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AIR POLLUTION BY INTERMEDIATE DUST REMOVAL AT MEDICAL WASTE INCINERATORS

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Abstract

Medical incinerators that meet the emission standards for PCDD/F of less than 0.1 ng TEQ/m^3 were installed last five years in Hungary and Poland. The system is featured by hot gas filters between the pyrolysis and the afterburner chamber. Reagent is in front of this filter. Two polishing filters using zeolite and coke, respectively, follow the waste heat boiler.

Keywords: air pollution control, medical waste, incineration, hot gas filter.

Introduction

In the past, medical waste incinerators operated largely without requirements for add-on pollution control equipment or combustion modification techniques (BUONICORE, 1992). Although much research (FIEDLER, 1993; ALTWICKER, 1993; FÄNGMARK, 1993; NAIKWAIDI et al., 1993; REIMANN, 1992; DICKSON et al., 1992; HALÁSZ, 1991; OAKLAND, 1988) has been conducted to study the formation of dioxins and furans, there is still no clear evidence which mechanism is dominating during medical waste incineration processes. Nevertheless, it is clear that the generation of PCDD/F occurs as a consequence of incomplete combustion of the raw gases or their particles, especially in the cooler zones, between temperatures 250 and 450 °C.

There are plenty of methods based on filter techniques regarding the emissions of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDDs and PCDFs) from waste incineration. This paper gives some information of another possible solution. It has been used for preventing of formation of PCDD/Fs and other toxic organic micropollutants (TOMPs). We give a brief summary of our results of the last five years.

Experimental

Our R&D activities began in the middle of 1980s and have continued since it was decided to develop a new technology by innovation of existing, well-known processes. In order to evaluate our efforts and developments the hospitals seemed to be ideal sites for the projects. They are generally situated in downtown. An innovative technology, namely MESTER Treatment System (shown schematically in *Fig. 1*), was chosen and put into practice.

Each of our experiments was conducted by operating full-scale medical waste incinerator (MedWI).

The management problem was solved in the following way. Local thermal treatment (in situ) was applied by incineration of medical wastes. Residues (slag and fly ash) and spent materials (exhaust zeolite) were collected, stored separately, and transported to a licensed hazardous waste disposal site.

The capacity of the neutralisation system was based on the maximum daily special waste quantity of the hospital, considering continuous operation. It was impossible to get exact data of waste composition. We evaluated the plastic content at 30 per cent, but did not know the quantity of PVC.

The experimental set-up is shown in *Fig. 1.*

The theory was based on separating dust and other inorganic solid particles from the gas stream immediately downstream from the primary chamber (1) (which may be either a combustion or a pyrolytic chamber), this results in less load for the afterburner chamber (4) (ABC). Moreover, it eliminates the possibility of toxic organic micropollutants (TOMPs) formation.

The primary chamber (1) was followed by mechanical separators (3.1) (cyclones) for removal of larger solid particles (more than 10 microns) and a hot ceramic gas filter (3.2) for fine particles (less than 10 microns). The material of the filter candles was light density ceramic. Reverse pulse jet blowing was used for removing the dust cake, controlled by monitoring the pressure drop through the filter.

Prior to these separators, in a reaction chamber (3), dry lime injection was used to remove hydrochloric acid (HCl) gas from the flue gas. Reaction products and excess reagent particles were retained in the ceramic filter (3.2) together with dust. Next, the partly cleaned flue gas entered the ABC (4), where the remaining combustible organic material was burnt out.

One of the most important requirements of the air pollution control system is to provide quick, efficient cooling (quench) of the gas from the incinerator (FOSTER, 1993). Following the ABC (4), a waste heat boiler (5) was used to produce saturated steam (0.3 bar and 10 bar, respectively).

