

## Lime Enhances Moving Bed Filters for Mercury and Dioxin Control

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## ABSTRACT

Moving bed carbon filters were developed and used in Europe to control mercury and dioxin emissions from municipal waste combustors (MWCs), crematories, hazardous waste incinerators and power plants. Although some operating problems such as a potential for fires to form in the carbon beds have caused operators some concern, more stable bed materials are presently being produced which can maintain the moving bed filter's capability in reducing mercury and dioxin emissions to very low levels while providing safe operations.

Märker Umwelttechnik GmbH (Märker) and Dravo Lime Company (Dravo) have developed a pelletized form of Sorbalit® that replaces the carbon in moving bed filters and is effective in removing mercury, dioxins, and acid gases without the inherent problems of using a carbon only adsorbent system. Sorbalit pellets are a formulation of portland cement, lime, carbon, and sulfur compounds. These pellets are currently being successfully applied in a hazardous waste incinerator, a foundry, a crematory, and a contaminated soil treatment plant.

This paper discusses the development of pellet technology and its application in moving bed filters. Safety aspects for the use of composite carbon/lime pellets will be discussed and a review of removal efficiencies among carbon alone, a composite carbon/lime material in a powder form, and composite carbon/lime adsorbents in a pellet form will be provided.

## INTRODUCTION

The German air pollution regulations, like those in most of Europe, are intended to reduce pollution to the lowest technologically achievable value regardless of economic considerations. This contrasts sharply with U.S. EPA's approach which is to balance the economics of the waste combustor and health benefits of the country. The rationale for the stricter standards in Europe lies in the closer proximity of sources of pollution to residences and business centers, and accordingly requires them to be extremely good neighbors. It is not at all uncommon for local air pollution control regulators and owners of facilities to demand much lower emission limits than those required by the already strict German Federal regulations in order to facilitate community acceptance of the proposed project during permitting. This mind-set to reduce air emissions to the maximum has resulted in cases wherein air pollution control technology systems required as many as five separate control methods/elements to achieve very stringent and contractually required air emissions reductions. To illustrate, Table 2 presents a summary of the emission standards in the 17th BImSchV (present German Federal law) and compares these regulations with the U.S. EPA standards for MWCs with all values converted to metric units for ease of review.

As a positive consequence of this regulatory philosophy, major advancements to the technology of air pollution control were developed in Germany which have resulted in significant reductions in emissions of certain key pollutants such as dioxins, mercury, and acid gases. One innovative approach that was developed in response to the goal of requiring the lowest possible emissions was the use of a moving bed filter as part of a multi-component pollution control system. The moving bed filter, located in the final position, is referred to as a "police" or "polishing filter". The term "polishing filter" is used because the device completes the pollution control process by reducing already low levels of pollutants to extremely low values while catching any potential breakthroughs. Generally, such a device would not be practical, efficient

or economic in reducing high levels of pollutant emissions to code requirements. However, when used to reduce low levels of pollutant emissions, extraordinary results can be achieved. For example, say an upstream pollution control device such as a dry scrubber / fabric filter has reduced SO<sub>2</sub> emissions from 250 ppm to 10 ppm, then typically, the addition of a moving bed filter to the pollution control train downstream of the dry scrubber could reduce or polish the SO<sub>2</sub> emissions from 10 ppm to <1 ppm before discharging the flue gases to the atmosphere. Such results, although unimaginable only a few years ago, are indicative of the progress that can be made when the public demands and is willing to pay for state-of-the-art technology when the possibility, however remote, of negative effects on human health are the alternative and money is viewed as an unlimited resource.

As illustrated in the above example, this innovative multi-component approach to air pollution control utilizing a moving bed filter technology has produced reductions in some pollutant levels on an order of magnitude lower than the already very low levels required by the regulations established in Germany by the 17th BImSchV, the Federal law in Germany which regulates the air emission standards for all waste management facilities.

The following is a summary of typical permit limits required by local government for various waste management projects implemented and built in Germany in the early 1990's. This summary illustrates the relentless ratcheting of German permit limits and contract specifications beyond those required by the 17th BImSchV.

