC with the flue gas. Figure 7 shows a schematic of the two CCC's installed in ROTEB. The combustion temperature is around 1,000°C to 1,200°C (1,830–2,200°F). The outlet flue gas is first cooled by injecting air and then quenched with water to a temperature around 250°C (480°F). The cooled flue gas is injected into the main flue gas stream coming from the boiler, before the ESP.

Conclusion and Outlook

This type of retrofit designed as a five stage gas cleaning system has become the state-of-the-art technology in central Europe. Especially in Holland, Germany, Austria and Switzerland virtually all new MWC plants as well as most existing facilities are being equipped with these systems. Table IV gives an overview of the contracts awarded to L. & C. Steinmüller within the last three years.

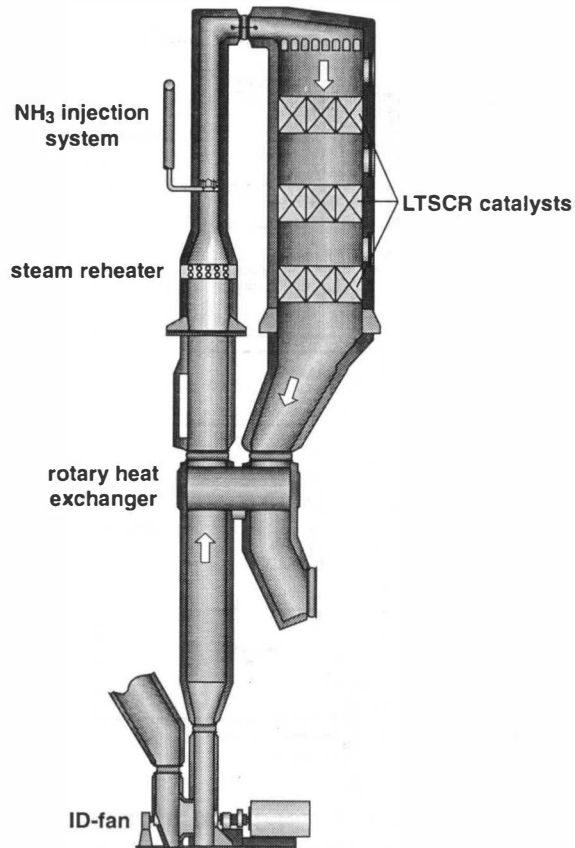


FIG. 5 THE LTSCR-DeNO_x SYSTEM OF THE MWC-PLANT ROTEB, ROTTERDAM

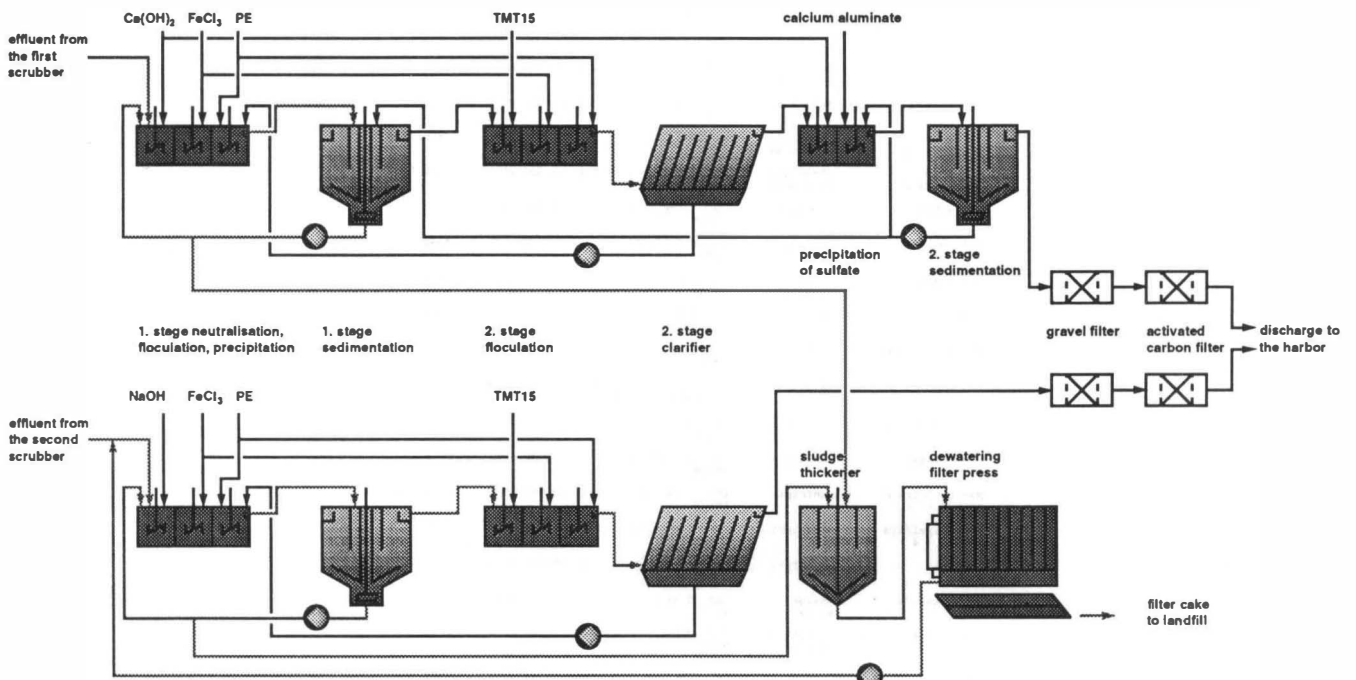


FIG. 6 WASTE WATER TREATMENT SYSTEM OF THE MWC-PLANT ROTEB, ROTTERDAM

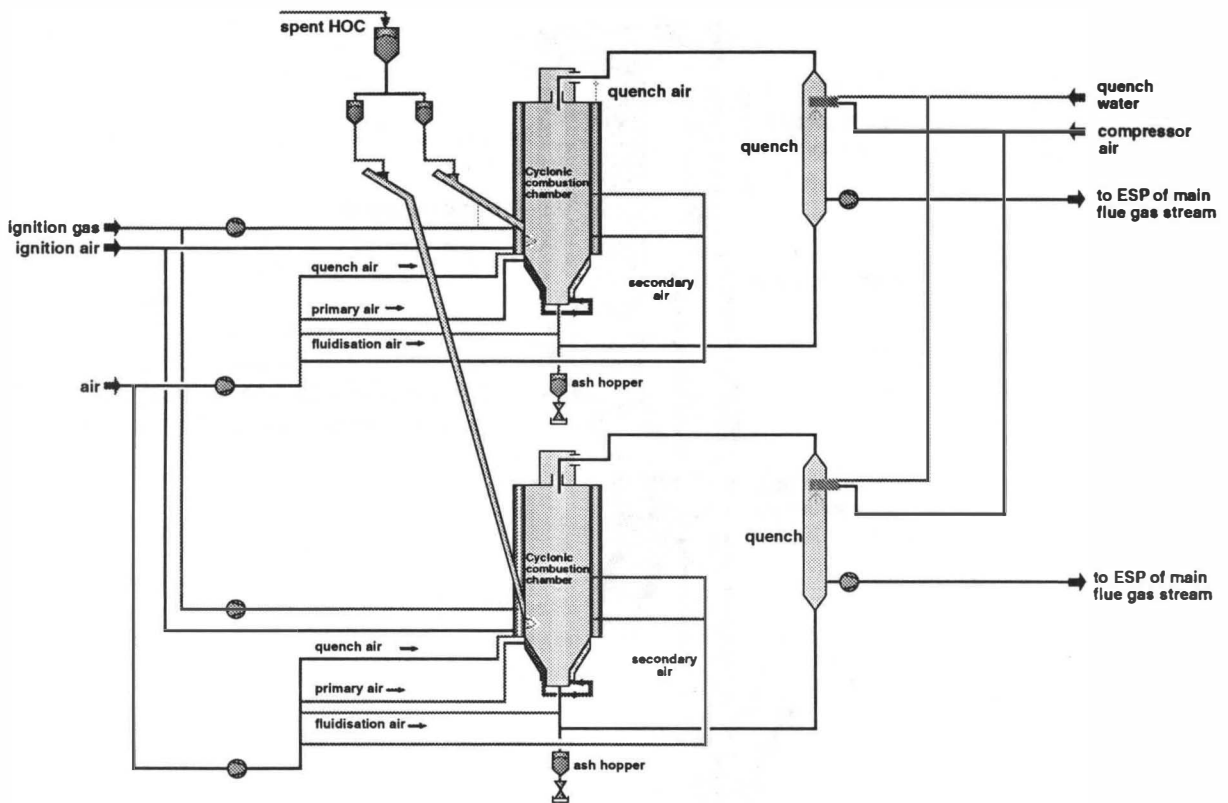


FIG. 7 THE STEINMÜLLER CYCLONIC COMBUSTION CHAMBER FOR DISPOSAL OF SPENT HOC AT THE MWC-PLANT ROTEB, ROTTERDAM

TABLE IV CONTRACTS AWARDED TO THE L. & C. STEINMÜLLER GmbH GUMMERSBACH AND ITS SUBSIDIARIES OVER THE LAST THREE YEARS

Plant	Type of Waste	Process Design	Flue Gas Volume	Start-up
RZR Herten IM 1	industrial/hazardous	ESP, 2-WS, ACR, ACCR	1 x 70.000 m ³ /h	1981/1991
RZR Herten IM 2	industrial/hazardous	ESP, 2-WS, ACR, LTSCR	1 x 70.000 m ³ /h	1988/1995
RZR Herten SM 3 + 4	municipal	FF, 2-WS, ACR, LTSCR	2 x 100.000 m ³ /h	1997
Bayer AG BÜrrig VA 1	chemical/hazardous	Q, 2-WS, WESP, SCR-OX	1 x 90.000 m ³ /h	1989/1995
