# CLEANING OF MUNICIPAL WASTE INCINERATOR FLUE GAS IN EUROPE

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## ABSTRACT

This paper presents an overview of a substantial ongoing air pollution control program activity in West Germany as it relates to emission of acid gases and other pollutants from municipal refuse incineration. Details are given of emission regulations, control means used, and technical advancements accomplished and foreseen. Test results and the approximate effectiveness for various controls in reducing acid gas, trace organic, trace heavy metal, and particulate matter emissions are presented. Available data indicate that lime spray dryer/ESP and spray dryer/fabric filter systems can attain 70–90% acid gas removal and 97% or more control of dioxins and furans while limiting mercury emissions to about 0.01–0.07 mg/$Nm^3$ (dry). In comparison, some wet scrubber systems can attain 90+% acid gas removal, have potential for removal of $NO_x$ and can achieve control of dioxins and furans comparable with semidry scrubbers while possibly providing consistently lower mercury emissions.

## INTRODUCTION

Significant design and operating experience has been gained in Europe over the past 20 years relating to municipal waste incinerator facilities. Approximately 180 such incineration systems, each with a capacity in excess of 200 tonnes per days of municipal refuse,[1] already exist in Europe, principally in West Germany, France, The United Kingdom, Switzerland, Italy, Sweden, Belgium, The Netherlands, and Denmark [1]. West Germany is the leading European country in the amount of municipal waste incinerated, the use of heat recovery facilities, and the number and efficiency of flue gas cleaning facilities. It is anticipated that availability of this European technology will be beneficial in the U.S., since approximately 125 municipal incinerator (resource recovery) projects are in the conceptual stage of development here [2].

## WEST GERMAN EMISSION REGULATIONS

Although incinerator flue gas emission limits for acid gases have been imposed by the federal government since 1974, a more stringent regulation was introduced through the West German "Clean Air Code" (TA Luft) enacted in February 1986 [3]. These new federal emission limits, expressed in mg/$Nm^3$ (approximate ppmv)[2] at 11% $O_2$ concentration are: $SO_2$, 100 (35); $NO_x$, 500 (250); CO, 100 (80); HCl, 50 (31); HF, 2

[1]With an incineration capacity ranging as high as 960 tonnes per day

[2]N denotes "German Standard" conditions: 1.013 bar, 0°C, no moisture (dry gas).

TABLE 1 SELECTED EMISSIONS STANDARDS FOR MUNICIPAL WASTE INCINERATORS [4]

| | U.S.[a] | California | Connecticut | Michigan | West Germany | Sweden |
|---|---|---|---|---|---|---|
| Solid Particulate Matter, gr/dscf (mg/Nm³) | 0.046 (113) | 0.01[b] (25) | 0.015 (37) | 0.015 (37) | 0.012 (30) | 0.008[c] (20) |
| Carbon Monoxide, ppm | --- | --- | --- | 113(24-hr avg) | 80 | --- |
| Hydrogen Chloride | --- | 30 ppmv (wet or dry scrubbers req'd) | 90% reduction | 90% reduction | 31 ppmv (50 mg/Nm³) | 63 ppmv 100 mg/Nm³) |
| Sulfur Dioxide, ppm | --- | 30 | 170[g] | 86 | 35 (100 mg/Nm³) | New SO2 limits reduce all acids significantly[d] |
| Dioxins measured as 2.3.7.8 - tetra-chlorodibenzo-p-dioxins (TCDD) | --- | [e] --- | [f] --- | --- | --- | Existing plants: 0.5-2.0 ng/Nm³ New plants: 0.1 ng/Nm³ |
| Total Organics, Common, Class I, mg/m³ | --- | --- | --- | --- | 20 | --- |
| Mercury + Cadmium + Thallium, mg/m³ (includes vapors) | --- | --- | --- | --- | 0.2 | 0.08 (Hg only) |
| Gas Correction | 12% CO2 dry | 12% CO2 dry | 12% CO2 dry | 12% CO2 dry | 11% O2 dry | 10% CO2 dry |

[a] Revised NSPS for pollutants scheduled to be proposed in 1989.

[b] California regulations permit more stringent local limits. Two state guidelines are reported: 0.01 gr/dscf (25 mg/m³) for total solid particulates (TSP) and 0.008 gr/dscf (20 mg/m³) for particles less than 2 um, where gr=grain.

[c] This limit and those below are from the Swedish Environmental Protection Board's "Temporary Emission Goals", July 1986.

[d] See 6NYCRR 255-1 for limits.

[e] Pollutant control requires use of the Best Available Control Technology (BACT), although no technology has yet been specified.

[f] The use of dry gas scrubbers and baghouses is expected to improve removal over ESPs alone.

[g] 0.32 lbs/MMBtu

(2.2); and total solid particulate, 30 (equivalent to 0.012 gr/dscf). Moreover, group 1 inorganic particulate (cadmium, mercury, and thallium) is limited to 0.2 mg/Nm$^3$; group 2 (arsenic, cobalt, nickel, selenium, and tellurium), to 1 mg/Nm$^3$; and group 3 (including lead), to 5 mg/Nm$^3$. Additionally, limits are imposed on three different groups, differentiated by level of toxicity, of organic vapor and carcinogenic compounds. Table 1, originating from Ref. [4], has been adjusted to give an updated comparison of several of the specific West German emission limits with requirements in the U.S. and Sweden.