#### Summary of Typical Permit Limits

Emissions @ 11% O <sub>2</sub>	17th BImSchV	Permit Limits	Contract Specifications
Dioxins ng/Nm <sup>3</sup>	0.1		
Range	-	0.05 - 0.1	0.01 - 0.05
Typical	-	-	0.05
Mercury µg/Nm <sup>3</sup>	50		
Range	-	5 - 50	1 - 25
Typical	-	20	10
NOx mg/Nm <sup>3</sup>	200		
Range	-	70 - 200	50 - 200
Typical	-	200	70 - 100

## TECHNOLOGY OF MOVING BED FILTERS

Moving bed filters have been successfully applied to the control of both particulate and gas phase contaminants in flue gas streams from a host of industrial and municipal processes. Particulate matter is removed by impaction on the bed media which is generally spherical with diameters in the range of 2mm to 8mm. Gas phase components are removed by the selection of a chemically reactive filter medium appropriate to the gas phase component to be removed.

For example, carbon media has been proven effective in the control of heavy metals and organic emissions. In this configuration, moving bed filters have two primary elements, the filter media (activated carbon or lignite coke) to adsorb pollutants from the flue gas and a housing or moving bed filter to contain the carbon. In the moving bed filters, the carbon is constantly fed into the top of the housing structure and is removed from the bottom. Both cross-flow and counter-flow moving bed filter system configurations are available. In the cross-flow design, the contaminated flue gases flow across the vertically downward moving bed in a horizontal direction. In the counter-flow design, the contaminated flue gases flow in an upward direction through the vertically downward moving bed. Hybrid configurations which apply both cross-flow and counter-flow schemes have also been built. Accordingly, moving bed filters can be built in a variety of ways to be used as a single stage or as a multi-stage control system. These stages can consist either of a single vessel with multiple bed levels or of multiple vessels each dedicated to the control of a single contaminant or group of contaminants.

Figure 1 illustrates the above described configurations for moving bed filter systems for air pollution control. Typically in an initial stage, dioxin, mercury, HCl and SO<sub>2</sub> are removed. In a secondary stage and after ammonia (NH<sub>3</sub>) is injected into the flue gases, NO<sub>x</sub> can be removed by the carbon. As described previously, moving bed filters are often used after the primary acid gas (SO<sub>2</sub>, HCl) control device such as a wet scrubber or spray dryer/fabric filter. This is to remove the majority of the acid gas (90 - 99%) using a calcium based reagent (\$80/ton) and thus minimize the usage of the very costly carbon (\$300 - \$900/ton) for acid gas control. Thus, as a practical matter and in terms of economics, moving bed filters are not used as a primary air pollution control system. They should only be used as the polishing component in multiple component system.

Moving bed filters offer the following advantages as pollution control devices:

- 1) Multiple pollutants can be removed in a single application.
- 2) They do not require a large pressure drop and can be retrofitted into many sites.
- 3) Carbon provides an excellent medium for the reduction of dioxins, organics, and mercury to well below permit limits.
- 4) In most cases, the used carbon can be injected back into the furnace and burned, thus eliminating a disposal problem and the associated disposal cost.

As pollution control devices, moving bed filters offer the following disadvantages:

- 1) The massive volume of carbon present in the filter is a potential fire hazard.
- 2) Good SO<sub>2</sub> controls are required prior to the moving bed carbon filter. Since carbon has a high adsorption affinity for SO<sub>2</sub>, this affinity coupled with the much higher amounts of SO<sub>2</sub> present in the gas stream from combustion sources will quickly use up the available carbon thereby letting mercury and dioxins pass through.

- 3) NO<sub>x</sub> reduction capability is not as good as that of other control methods such as selective catalytic reduction technology (SCR). If high levels of NO<sub>x</sub> control are required, (below 100 mg/Nm<sup>3</sup>) other more effective technologies such as SCR technology should be employed.
- 4) Handling granular carbon is messy and requires additional housekeeping. The use of composite carbon/lime pellets can almost completely mitigate this problem.

### **A SORBALIT CASE HISTORY**

Märker was called by the owner of an industrial sludge incinerator and asked for help in solving several operating problems at the sludge plant connected with the plant's air pollution control system. The air pollution control system consisted of a dry scrubber with a fabric filter followed by a moving bed carbon filter. After careful review, the sludge at this facility proved to have a higher than normal sulfur and chlorine content which increased the acid gas quantities exiting the dry scrubber and entering the moving bed filter system. This resulted in a very high carbon usage rate since the moving bed filter system had been originally designed to control only mercury and dioxins. There were additional material handling problems at the plant resulting from the use of carbon.