A 3-stage-scrubber (7), consisting of a Venturi scrubber (7.1) operated acid washing liquid, a packed tower (7.2) in a basic washing circle and an aerosol removal unit (7.4) was designed for cooling of the gas, to absorb the acidic components and to remove the very fine particles. After the scrubber (7), the cooled and purified flue gas was reheated by means of heat exchangers. On the other hand, in a heat exchanger this relatively cooler gas helped to decrease the temperature of the gas coming from the waste heat boiler (5). Moreover, it reduces the amount of water to be injected into the gas, which is important where water is at a premium (BUEKENS, 1984). In a secondary air pollution control system (7.5) (APCS) dry sodium bicarbonate ($NaHCO_3$) powder was mixed with zeolite for removal of the remaining HCl and SO_2, and for adsorption of heavy metals. A coke bed filter (7.6) also was used, for adsorption of TOMPs.

Finally, an ID fan (8) pulled the flue gas from the system (creating a slight depression) and discharged it into the atmosphere via a chimney (6).

During the tests, waste in bags or containers representing all the departments of the hospital with a plastics content of 30% was incinerated. The maximum emission values never exceed the emission limits. The temperature of the primary chamber and ABC remained fairly constant, between 510 and 560 °C, respectively 1180 and 1230 °C.

Experimental Set-up

The new multiple-stage system has the following main components :

1. Feeder

A pneumatic feeder is for replenishing the primary chamber with waste during combustion cycle.

2. Primary Chamber

The primary chamber allows thermal decomposition of organic material into combustible gases and a carbon rich char by operating with starved air. The chamber is a vertical cylinder with an air cooled, welded, steel shell and reinforcing profiles, internally lined with a fire resistant refractory concrete moulding that is separated from the steel construction by a second layer of insulating material.

A start-up burner is operated with natural gas, and primary air is distributed via numerous small holes at the bottom producing approximately

600 °C operating temperature in the primary chamber. Its effective volume was approximately 4 m^3. Incineration capacity was from 80 to 110 kg of medical waste per hour.

3. *Reaction Chamber*

A chamber was used to ensure room for reaction of injected Ca-based reagent and the gas generated in the primary chamber. Dry lime for neutralisation was injected with air at a rate of 2 to 4 kg/h immediately before the cyclone and the hot gas filter used for primary dust removal. Following the primary filter a gas burner restored lost heat and a second burner in the ABC maintained the required temperature.

3.1 Mechanical Separators

Mechanical separators (cyclones) were used for removal of larger solid particles (more than 10 microns) from the gas.

3.2. Hot Gas Filter

Light density ceramic candles filtered the fine particles (less than 10 microns) from the hot gas. Reverse pulse jet blowing was used for removing the dust cake, controlled by monitoring the pressure drop through the filter.

4. *Afterburner Chamber (ABC)*

An ABC was for complete combustion of the pyrolysis gases at a temperature of approximately 1150 °C. The residence time was more than 2 seconds for the gases. Effective volume was nearly 4.8 m^3. The increased temperature, residence time, enhanced turbulence, graduated secondary air introduction, avoiding CO peaks and high oxygen surplus, ensuring no cold blowing effects (through preheating of combustion air) were together to destroy products of incomplete combustion (PICs) and to prevent formation of PCDD/PCDF.

5. *Waste Heat Boiler*

A heat recovery boiler was able to generate saturated steam from the exhaust gases. It consisted of coil pipes and refractory concrete lined exhaust gas inlet and outlet in horizontal position. The boiler was equipped with fine armatures. Its heating capacity was from 300 to 900 kW at an operating pressure of steam of 0.5 bar and 10 bar, respectively. Special design guaranteed an effective cooling section for the flue gas, the so-called quenching effect.

6. Scrubber

A 3-stage wet scrubber system was designed combining with a dry scrubber for achieving a perfect air pollution control (APC). The pH value in the acid circle of the Venturi was about 1, and it was approximately pH = 8 in the basic circle of the packed tower.

In the most cases there were no need to operate the former one. The latter one was able to control emission of particulate matter and absorb acid gases too. It was designed with adsorption filters for the removal of noxious gases, heavy metals, very fine dust particles and dioxins/furans of the exhaust gases.