## GROSS EMISSION LEVELS

Typical ranges of actual flue gas pollutant emission concentrations from pre-TA Luft incinerator installations in West Germany [5] are given in Table 2. For comparison, emission limits cited above are also shown in this table.

TABLE 2 WEST GERMAN EMISSION LEVELS AND LIMITS, PPMV (mg/Nm$^3$) @ 11% $O_2$

| Pollutant | Incinerator Gross Emissions | TA Luft Emission Limits (2/86) |
|---|---|---|
| HCl | 30-500 (45-770) | 31 (50) |
| HF | 0.5-9 (0.4-8) | 2.2 (2) |
| $SO_2$ | 20-220 (60-620) | 35 (100) |
| $NO^2$ | 70-140 (150-300) | 250 (500) |
| $CO^x$ | 40-500 (45-620) | 80 (100) |
| Solid Particulate Matter, gr/dscf (mg/Nm') | 0.006-0.04 (15-95) | 0.012 (30) |

## FLUE GAS CLEANING METHODS

The earliest European incinerators were equipped with electrostatic precipitators (ESPs), but wet scrubbers have more recently supplemented ESPs extensively in West Germany so as to limit acid gas emissions. To avoid the resulting liquid effluent discharge, spray dryers are now also introduced upstream of a wet alkali scrubbing facility. In this arrangement, the wet scrubber liquid effluent is the liquid feed to the spray dryer. Due to the high HCl concentration in the flue gas and the hygroscopic characteristics of the dry $CaCl_2$ formed from it, acid gases (HCl and $SO_2$) are absorbed at high efficiency by dry scrubbing systems like spray dryer absorbers or dry injection systems using lime as sorbent. Although the uncontrolled $NO_x$ emissions are typically no more than 300 mg/Nm$^3$, substantially less than the new TA Luft limit of 500 mg/Nm$^3$ [6], some new incinerator installations are providing for $NO_x$ removal because of site-specific factors, including anticipation of more stringent local/provincial emission regulations. In the most recent installations, particulate emissions are frequently being controlled by the use of fabric filters in lieu of ESPs.

### Wet Scrubbers

Spray tower and venturi wet scrubbers are commonly used downstream of ESPs to remove HCl, HF, and $SO_2$. HCl and HF are frequently removed in the first scrubber stage (or prescrubber), and $SO_2$ is collected in a separate second scrubber stage. A heat exchanger can be included downstream of the $SO_2$ scrubber to condense water vapor from the water-saturated, cleaned flue gas. This new concept, which is termed subcooling, reduces the visible steam-plume discharge and improves removal of submicrometer (submicron) particles and metallic vapors. Some recent gas cleaning applications have a wet scrubber system (see Fig. 1) downstream of a spray dryer that receives the wet scrubber effluent and converts it to a solid waste. The spray dryer in this configuration is designed to dry only the wet scrubber effluent; it is not designed for significant removal of acid gases.

The system shown in Fig. 1 can be modified to remove $NO_x$. This will be discussed in the section on postcombustion $NO_x$ control.

### Spray Dryer Absorber Scrubbers

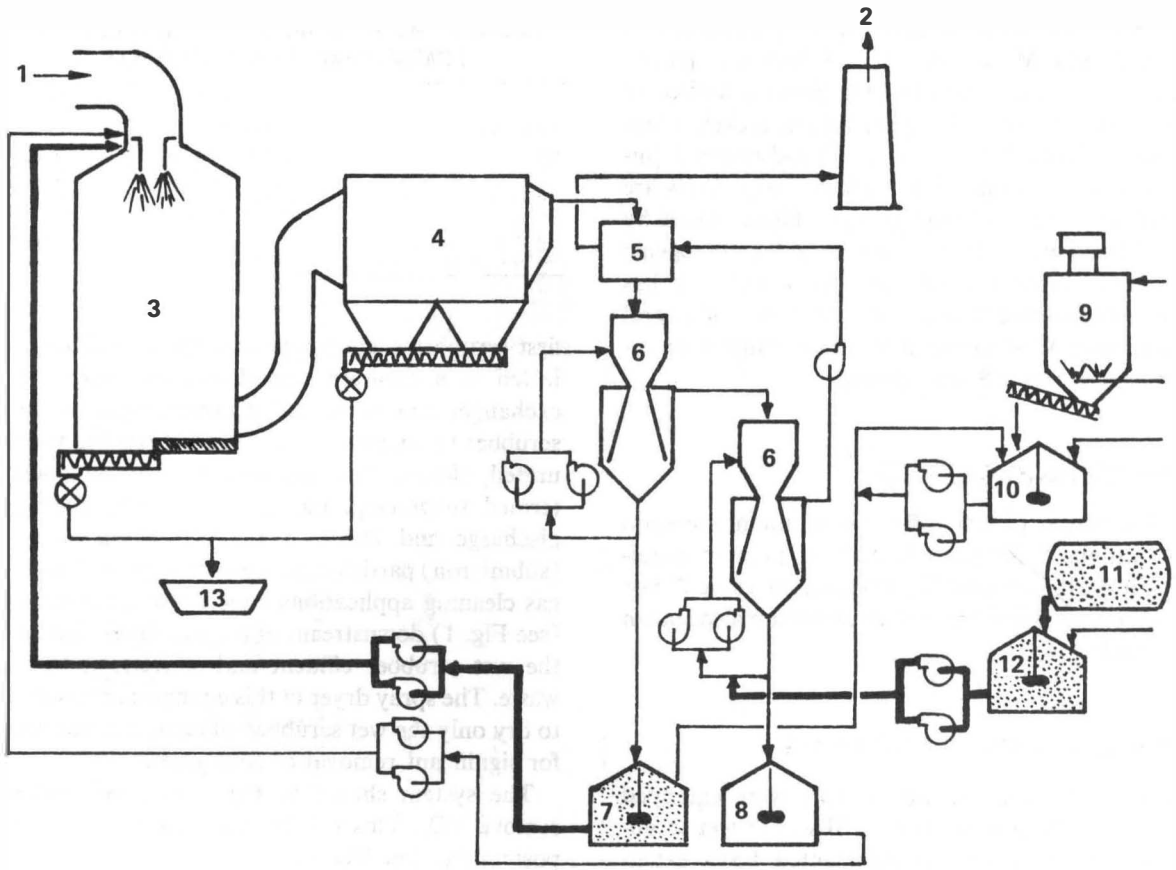
In the common semidry (wet/dry) system design illustrated in Fig. 2, the raw flue gas is contacted with a cloud of fine slaked-lime slurry droplets from a rotary atomizer or dual-fluid nozzles. Employed in conjunction with a downstream fabric filter or ESP, HCl, $SO_2$, and fine particulates can be removed efficiently and effectively.