To solve the problem, Märker developed a plan to replace the granular carbon (4mm) in the filter and replace it with a pelletized form of their Sorbalit technology. Sorbalit is a formulation of lime, activated carbon or lignite coke, and proprietary sulfur compounds. A binder such as portland cement or bentonite is used to strengthen the formulation in order to form pellets. The activated carbon component in the composite carbon/lime pellets ranges from 5% to 35% by weight. Photos of typical pellets are presented in Figure 2.

Composite carbon/lime pellets can be manufactured in a variety of sizes and shapes to meet the size of the filter media material handling requirements for the different manufactures of moving beds. The pellets in Figure 2 were produced by the "spinning disks" or "snow balling" technique. The nominal 4mm pellets on the left were made in Märker's laboratory in Germany using portland cement as a binder with composite carbon/lime. Dravo Lime made the 10mm pellets using bentonite as the binder. Both portland cement and bentonite have proven to be effective binders. They provide sufficient surface strength so that the pellets do not crush using screw feeder in the material handling process. The second property of the binder is that it is porous and permits flue gases to enter the pellet so that the carbon and lime can adsorb or absorb their respective pollutants.

The concept for the use of the composite carbon/lime pellets was that the lime would absorb the acid gases while the carbon adsorbed the dioxins and mercury. The only modification made to the moving bed filter was to replace the granular carbon with the composite carbon/lime pellets in the feed hopper. Test results of the air pollution control system demonstrated that the use of the composite carbon/lime pellets reduced the emissions to within specified levels on a sustained basis at expected composite carbon/lime usage rates. The composite carbon/lime formulation used for this application based on laboratory testing consisted of 10% lignite coke, 10% portland cement, and 0.25% sulfur compounds, and the balance hydrated lime.

Of prime interest to all parties during the development of the pellet technology was the confirmation that the binders would not affect the ability of adsorbents to control dioxin and mercury emissions. Unfortunately, Märker cannot presently test dioxin removal in the laboratory. However, Märker does have the capability to determine the effectiveness of different adsorbents with HgCl<sub>2</sub>. Consequently in their

research laboratory, Märker compared formulations of their regular adsorbents containing 5% carbon and 95% hydrated lime with Dravo's pellet formulation which contained the same mixture plus a 5% bentonite binder. The test results show that there were no negative effects caused by the presence of the binder in the pellets on the Hg adsorption capacity of the composite carbon/lime. The test data are presented in Table 1.

These results are also encouraging as to dioxin adsorption in that Märker's past experience has been that Hg capture with carbon or carbon based sorbents is more difficult than dioxin capture under any given set of flue gas conditions. The literature is replete with many examples of field test data typically showing >95% capture rates of dioxins at concentration levels in the low ng/dscm range with concurrent and somewhat lower Hg capture rates of 85 - 95% when the Hg concentration levels were in the  $\mu\text{g/dscm}$  range. As a result, testing of the sorbents for dioxin removal are expected to show higher levels of dioxin removal than Hg removal.

## THE CARBON ADSORPTION PROCESS

The adsorption of mercury and organic materials such as dioxin into activated carbon and coke is controlled by the properties of both the carbon and the adsorbate, and by the conditions under which they are contacted. This phenomenon is generally believed to result from the diffusion of vapor molecules into the surface of the carbon. These molecules are retained at the surface in the liquid state because of intermolecular or Van der Waals forces.

As the temperature falls, or as the partial pressure of the vapor above the carbon rises, the average time that a molecule resides on the surface increases. So does the fraction of the available surface covered by the adsorbate. However, the carbon surface is not uniform and consists of sites whose activities vary. More active sites will become occupied first and, as the activity of the remaining available sites decreases, the adsorption energy will change.

The physical structure of activated carbon and coke is not known in detail, but it is believed to contain randomly distributed pores in the carbon, between which lies a complex network of irregular interconnected passages. Pores range in diameter down to a few angstroms, and provide a internal surface area from 300 to 1,000  $\text{m}^2/\text{gram}$  of carbon. The volume of pores at each diameter is an important variable that directly affects carbon performance.

Since adsorption takes place at the carbon-gas interface, the surface area of the carbon is one of the most important factors to consider. The second factor is the pore radius. However, the surface area must be available in the proper range of pore sizes. If too much of the area is available in pores smaller than 5 Å, many molecules will be unable to penetrate the pores and that area of the carbon will essentially be unavailable for adsorption. For most pollution-control applications, the surface areas of pores whose diameters range between 5 and 50 Å yield good efficiency rates because the relative pressure of the vapor is usually too low for the larger pores to become filled. At high relative pressures, however, the total pore volume becomes important because the macropores also become active.