Bayer AG BÜrrig VA 2	chemical/hazardous	ESP, Q, 2-WS, WESP, SCR-OX	1 x 45.000 m ³ /h	1992/1995
AVI ROTEB	municipal	ESP, 2-WS, ACR, LTSCR	4 x 75.000 m ³ /h	1993
MVB Hamburg	municipal	Q, FFAC, 2-WS, WESP	2 x 125.000 m ³ /h	1994
AVR-Chemie DTO 8	industrial/chemical	ESP, 1-WS, ACR, LTSCR	1 x 70.000 m ³ /h	1994
SAV Kehl	hazardous	SD, ESP, 2-WS, ACR, LTSCR	2 x 40.000 m ³ /h	1997
RHMKW Böblingen	municipal	FF, 2-WS, ACR, LTSCR	3 x 75.000 m ³ /h	1996
AKZ Asdonkshof	municipal	ESP, SD, ESP, 2-WS, SCR-OX, ACR	2 x 90.000 m ³ /h	1996
MVA Niederkassel	municipal	ESP, 2-WS, ACR, LTSCR	3 x 55.000 m ³ /h	1997
MVKW Kassel	municipal	ESP, SD, FF, ACR, LTSCR	2 x 70.000 m ³ /h	1996
MVA Stapelfeld unit 1 + 2	municipal	ESP, 2-WS, ACR, LTSCR	2 x 100.000 m ³ /h	1983/1995
MVA Stapelfeld unit 3 + 4	municipal	ESP, 2-WS, ACR, LTSCR	2 x 100.000 m ³ /h	1997
AVG Köln	municipal	SD, FF, 2-WS, SCR-Ox, ACR	4 x 95.000 m ³ /h	1998
VERA Hamburg	sewage sludge	ESP, 2-WS, FFAC	3 x 20.000 m ³ /h	1996
AVR-Chemie DTO-10	industrial/chemical	ESP, 2-WS, FFAC	1 x 70.000 m ³ /h	1996

.LTSCR = Low Temperature SCR
 SCR-Ox = SCR-DeNOx with PCDD/F Oxidation Catalyst
 2-WS = Two wet scrubbers
 1-WS = One wet scrubber
 SCR = Catalytic NOx Reduction
 FFAC = Fabric Filter with Activated Carbon Injection
 ACCR = NOx Reduction with Activated Carbon

ACR = Activated Carbon Reactor
 ESP = Electrostatic Precipitator
 FF = Fabric Filter
 Q = Quench Cooler
 WESP = Wet Electrostatic Precipitator
 SD = Spray Dryer