### Dry Lime Injection

Effective dry absorption of acid gases is possible through pneumatic injection [7] of hydrated lime solely or with recirculated dust-catch into flue gas cooled to 110–170°C (230–335°F), as shown in Fig. 3. A circulating fluid-bed absorption system (see Fig. 4) is also used for dry absorption in incinerator applications, providing significantly increased sorbent residence time upstream of an ESP.

### Major European Installations in Operation

In the results of a mail survey [8] that obtained information on 30 European waste-to-energy facilities




1. FLUE GAS
2. EXHAUST GAS
3. SPRAY DRYER
4. ELECTROSTATIC PRECIPITATOR OR FABRIC FILTER
5. GAS-GAS HEAT EXCHANGER
6. VENTURI SCRUBBER
7. NEUTRALIZATION TANK
8. SLUDGE TANK
9. LIME SILO
10. LIME SLAKER
11. SODIUM HYDROXIDE STORAGE
12. SODIUM AIR TANK
13. DRY WASTE

FIG. 1 SEMIDRY/WET SCRUBBER [4]

in commercial operation using dry scrubbing and/or fabric filtration, many applications of fabric filters, semidry (spray dryer) scrubbers, and dry absorption (dry injection) systems are given and illustrate the extensive use of these types of equipment. This survey indicated a preference for fabric filters over ESPs for particulate matter collection. Table 3 summarizes the results of this survey and includes a number of pilot plant and very small capacity installations. Table 4 is a more complete and recent list of operational commercial systems in West Germany and reflects a substantial proportion (about 60%) of wet scrubber installations [9].

## POLLUTANTS OF SPECIAL CONCERN

### Particulate Matter Control

Particulate matter control for solid waste combustors is practiced in all European countries. With the traditionally used ESPs, very low emission levels are achievable, less than 45 mg/Nm$^3$ (0.02 gr/dscf) at a high ratio of collector plate surface area to gas flow volume [i.e., in the range of 170 m$^2$-min/m$^3$ or min/m (52 min/ft) or greater].

Due to the fine size of incinerator particulates, normal wet venturi scrubbers are relatively ineffective for particle emission control, removing 80–95% in normal

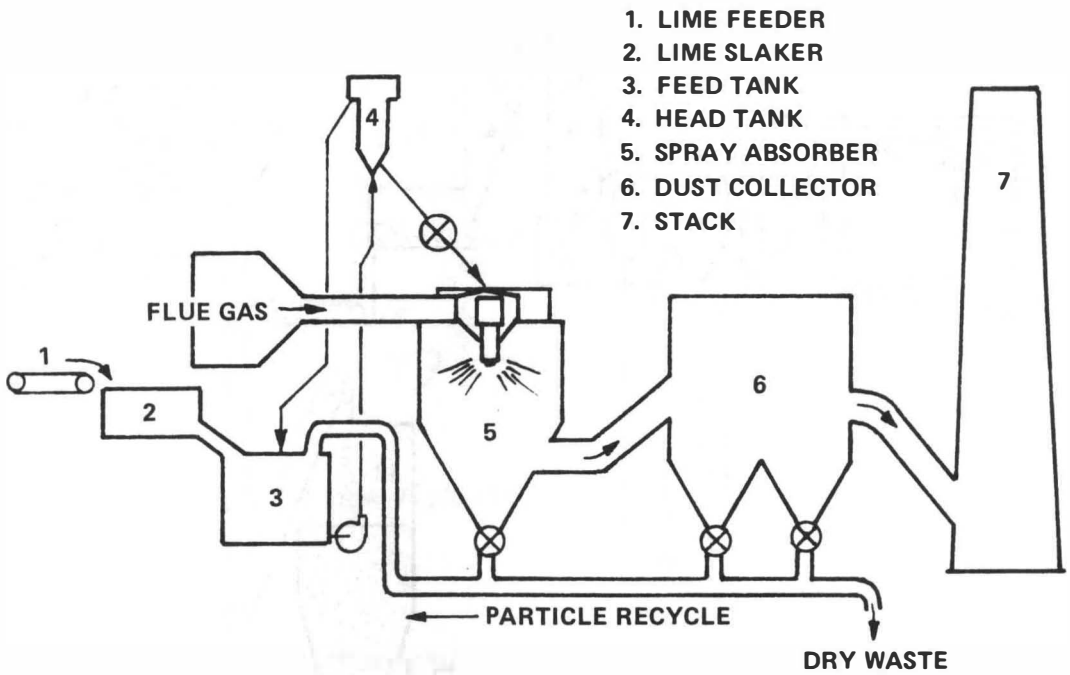



FIG. 2 SPRAY ABSORPTION (SEMIDRY) PROCESS [4]