The size of a molecule of mercury is approximately 3.6 Å and the dioxin molecule is 10 Å x 3 Å. Both molecules are adsorbed in different parts of the carbon particle. In theory, dioxins are collected in the

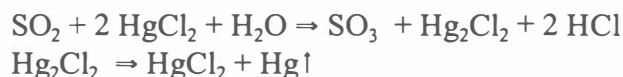
macropores ( $r > 25\text{nm}$  [ $250\text{\AA}$ ]) while the mercury is collected in the micropores ( $0.4\text{nm}$  [ $4\text{\AA}$ ]  $< r < 1\text{nm}$  [ $10\text{\AA}$ ]). Dioxin, being larger, blocks the passages, preventing mercury from entering the micropores. To increase the mercury capture rate the amount of carbon used must be significantly increased, the surface area of the carbon must be increased, or sulfur added.

## SULFUR'S ROLE IN MERCURY ADSORPTION

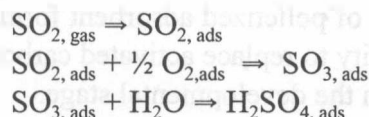
The addition of sulfur compounds to the process plays a major role in the adsorption of mercury but not in the adsorption of dioxin. Sulfur's role in the adsorption is two-fold:

- First, the sulfur compounds maintain the active state of the carbon. Activity is defined as the amount of open pores in the carbon. Sulfur's role is to keep these pores open and to allow the mercury to get into the sub-structure pores. The exact process in which the sulfur keeps the pores open has not been defined. One theory is that the sulfur reacts with water which is adsorbed or is on the surface of the carbon particles to form an acid that penetrates the pores.
- The second role for sulfur is to convert elemental mercury ( $\text{Hg}^\circ$ ) to a sulfate.  $\text{Hg}^\circ$  is more difficult to capture than  $\text{Hg}_2\text{Cl}_2$  (which is the predominant species in MWC emissions) or  $\text{Hg}_2\text{SO}_4$ .

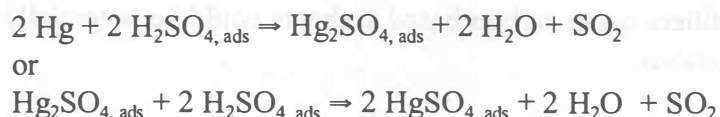
$\text{Hg}^\circ$  accounts for 5 to 10% of the total mercury emissions from an MWC. For HWIs and fossil fuel fired power plants as well as other combustion sources however, elemental mercury can be 50% of the total mercury emission. Flue gas constituents such as  $\text{SO}_2$  can further increase the elemental mercury content by reducing the dissolved  $\text{HgCl}_2$  in wet scrubber liquors to  $\text{Hg}^\circ$  which is consequently driven into the gas stream due to its poor solubility.



The adsorption capacity of carbon is affected by formation of sulfuric acid on the carbon owing to adsorption of the flue gas constituents  $\text{SO}_2$  and  $\text{H}_2\text{O}$ :



Elemental mercury then reacts with the sulfuric acid to form mercurous sulfate ( $\text{Hg}_2\text{SO}_4$ ) or in the presence of excess acid to form mercuric sulfate ( $\text{HgSO}_4$ ):



Since the lime component of composite carbon/lime removes the  $\text{SO}_2$  from the flue gas, some adsorption capacity of the carbon for  $\text{Hg}^\circ$  is diminished. The sulfur component in Sorbalit added during

manufacturing, replaces the missing SO<sub>2</sub> and enhances the adsorption of Hg<sup>0</sup>. Mercuric chloride does not react with the sulfuric acid, but is dissolved in sulfuric acid.

## FIELD TEST RESULTS

To date, composite carbon/lime pellets have replaced granular carbon in moving bed filters at a sludge incinerator (hazardous waste), a "green food" dryer, a foundry, and a soil treatment plant. Due to the competitive business these plants are in and the contractual obligations associated with the manufactures of the moving bed filters, Märker cannot presently publish the actual emission data. However, we can acknowledge that these facilities are currently meeting the strict German Federal emission regulations. For informational purposes Table 2 is a comparison in European units of Germany's emission regulation for waste management facilities and U.S. EPA's emission standards for new large MWC's. Table 3 is a tabulation of emission standard for hazardous waste facilities in Europe and Table 4 is a summary of U.S. EPA's proposed emission standards for hazardous waste facilities. Based on the test data currently available, the composite carbon/lime pellets used in a moving bed filter as a police filter will easily meet the U.S. EPA emissions regulations as well as the more stringent German and European standards.