Zeolite and coke were used to adsorb the foregoing materials. The first adsorption filter filled with natural zeolite originated from Tokaj Mountain has a large chemisorptive capability. Beside the zeolite was installed a second filter filled with coke. Both of them were cross-current filters. The depth of the zeolite bed was about 800 mm, and the same for the coke bed. Beyond adsorptive processes they worked as auxiliary dust filters, too.

Monitoring

There was a monitoring system supported by automatic gas sensors and analysers to guarantee meeting the emission standards.

Sampling and analysing procedures were done by the National (Hungarian) Environmental Protection Institute and the Technical University of Cracow, respectively, using modern analytical methods. Dioxins and furans were determined with the following equipment :

Apparatus : HP-5890 A/HP-5970 MSD
Colonna : ULTRA-2 Type 25 × 0.2 mm quartz capillary tube
Injector : 300 °C splitless
Carrying gas : 1 ml helium/min
Detection : by SIM program
Column operation : at 105 °C for 1 min
25 °C/min heating velocity by 300 °C
at 300 °C for 25 minutes

All gas volumes are reported in normal m^3. Dioxins are reported in ng/m^3 of dry gas.

Results and Discussion

Results are shown in *Tables 1–10*. (*Remark*: The Cracow University did not issue the detailed measuring parameters, only the average values.)

Emission controls for PCDD/PCDF at the less than 0.1 ng TEQ/m^3 level have been discussed widely, and range from good combustion practice to inhibitors to addition control devices. We tried to answer the question how can PCDD/PCDF concentrations be controlled.

As can be seen in *Table 1* to *Table 10*, the results obtained from testing the presented treatment system indicate a good suitability for neutralisation of medical wastes, and purification of its flue gases.

The mean values of contamination of flue gases never exceeded the allowed emission limits. Sometimes their values were more than one order of magnitude below the standards.

We assumed the good results were obtained first by correct site of dry lime injection, and removal of solid particles prior to the afterburner chamber. Then there was immediate dust filtration after injection of sorbent powder. In addition, due to the reduction of the possible starting sites of formation of dioxins and furans, concentrations of TOMPs were practically totally eliminated from the gas stream.

Conclusions

A series of tests with intermediate dust removal has been conducted in the last five years in Hungarian and Polish hospitals for neutralisation of medical wastes. The process substantially decreased all kinds of the emissions of the medical waste incinerator (MedWI), as it was reported by the testing institute. The comparison between the investigated system and other existing incineration methods is more than satisfactory. The results have been valuable for demonstration of the feasibility of this innovated thermal treatment of the medical wastes. The treatment process makes possible a safe and practical technology for excellent total cost efficiency. Additional research is called for to determine the effects of particle size distribution, special surface area, and residence time on the system.

Table 1
Solid Particles in Dry Standard Gas

Experiment	A	B	C	D	E	F	G	H
Sampling	Computed conc. for 17 vol.% of O_2 mg/m^3	Computed conc. for 17 vol.% of O_2 mg/m^3	Computed conc. for 17 vol.% of O_2 mg/m^3	Computed conc. for 11 vol.% of O_2 mg/m^3	Computed conc. for 11 vol.% of O_2 mg/m^3	Computed conc. for 17 vol.% of O_2 mg/m^3	Computed conc. for 11 vol.% of O_2 mg/m^3	EU Emission Limit for 11 vol.% of O_2 mg/m^3
1. 30' sampling		6.3	10.2			1.72		
2. 30' sampling		5.4	7.6			2.23		
3. 30' sampling		4.8	2.2					
4. 30' sampling		5.6	1.8					
5. 30' sampling		6.7	1.1					
6. 30' sampling		7.5	0.5					
7. 30' sampling		6.7	1.0					
8. 30' sampling		5.2	1.4					
9. 30' sampling		5.1	1.2					
Average	14	5.9	3.0	< 0.1	< 0.1	2.0	$0.1 - 1$	
Emission Limit		30						10