The extremely high removal efficiencies obtained by these advanced flue gas cleaning systems, especially attributable to the activated char adsorbers yield an increase in political and public acceptance of MWCs in central Europe. The concerned public is slowly starting to accept the fact that waste incineration is the only form of true inertization. When combined with flue gas treatment of this kind the environmental impact of waste disposal becomes negligible. Not only on a relative scale compared to other means of waste treatment and disposal but also on an absolute scale. Thus waste disposal by means of combustion in a state-of-the-art MWC facility is by far more environmentally acceptable than most production processes, power generation, traffic and other every day activities widely accepted as unavoidable in a modern industrialized society.

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[5] H.-U. Hartenstein, "A Fixed Bed Activated Coke/Carbon Filter as a Final Gas Cleaning Stage Retrofitted for a Hazardous Waste Incineration Plant—The First 6 Months of Operating Experience", presented at the 85th annual AWMA meeting, Kansas City Mo, USA 1992

[6] H.-U. Hartenstein, H. Hemschemeier "Retrofitting of an Existing Hazardous Waste Incineration Plant with an Activated Carbon Filter for Removal of Dioxins and other Air Toxics", presented at the Dioxin '91/EPRI-Seminar, Research Triangle Park NC, USA 1991

[7] H.-U. Hartenstein, "Fixed Bed Activated Coke Filters for the Control of Toxic Metals and Organics from Waste Incinerators—the Second Generation", presented at the 86th annual AWMA meeting, Denver Co, USA 1993

[8] H.-U. Hartenstein, "Fixed Bed Activated Coke Filters for the Control of Toxic Metals and Organics from Waste Incinerators", presented at the Dioxin'93, 13th International Symposium on Chlorinated Dioxins and Related Compounds, Vienna, Austria 1993