The Institute of Gas Technology (IGT) has undertaken a development program of converting contaminated sludges from U.S. harbors and turn them into saleable "tiles". IGT has several combustion technologies that they employ to slag the harbor dredging and to destroy the organics which include PCB's and dioxins. In IGT's pilot plant test program, they wanted to ensure that they had effective methods to capture organics that were a result of incomplete combustion. IGT evaluated both a fixed carbon bed and a fixed bed of composite carbon/lime pellets to control the off gases from their process. At the time of the writing of this paper, the pilot plant test has been complete, however, the laboratory work still requires several months to confirm that European and U.S. experience coincide.

## CONCLUSIONS

Carbon adsorption has been developed into a proven and effective method of controlling various hazardous pollutants to extremely low levels. The use of carbon as a collection medium in a moving bed filter has resulted in operating problems at various facilities. Typically for combustion sources, temperature excursions have resulted fires. Consequently, the selection and use of pelletized adsorbent formulations such as composite carbon/lime pellets has demonstrated the capability to replace activated carbon and to mitigate their safety and material handling problems although still in the developmental stage.

There are many other potential applications yet to be developed for composite carbon/lime's use as the adsorbent medium in a police or polishing filter as technology develops. At a U.S. EPA workshop on Dioxins held in Washington in December, 1996 a number of industrial and combustion sources of dioxin emissions were identified. Moving bed filters using carbon based sorbents could be potentially utilized widely in many of these industrial applications.



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4. A. Licata, M. Babu, W. Carlson " The Application of Activated Carbon Enhanced Lime for Controlling Acid Gases, Mercury, and Dioxins form MWCs," American Chemical Society, Spring Meeting, New Orleans, 1996
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Table 1. Sorbalit research test data.

Test No.	Reaction Conditions (Adsorbent Weight, mg)	Adsorbent	Reactor Temp °C	HgCl <sub>2</sub> Solution			Hg Total Quantity In µg	Hg Total Quantity Out µg	% Hg Removal
				Hg Content µg/g	HCl Content mg/g	Solution Metered g			
1A	250	Sorbalit with 5% lignite coke	180	1.7	125	4	6.8	0.49	92.8%
1B	250		180	1.7	125	4	6.8	0.19	97.2%
1C	250		180	1.7	125	4	6.8	0.13	98.1%
Average Test 1			180	1.7	125	4	6.8	0.27	96.0%
2A	250	Dravo Lime pellets: 5% Carbon 0.5% Sulfur 5% Bentoni te	180	1.7	125	4	6.8	0.32	95.3%
2B	250		180	1.7	125	4	6.8	0.14	97.9%
2C	250		180	1.7	125	4	6.8	0.13	98.1%
Average Test 2			180	1.7	125	4	6.8	0.20	97.1%

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Table 2. German and U.S. EPA standards for MWCs

<sup>(1)</sup> (metric units corrected to 11% O<sub>2</sub>).

Pollutant		Germany Bundesgesetzblatt - 1990 All Sized Units		U.S. EPA Promulgated 12/95 New Large Units
SO <sub>2</sub>	mg/Nm <sup>3</sup>	200	50	61 or
	% reduction	N/A	N/A	80%
	Avg. time-hrs.	0.5	24	24
HCl	mg/Nm <sup>3</sup>	60	10	28 or
	% reduction	N/A	N/A	95%
	Avg. time-hrs.	0.5	24	24
PM	mg/Nm <sup>3</sup>	30	10	18.3
	Avg. time-hrs.	0.5	24	-
Cd	mg/Nm <sup>3</sup>	Included in Class I Metals <sup>(2)</sup>	0.05	0.0153
Pb	mg/Nm <sup>3</sup>	Included in Class III Metals	0.5	0.153
Hg	mg/Nm <sup>3</sup>	Included in Class II Metals	0.05	0.061 or
	% reduction	-	N/A	85%
	Avg. time-hrs.	-	>60 min.	-
Dioxin Furan <sup>(3)</sup>	ng/Nm <sup>3</sup> TEQ	-	0.1 <sup>(4)</sup>	≈0.2 <sup>(5)</sup>
	ng/Nm <sup>3</sup> mass	-	N/A	13
	Avg. time-hrs.	-	>500 min.	-
NOx	mg/Nm <sup>3</sup>	400	200	219
	Avg. time-hrs.	0.5	24	24
CO	mg/Nm <sup>3</sup>	100	50	89
	Avg. time-hrs.	1	24	4

<sup>(1)</sup> All emission data based on mass burn water wall technology

<sup>(2)</sup> Class I Heavy Metals: Cd & Tl

Class II Heavy Metals: Hg

Class III Heavy Metals: As, Co, Cr, Cu, Mn, Ni, Pb, Sb, Sn, & V

<sup>(3)</sup> U.S. EPA dioxin standards are on a mass basis. There is no direct correlation to TEQs and only an approximate conversion can be made with a ± error.