Table 2

Concentration of Sulphur Dioxide

Experiment	A	B	C	D	E	F	G	H
Sampling	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 11 vol.% of O_2 mg/m^3	Computed concentration for 11 vol.% of O_2 mg/m^3	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 11 vol.% of O_2 mg/m^3	EU Emission Limit for 11 vol.% of O_2 mg/m^3
1. 30' sampling	67.3	10	1.1			3.74		
2. 30' sampling	20.1	9	1.0			3.71		
3. 30' sampling	59.6	12	1.0			9.44		
4. 30' sampling	34.7	7	1.0			4.93		
5. 30' sampling	101.3	3	1.0			7.36		
6. 30' sampling	27.2	5	1.1			8.42		
7. 30' sampling	19.1	3	1.3			13.37		
8. 30' sampling	50.2	1	1.1			4.68		
9. 30' sampling	58.5	2	1.2			6.56		
10. 30' sampling	21.4	1	1.2					
Average	45.9	5.3	1.1	< 1	< 1	6.91	< 1	
Emission Limit		200						50

Table 3

Concentration of Carbon Monoxide

Experiment	A	B	C	D	E	F	G	H
Sampling	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 11 vol.% of O_2 mg/m^3	Computed concentration for 11 vol.% of O_2 mg/m^3	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 11 vol.% of O_2 mg/m^3	EU Emission Limit for 11 vol.% of O_2 mg/m^3
1. 30' sampling	39	11	97.6			7.28		
2. 30' sampling	13	7	7.9			5.19		
3. 30' sampling	9	14	3.8			4.88		
4. 30' sampling	9	7	5.1			4.43		
5. 30' sampling	10	23	3.1			3.88		
6. 30' sampling	(268)	8	9.6			4.29		
7. 30' sampling	76	15	2.0			12.43		
8. 30' sampling	13	14	1.9			2.28		
9. 30' sampling	7	5	1.9			2.05		
10. 30' sampling	(165)	5	1.9					
Average	22 (60.9)	10.9	13.5	4	1	5.19	< 1	
Emission Limit		100						50

Table 4

Concentration of Oxygen

Experiment	A	B	C	D	E	F	G
Sampling							
1. 30' sampling	14.8	10.7	14.0			11.87	
2. 30' sampling	12.6	10.3	13.6			11.70	
3. 30' sampling	12.1	8.6	12.8			11.56	
4. 30' sampling	12.9	10.5	13.1			12.25	
5. 30' sampling	12.4	9.5	13.4			12.19	
6. 30' sampling	13.9	13.5	13.6			12.11	
7. 30' sampling	12.4	13.9	13.6			12.22	
8. 30' sampling	13.4	9.5	13.7			11.96	
9. 30' sampling	13.4	7.6	13.9			12.14	
10. 30' sampling	12.3	8.4	13.7				
Average	13.0	10.2	13.5	12.5	7.8	12.00	14.8–17

Experimental Set-up Parameters

Throughput : 80 – 110 kg/h of medical waste
Natural gas consumption of the ABC : max. 30 m^3/h
Temperature of the primary chamber : 500 – 600 °C
Temperature of the afterburner chamber (ABC) : 1.150 ± 50 °C
Residence time in ABC : 2–3 seconds
Thermal rating : 300 – 500 kW
Flue gas temp. at the outlet : max. 200 °C
Flue gas stream : max. 0.3 m^3/s (1.100 m^3/h)

Experiments :

A: 24th September 1991 Semmelweis Hospital (Kiskunhalas, Hungary)
B: 9th February 1994 Markhot Ferenc Hospital (Eger, Hungary)
C: 13th December 1994 Bugát Pál Hospital (Gyöngyös, Hungary)
D: 10th/11th February 1995 Skierniewice Hospital (Poland)
E: 16th June 1995 Lódz Hospital (Poland)
F: 10th January 1996 Szent György H. (Székesfehérvár, Hungary)
G: 20th April 1996 Oncology Centre (Bydgoszcz, Poland)
H: Emission Limits of the European Union (EU)