operation. Very high gas-pressure-drop is required to remove fine particulates; hence, these scrubbers are not generally used as the principal particulate control means.

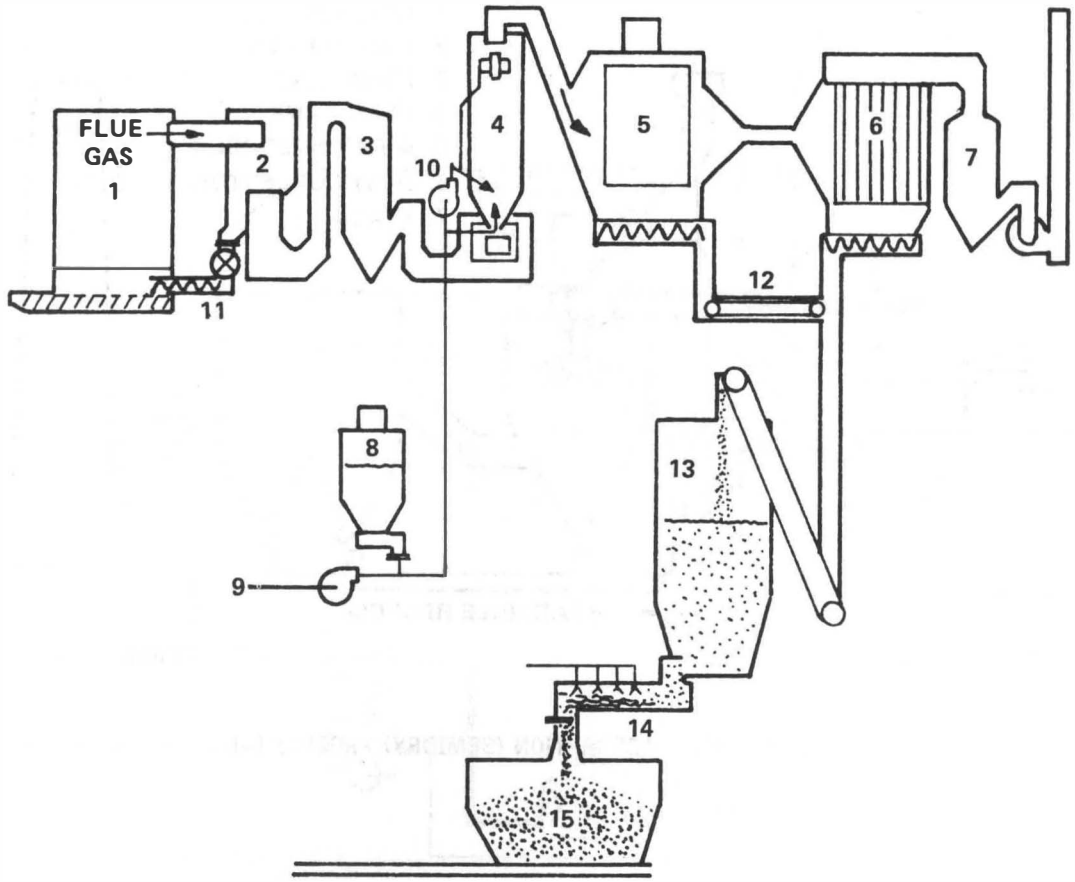
Fabric filters were traditionally used sparingly because of the perceived failures caused by hot gases, spark carryover, or sticky particles. However, fabric filters can control particulate to 45 mg/Nm$^3$ (0.02 gr/dscf) or less without operational upsets due to varying fuel and ash composition, which may adversely affect ESPs. With the increasing use of spray dryer scrubbing systems in Europe, particulate emissions from incinerators are being controlled by highly efficient fabric filters or ESPs.

### Acid Gas Control

Control of acid gases (HCl, HF, and $SO_2$) requires scrubbing or devices for gas/liquid or gas/solid contact. Water alone is a reasonably effective sorbent for very reactive acid gases such as HCl (and HF) in the first scrubber stage, but an alkali sorbent (i.e., control of liquid pH to 5 or higher) and additional liquid/gas contact time in a second stage are necessary for substantial $SO_2$ control. Sodium hydroxide rather than lime/limestone is most often used in the second wet scrubbing stage to avoid scaling. (The sodium sulfite reaction product is water soluble as contrasted with calcium sulfite, which is highly insoluble.) Highly efficient control of acid gases may be achieved by alkali wet scrubbers operating at saturation (65°C or 150°F outlet temperature), but typically requires the management of liquid blowdown.