<sup>(4)</sup> Germany requires a minimum combustion zone temperature of 850°C for 2 seconds.

<sup>(5)</sup> U.S. EPA requires control of temperature at APC system.

Table 3. HWI emission guidelines for some European countries (mg/Nm<sup>3</sup> dry at 11% O<sub>2</sub>).

Basis	Federal Republic of Germany 17th BImSchV 11/90		Netherlands BLA 1993	EC Directive	
	Corrected only when >11% O <sub>2</sub>		Corrected at All Times	max. ½ hr.	24 hr. Max
Measurement	24 hr. avg	max. ½ hr.	max. 1 hr. mean		
HCl	10	60	10	10	5
SO (SO <sub>2</sub> + SO <sub>3</sub> )	50	200	40	50	25
HF	1	4	1	2	1
NO <sub>x</sub> (NO <sub>2</sub> )	200	400	70	-	-
CO	50	(hr.) 100	(Boiler) 50	-	50
C (organic)	10	20	10	10	5
Particulate	10	30	(8 hr. avg.) 5	10	5
Heavy Metals					
Class I	Cd + Tl $\sum$ = 0.05 (>.5 hr.)		Hg = 0.05 (8 hr. avg.)	Cd + Tl $\sum$ = 0.05 (>.5 hr.)	
Class II	Hg = 0.05 (>.5 hr.)		Cd = 0.05 (8 hr. avg.)	Hg = 0.05 (>.5 hr.)	
Class III	Sb,As,Pb,Co,Cr,Cu, Mn,V,Sn,Ni $\sum$ = 0.5 (>.5 hr.)		Sb,As,Pb,Co,Cr, Cu,Mn,V,Sn,Ni, Te, Se $\sum$ = 1.0 (8 hr. avg.)	Sb,As,Pb,Co,Cr,Cu, Mn,V,Sn,Ni $\sum$ = 0.5 (>.5 hr.)	
PCDD/PCDF (ng/Nm <sup>3</sup> )	0.1 I-TEQ > 500 min.		0.1 I-TEQ (8 hr. avg.)	0.1 I-TEQ <sup>(6)</sup> (8 hr. avg.)	
Combustion Temperature	1200°C >2 sec.		850°C at >6%O <sub>2</sub> >2 sec.	850°C at >6%O <sub>2</sub> >2 sec.	

<sup>(6)</sup> Guideline only.

Table 4. U.S. EPA Emission Limits for Hazardous Waste Combustors (Proposed 4/96)

Pollutant	Averaging Time <sup>(5)</sup>	Units	Emission Limit <sup>(1)</sup>					
			Incinerator		Cement Kiln		Lightweight Aggregate Kiln	
			Existing	New	Existing	New	Existing	New
PM <sup>(7)</sup>	CEMS - 2 hours	mg/dscm (gr/dscf)	69 (0.030)	69 (0.030)	69 (0.030)	69 (0.030)	69 (0.030)	69 (0.030)
Dioxins / Furans <sup>(2) (6)</sup>	stack test	ng/dscm	0.20	0.20	0.20	0.20	0.20	0.20
Hydrocarbons <sup>(7)</sup>	CEMS - hourly	ppmv	12	12	20 <sup>(3)</sup> <sup>(4)</sup>	20 <sup>(3)</sup> <sup>(4)</sup>	14	14
CO <sup>(7)</sup>	CEMS - hourly	ppmv	100	100			100	100
HCl + Cl <sub>2</sub> <sup>(7)</sup>	CEMS - hourly	ppmv	280	67	630	67	450	62
Hg <sup>(7)</sup>	CEMS - 10 hours	μg/dscm	50	50	50	50	72	72
	stack test or	μg/dscm	-	-	-	55	12	5.2
Semivolatile Metals (Pb, Cd) (sum) <sup>(7)</sup>	CEMS - averaging times vary	μg/dscm -	270 12 hours	62 10 hours	57 10 hours	60 10 hours	60 10 hours	60 10 hours
	stack test or	μg/dscm	-	60	-	44	-	55
Low Volatility Metals (As, Be, Cr, Sb) (sum) <sup>(7)</sup>	CEMS - 10 hours	μg/dscm	210	80	130	80	340	80

(1) All limits are corrected to 7% oxygen and 20°C.