Measuring Institutes:
A, B, C and F : KGI-KVI Environmental Protection Institute (Budapest, Hungary)
D, E and G : Technical University of Cracow (Cracow, Poland)

Table 5
Concentration of Nitrogen Oxides

Experiment	A	B	C	D	E	F	G	H
Sampling	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 11 vol.% of O_2 mg/m^3	Computed concentration for 11 vol.% of O_2 mg/m^3	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 11 vol.% of O_2 mg/m^3	EU Emission Limit for 11 vol.% O_2 mg/m^3
1. 30' sampling	207.7	47	11.7			68.33		
2. 30' sampling	150.6	43	13.7			46.02		
3. 30' sampling	141.4	45	15.5			33.25		
4. 30' sampling	219.0	42	15.7			33.41		
5. 30' sampling	130.8	44	15.2			29.52		
6. 30' sampling	245.6	46	13.0			27.78		
7. 30' sampling	260.4	50	10.9			30.41		
8. 30' sampling	190.2	54	10.6			27.69		
9. 30' sampling	245.6	33	11.5			30.41		
10. 30' sampling	209.4	30	11.6					
Average	200.0	43.4	12.9	37	33	36.31	130	
Emission Limit		400						200

Table 6
Concentration of Hydrogen Chloride

Experiment	A	B	C	D	E	F	G	H
Sampling	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 11 vol.% of O_2 mg/m^3	Computed concentration for 11 vol.% of O_2 mg/m^3	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 11 vol.% of O_2 mg/m^3	EU Emission Limit for 11 vol.% of O_2 mg/m^3
1. 30' sampling	31.7	4.1	12.2			< 3.2		
2. 30' sampling	5.5	1.6	7.2			< 2.9		
3. 30' sampling	71.8	8.1	7.6			18.5		
4. 30' sampling	11.6	3.3	6.7					
5. 30' sampling		4.6	8.2					
6. 30' sampling		2.1	8.5					
7. 30' sampling			6.1					
8. 30' sampling			4.4					
Average	30.2	4.0	7.6	0.15	1.2	8.2	2.8	
Emission Limit		50						10

Table 7

Concentration of Hydrogen Fluoride

Experiment	A	B	C	D	E	F	G	H
Sampling	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 11 vol.% of O_2 mg/m^3	Computed concentration for 11 vol.% of O_2 mg/m^3	Computed concentration for 17 vol.% of O_2 mg/m^3	Computed concentration for 11 vol.% of O_2 mg/m^3	EU Emission Limit for 11 vol.% of O_2 mg/m^3
1. 30' sampling	0.25	0.31	0.11			< 1.67		
2. 30' sampling	0.63	0.35	0.12			< 0.59		
3. 30' sampling	0.40	1.6	0.09			< 0.21		
4. 30' sampling		1.3	< 0.07					
5. 30' sampling		1.0	< 0.07					
6. 30' sampling		1.7	< 0.08					
7. 30' sampling			< 0.05					
8. 30' sampling			< 0.04					
Average	0.43	1.04	0.08	0.75	0.55	0.49	0.01	
Emission Limit		2						1

Table 8
Concentration of Noncombusted Organic Compounds

Experiment	A	B	C	D	E	F	G	H
Sampling	Computed concentration for 17 vol.% O_2 expressed in C_1 of mg/m^3	Computed concentration for 17 vol.% O_2 expressed in C_1 of mg/m^3	Computed concentration for 17 vol.% O_2 expressed in C_1 of mg/m^3	Computed concentration for 11 vol.% O_2 expressed in C_1 of mg/m^3	Computed concentration for 11 vol.% O_2 expressed in C_1 of mg/m^3	Computed concentration for 17 vol.% O_2 expressed in C_1 of mg/m^3	Computed concentration for 11 vol.% O_2 expressed in C_1 of mg/m^3	EU Emission Limit for 11 vol.% O_2 expressed in C_1 of mg/m^3
1. 30' sampling	29.0	2.0	2.68			0.16		
2. 30' sampling	4.9	3.2	0.83			0.24		
3. 30' sampling	15.7	2.8	0.48			0.24		
4. 30' sampling	7.6	0.8	0.58			0.14		
5. 30' sampling	29.7	2.4	0.65			0.21		
6. 30' sampling	5.7	1.5	0.56			0.44		
7. 30' sampling	5.5	2.1	0.38			0.47		
8. 30' sampling	6.6	1.7	0.28			0.22		
9. 30' sampling	11.4	0.2	0.22			0.16		
10. 30' sampling	7.9	0.1	0.13					
Average	12.4	1.7	0.7	15.35	11.6	0.25	2	
Emission Limit		20						20