Totally dry sorbents, on the other hand, require substantial residence time in the gas for effective acid gas control. To be effective, injection of sorbent into a duct must be complemented by a fluid-bed reactor, humidification, a fabric filter dust collector, or combinations of these (Figs. 3 and 4).

Spray drying or semidry injection of sorbent is more effective than dry injection, with increasing acid gas control as the outlet gas temperature decreases toward the saturation temperature. It appears that the existing spray dryer absorbers at incinerators operate at an outlet temperature in the range of 120–160°C (248–320°F), while dry injection systems without gas humidification operate at a higher gas temperature. Both the spray dryer absorber and dry sorbent injection into the flue gas duct are followed by an ESP or a fabric filter for particulate removal. Note that the perform-




1. FURNACE AND BOILER
2. PRECOLLECTOR
3. WASTE HEAT BOILER NO. 1
4. REACTOR
5. ELECTROSTATIC PRECIPITATOR
6. FABRIC FILTER
7. WASTE HEAT BOILER NO. 2
8. LIME SILO
9. LIME FEEDING
10. LIME RECIRCULATION
11. COARSE DUST CONVEYING
12. FINE DUST CONVEYING
13. DUST SILO
14. DUST HUMIDIFIER
15. DUST BIN

FIG. 3 DRY ABSORPTION SYSTEM [4]

ance of an ESP actually appears to improve when located downstream of a spray dryer, probably due to the reduced gas volume and gas particle changes resulting at the lower gas temperature. Table 5 indicates the approximate acid gas removal capabilities of many gas cleaning arrangements that have been applied or proposed. Since the removals given in the table are based mainly on pilot plant results, they should be applied to full scale units with caution.

**Postcombustion $NO_x$ Control**

Probably the most difficult and expensive pollutant to control is $NO_x$, primarily due to the low reactivity and water solubility of NO, which comprises 95% or more of the total uncontrolled $NO_x$. Technology recently introduced in Europe for $NO_x$ removal includes wet absorption in either the oxidation–absorption or absorption–reduction mode.

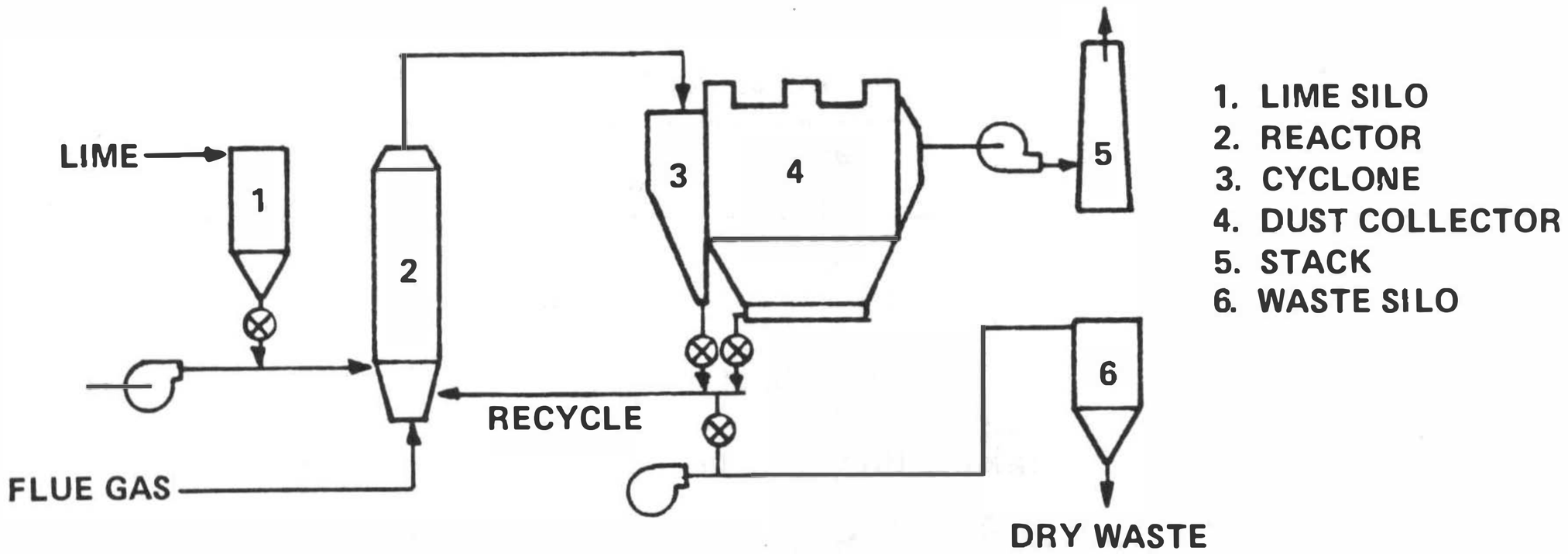



FIG. 4 CIRCULATING FLUID-BED ABSORPTION (Dry) PROCESS [4]

*Oxidation–Absorption*

In a wet scrubber system operating downstream of a spray dryer (Fig. 1), an oxidizer, such as sodium chlorite ($NaClO_2$), is added to oxidize flue gas NO to $NO_2$, which can be removed by a sodium-base wet scrubbing operation [1]. For example, with the addition of $NaClO_2$ to the upstream venturi (HCl) scrubber and raising the pH to 3–4, some NO is oxidized to $NO_2$ in the first venturi scrubber (see Fig. 1) and is removed in this scrubber and along with $SO_2$ in the following venturi scrubber.