(2) TEQ basis.

(3) The limit given is for the main stack, with the option of meeting a 6.7 ppmv by-pass duct limit.

(4) The limit for the by-pass duct is 100 ppmv; there is no applicable CO limit for cement kiln main stacks.

(5) Average time based on "rolling averages."

(6) Based on confirmatory test under normal conditions.

(7) Determined during comprehensive test (an operating condition that will result in higher than normal emissions).

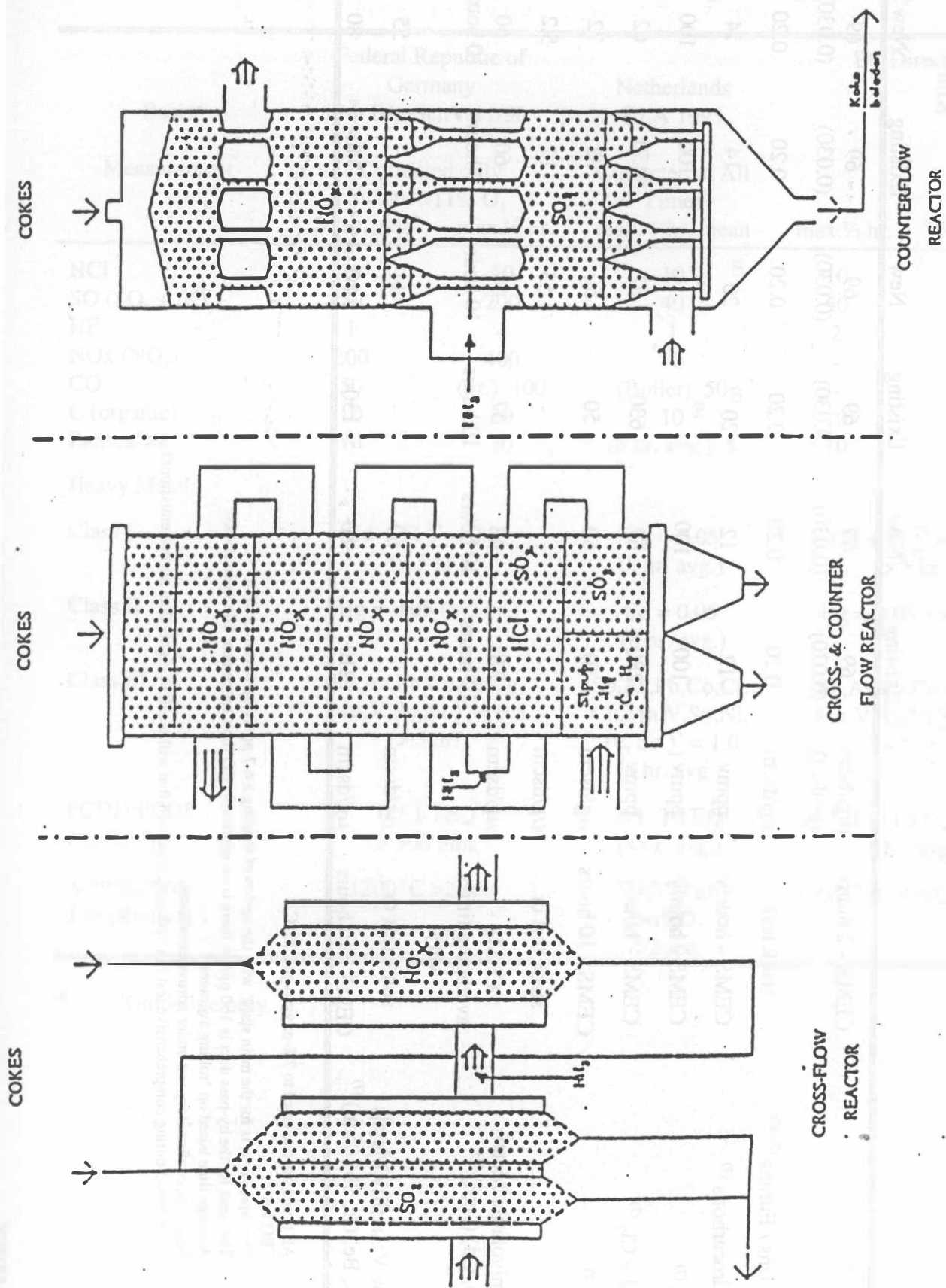


Figure 1. Various moving bed filter configurations.