Table 9
Concentration of Toxic Metals

Experiment	A	B	C	D	E	F	G	H
Toxic Metals	Computed concentration for 17 vol.% of O_2 $\mu g/m^3$	Computed concentration for 17 vol.% of O_2 $\mu g/m^3$	Computed concentration for 17 vol.% of O_2 $\mu g/m^3$	Computed concentration for 11 vol.% of O_2 $\mu g/m^3$	Computed concentration for 11 vol.% of O_2 $\mu g/m^3$	Computed concentration for 17 vol.% of O_2 $\mu g/m^3$	Computed concentration for 11 vol.% of O_2 $\mu g/m^3$	Hungarian (H) EU Emission Limit O_2 $\mu g/m^3$
Hg	18	10	0.18	0.08	1.5	< 0.001	< 0.1	100 (H) 50 (EU)
Cd		0.037	0.15	0.4	0.5	0.01	0.5	50 (EU)
Tl		< 0.05	< 0.04			< 0.04		
Total	< 14	< 0.087	0.19			< 0.05		100 (H)
As		0.7	0.30	0.2	4	2.24	20	
Se		< 0.1	< 0.84			< 0.8		
Ni		0.47	0.58	11.2	8	0.25	10	
Co		0.01	0.07	0.03	0.5	< 0.05	0.5	
Te		< 0.027	0.04			< 0.04		
Total	< 5.7	< 1.3	< 1.83			< 3.38		1000 (H)
Fe				31.1	311		70	
Pb		0.08	3.27	78.8	95	1.08	120	
Cr		0.3	1.18	0.3	46	0.23	45	
Cu		0.04	7.96			0.82		
V		1	0.17			0.14		
Sn		0.5	4.02			< 0.84		
Mn		0.2	0.42	0.3	2	0.22	5	
Sb		0.5	< 1.26			< 1.27		
Total	320	2.4	< 18.28			< 4.7		1000 (H)
Total of Ni, Cr, Pb, Fe, Mn, Co and As				120	466.5		270.5	500 (EU)

Table 10

Concentration of Polychlorinated Dibenzo-p-dioxins and Polychlorinated Dibenzofurans (PCDDs and PCDFs) in the Sample

Experiment	A	B	C	D	E	F	G	H
Sampling	Computed concentration for 17 vol.% of O_2 expressed in 2,3,7,8-TCDD ng/m^3	Computed concentration for 17 vol.% of O_2 expressed in 2,3,7,8-TCDD ng/m^3	Computed concentration for 17 vol.% of O_2 expressed in 2,3,7,8-TCDD ng/m^3	Computed concentration for 11 vol.% of O_2 expressed in 2,3,7,8-TCDD ng/m^3	Computed concentration for 11 vol.% of O_2 expressed in 2,3,7,8-TCDD ng/m^3	Computed concentration for 17 vol.% of O_2 expressed in 2,3,7,8-TCDD ng/m^3	Computed concentration for 11 vol.% of O_2 expressed in 2,3,7,8-TCDD ng/m^3	EU Emission Limit for 11 vol.% O_2 expressed in 2,3,7,8-TCDD ng/m^3
Average	0.0739	$\ll 0.0049$	$\ll 0.0048$	0.079	0.05	< 0.014	0.015	< 0.1

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