*Absorption-Reduction*

Another approach used to deal with the limited reactivity of flue gas NO and its poor absorption in typical wet scrubber operations is absorption-reduction. This method of NO removal was applied at municipal refuse incinerators in Bremerhaven, West Germany, in 1987 [10]. In this system, ferrous ions ($Fe^{2+}$) tie up NO in the liquid phase by the formation of ethylene diaminetetraacetic acid (EDTA) complexes. These complexes, in turn, react with $HSO_3^-$ and $SO_3^{2-}$ ions (from $SO_2$ absorption), leaving $N_2$ and sulfate ($SO_4^{2-}$) as reaction products. Chemical additive cost for this technology is reported to be approximately 4–11 DM (approximately $2–5 U.S.) per tonne (of waste processed) less than that for oxidation-absorption processing for $NO_x$ removal [11].

## Postcombustion Organic Pollutant Control (Products of Incomplete Combustion, PICs)

Control of dioxins and furans, as well as other trace organic compounds, seems to be somewhat controversial, partly because the mechanism of capture is not well understood. It seems likely that their condensation and capture as particular matter is significant, and reaction and capture by caustic reagents is also probable. These capture phenomena are best utilized by lowering flue gas temperatures, subjecting flue gas to caustic sorbent, and collecting the product in a highly efficient particulate collector. Limited data show that spray drying followed by fabric filtration is very effective for organic vapor control and superior to a spray dryer/ESP system [12]. Also, lower flue gas temperatures favor increased control of organics. Reference [12], dealing with spray dryer control of organics, is a good discussion of these observations. Pilot plant results are summarized in Table 6, where CDD refers to chlorinated dibenzo-para-dioxins and CDF to chlorinated dibenzofurans. The low dust-collector temperature is 120°C (248°F), and the high temperature is 160°C (320°F). The superiority of a sorbent dispersed on a fabric filter over that with ESP for control of dioxins and furans is evident from Table 6.

Similar high efficiency removal has been achieved by Environment Canada in pilot plant work, both with a lime spray dryer and dry lime injection into cooled/humidified flue gas upstream of fabric filtration [13]. A total dioxins removal efficiency of 99.9% was demonstrated with a fabric filter inlet gas temperature of 140°C (284°F) and below. Tetra CDD, the most toxic dioxin homolog, showed the lowest outlet concentration, typically nondetectable. A minimum of 99.3% total furans removal efficiency was demonstrated at all outlet temperatures; i.e. 110–209°C (230–408°F) [13]. While the dry lime injection tests were carried out over this full range of temperatures, the spray dryer tests were performed only at the 140°C (284°F) temperature.

**TABLE 3 EUROPEAN DRY FLUE GAS CLEANING SYSTEM SURVEY [8]**

| Plant Owner | Location | Waste Type | Gas Flow, 1000 cfm | Emission Control | Start-up |
|---|---|---|---|---|---|
| City of Vienna | Vienna[a] | MSW | 3.5 | DS | 1977 |
| Niro | Copenhagen[b] | | 5.3 | DS | h |
| Kommunekemi A/S | Nyborg[b] | Haz Waste | 63.1 | DS/ESP | 1982 |
| Granges | Finspang[c] | MSW | 8.8 | DAS | 1977 |
| Suomen Ongelmajate OY | Riihimaki[c] | Haz Waste | 61.4 | DS/FF | 1984 |
| Stadtreinigung (MVA Ruhleben) | Berlin[d] | MSW | 551 | DAS | 1985 |
| Dortmund University | Dortmund[d] | MSW | | DS | 1976[h] |
| City of Dusseldorf | Dusseldorf[d] | MSW | 90 | DS | 1980 |
| Passavant-Werke | Dusseldorf[d] | Sludge | 47.6 | DS | 1980 |
| Von Roll (MVA Geiselbullach) | Geiselbullach[d] | MSW | 97.7 | DAS | 1985 |
| City of Hamburg | Hamburg[d] | MSW | 242 | DS/ESP | 1978 |
| City of Hamburg | Hamburg[d] | MSW | 266 | DS/ESP | 1978 |
| City of Hamm | Hamm[d] | MSW | 235 | DS/FF | 1982 |
| Von Roll (MVA Kempten III) | Kempten[d] | MSW | 57.1 | DAS/ESP & FF | 1983 |
| MVA Leverkusen | Leverkusen[d] | Ind /MSW | 227 | DS/ESP | 1986 |
| City of Munich | Munich[d] | MSW | 470 | DS | 1978 |
| Oberhausen | Oberhausen[d] | MSW | 7.1 | DS/FF | 1979[h] |
| Pinneberg County | Pinneberg[d] | MSW | 142 | DS | 1976 |
| Accam | Busto Arsizio[e] | MSW | 2.47 | DAS/ESP | 1983 |
| SYSAV | Malmo[f] | MSW | 159 | DAS/ESP & FF | 1981 |
| SAKAB | Norrtorp[f] | Haz Waste | 81.0 | DS/ESP | 1983 |
| Chocolate Frey | Aarau[g] | | 7.1 | FF | 1973 |
| Migros | Basel[g] | | 18.2 | FF | 1970 |
| Gebr Loeb. | Bern[g] | | 18.2 | FF | 1974 |
| Migros Genossensch. | Dierikon[g] | | 18.8 | FF | 1971 |
| Migros | Geneva[g] | | 21.2 | FF | 1976 |
| UI Cottendart | Neuchatel[g] | | 37.2 | FF | 1971 |
| Migros Genossensch. | Schoenbuekl[g] | | 18.8 | FF | 1973 |
| Hospital | Sonedan[g] | | 0.6 | FF | 1978 |
| Yverdon | Yverdon[g] | | | FF | |