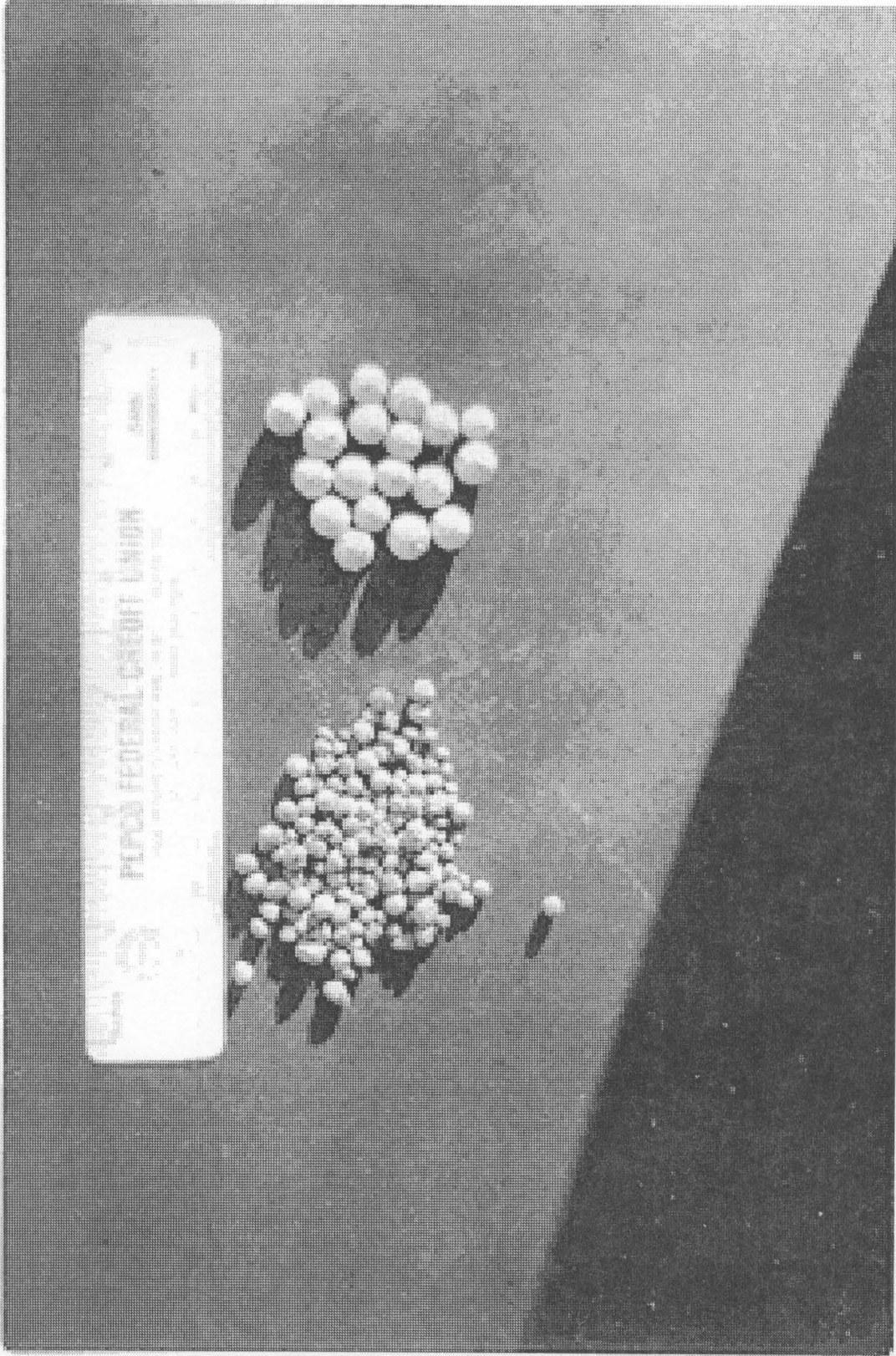


Figure 2. Photograph of Sorbalit Pellets

PEER-REVIEW