DAS -- Dry Absorption System ESP -- Electrostatic Precipitator
DS -- Dry Scrubber FF -- Fabric Filter

[a]Austria [b] Denmark [c]Finland [d]West Germany [e]Italy [f]Sweden
[g]Switzerland [h]Pilot Unit

Note: 1000 cfm = 1,700 $m^3/h$ (at actual incinerator outlet conditions)

## TABLE 4 MUNICIPAL INCINERATION FLUE GAS CLEANING PLANT SUMMARY, WEST GERMANY (JUNE 1986 SUMMARY)

| Location | System Supplier | Gas Flow, 1000 Nm³/h(wet) | Acid Gas Emission Control | Particulate Emission Control | Start-up |
|---|---|---|---|---|---|
| Bamberg | Babcock BSH | 2x45, 1x50 | WS | ESP | 1978, 1981 |
| Berlin | Flakt | 7x66 | DAS | ESP(/BH) | 1987-89 |
| Bielefeld-Werford | Lugar | 3x132 | WS | ESP | 1981-82 |
| Bremen | Lurgi | 2x110, 1x150 | DS | BH | 1987-88 |
| Bremerhaven | Von Roll | 3x80 | WS | ESP | 1977, 1986-7 |
| Darmstadt | Ciba-Geigy | 1x50 (Est.) | WS | | 1987-88 |
| Duesseldorf | Babcock BSH | 3x140 | DS | ESP | 1984-85 |
| Essen-Karnap II | Babcock BSH | 4x120 | WS | ESP | 1987 |
| Frankfurt/Main | Lurgi | 4x120 | DS | ESP(/BH) | 1987 |
| Geiselbullach | Flakt | 2x42 | DAS | BH | 1986 |
| Goppingen | Babcock BSH | 2x62 | WS | ESP | 1985-87 |
| Hagen | Babcock BSH | 3x40 | DS | ESP | 1986-87 |
| Hamburg 1 | Babcock, HDW | 2x65 | DS | ESP | 1985-86 |
| Hamburg 2 | Babcock, HDW | 2x70 | DS | ESP | |
| Hameln | (KW Wesertal AG) | 2x60 | DAS | ESP | 1983 |
| Hamm | Babcock BSH | 4x50 | DS | BH | 1985-86 |
| Herten | Saarberg-Hoelter | 1x124 | DAS | ESP | 1982-83 |
| Ingolstadt | GfE | 2x56, 1x68 | WS | ESP | 1977, 1983 |
| Iserlohn | Lurgi | 2x50, 1x100 | WS | ESP | 1986 |
| Kassel | Niro Atomizer | 2x63 | DS | BH | 1987 |
| Kempten/Allgäu | Flakt | 1x49 | DAS | BH | 1984 |
| Kiel-South | Babcock BSH | 2x31, 1x62 | WS | ESP | 1975, 1980 |
| Krefeld | Lugar | 2x75 | WS | | 1976 |
| Krefeld | Babcock BSH | 3x110 | WS | ESP | 1982 |
| Landshut | N/A | 2x51 | WS | ESP | 1988 |
| Leverkusen | Niro Atomizer | 2x54, 1x72 | DS | ESP | 1986-87 |
| Ludwigshafen | Babcock BSH | 2x54 | WS | ESP | 1988-89 |
| Mannheim | Babcock BSH | 2x150 | WS | ESP | 1987 |
| Marktoberdorf | Lurgi | 1x15 | WS | BH | 1974, 1985-86 |
| Munich-North | Babcock BSH | 2x140 | DS | ESP | 1983 |
| Munich-South | Ciba Geigy | 2x210 | WS | | 1988 |
| Neufahrn-Freising | Flakt | 1x16 (Est.) | DAS | ESP | 1987 |
| Neunkirchen | GfE | 1x26, 1x54 | WS | ESP | 1986-87 |
| Neustadt/Holst. | Ciba Geigy | 1x65 | WS | Cyclone/WS | 1984 |
| Nuremberg | Saarberg-Hoelter-Lurgi | 1x100 | DS | ESP | 1985-86 |
| Oberhausen | Babcock BSH | 4x130 | WS | ESP | 1985 |
| Offenbach | Babcock BSH | 3x55 | WS | ESP | 1987 |
| Pinneberg | Babcock BSH | 52 | DS | | 1987 |
| Rosenheim | Saarberg-Hoelter-Lurgi | 1x60 | DS | BH | 1986 |
| Schwandorf | Lurgi | 3x100 | DAS | ESP | 1982 |
| Solingen | Niro Atomizer | 69 | DS | | 1987 |
| Stapelfeld | GfE | 2x120 | WS | ESP | 1978 |
| Stuttgart | Ciba Geigy | 3x180 | WS | | 1989 |
| Würzburg | Steinmueller | 1x65, 1x70 | DAS | BH | 1984 |
| Wuppertal | Babcock BSH | 2x100 | WS | ESP | 1976 |
| Zirndorf | GfE, Lugar | 1x25, 1x36 | WS | ESP | 1984, 1986-87 |

WS -- Wet Scrubber (i.e., 1 or 2 stages of alkali wet removal for acid gases)

DAS -- Dry Absorption System (i.e., dry sorbent injection or circulating fluid bed)

DS -- Dry Scrubber (i.e., spray dryer or semi-dry scrubber)

ESP -- Electrostatic Precipitator

BH - Baghouse (i.e., fabric filtration)

Note: 1000 scfm (at 68°F or 20°C) = 1580 Nm³/h (at 0°C)

**TABLE 5 EFFECTIVENESS OF ACID GAS CONTROLS (% Removal) [4]**

| Control System | Pollutant HCl | HF | SO2 |
|---|---|---|---|
| Dry Injection + Fabric Filter (FF)[a] | 80 | 98 | 50 |
| Dry Injection + Entrained Fluid-Bed Reactor + ESP[b] | 90 | 99 | 60 |
| Spray Dryer Absorber + ESP | 95+ | 99 | 50-70 |
| (With Sorbent Recycle)[c] | (95+) | (99) | (70-90) |
| Spray Dryer Absorber + Fabric Filter | 95+ | 99 | 70-90 |
| (With Sorbent Recycle)[c] | (95+) | (99) | (80-95) |
| Spray Dryer Absorber + Dry Injection + ESP or FF[d] | 95+ | 99 | 90+ |
| ESP + Wet Scrubber[e] | 95+ | 99 | 90+ |
| Spray Dryer + Particulate Collector + Wet Scrubber(s) | 95+ | 99 | 90+ |

[a] T = 160-180°C (320-356°F)

[b] T = 230°C (446°F)

[c] T = 140-160°C (284-320°F)

[d] T = 200°C (392°F)

[e] T = 40-50°C (104-122°F)

(T = the flue gas temperature at the exit of the control device.)

**TABLE 6 SPRAY DRYER CONTROL OF SELECTED ORGANIC POLLUTANTS [12]**

| Compound | Control System (% Removal) SD + ESP | SD + FF @ High Temp. | SD + FF @ Low Temp. |
|---|---|---|---|
| Dioxins | | | |
| tetra CDD | 48 | <52 | >97 |
| penta CDD | 51 | 75 | >99.6 |
| hexa CDD | 73 | 93 | >99.5 |
| hepta CDD | 83 | 82 | >99.6 |
| octa CDD | 89 | NA | >99.8 |
| Furans | | | |
| tetra CDF | 65 | 98 | >99.4 |
| penta CDF | 64 | 88 | >99.6 |
| hexa CDF | 82 | 86 | >99.7 |
| hepta CDF | 83 | 92 | >99.8 |
| octa CDF | 85 | NA | >99.8 |

SD -- Spray Dryer
FF -- Fabric Filter
CDF -- Chlorinated dibenzofurans
ESP -- Electrostatic Precipitator
CDD -- Chlorinated dibenzo-p-dioxins

### Heavy Metals Control

The control of emissions of heavy metals, which in Europe has attracted at least as much attention as have PICs, is similar to organic pollutant control in that effective particulate capture and low flue gas temperature are major factors. Sorbents, however, are not seen to play a major role in heavy metals capture. Toxic metals enter the collectors as solids, liquids, and vapors and, as the flue gas cools, the vapor portion converts to collectible solids and liquids. However, very volatile metals, particularly mercury, are present as vapor in measurable amounts even at the lowest outlet temperatures at which collectors are designed and operated. In general, the effectiveness of heavy metals emission control by diverse gas cleaning system designs appears to be inversely related to system outlet temperature. Testing in Sweden of a pilot wet scrubber downstream of an ESP indicated that, with subcooling of saturated flue gas to approximately 60°C (140°F), the total (particulate and gaseous) mercury emissions from a municipal waste incinerator were reduced to as low as 0.01 mg/Nm$^3$ (dry) [14]. Tests of a German municipal refuse incinerator equipped with a spray dryer followed by an ESP operating at 150°C (302°F) indicated that vapor-phase mercury emission alone was 0.05 mg/m$^3$ or greater, (11% $O_2$ basis) [14]. A dry injection facility serving a municipal waste refuse incinerator in Sweden, with its downstream fabric filter operating at approximately 160°C (320°F), is reported [14] to reduce particulate mercury to a typically nondetectable concentration and gaseous mercury to the range of 0.012–0.065 mg/Nm$^3$ dry (11% $O_2$ basis).

## SUMMARY AND CONCLUSIONS

The European incineration market, specifically the large German (and Scandinavian) speaking area, has been pursuing the best available control technology for waste incineration flue gas cleaning for the last 5–10 years. Basically, two different processes are claimed to meet this goal: *(a)* two-stage wet scrubbing for acid gas removal, which may use the sensible heat in the flue gas for upstream spray drying of the wet scrubber liquid waste stream; and *(b)* lime dry absorption in humidified flue gas or lime spray drying absorption for acid gas control, followed in either case by particulate collection using an ESP or a fabric filter.

While wet scrubbers may achieve slightly lower emissions of acid gases (HCl, HF, and $SO_2$) than spray dryer absorbers, this appears less important than other emerging emission concerns, such as heavy metals, organics and, in some instances, $NO_x$. Spray dryer absorbers followed by ESPs or fabric filters have demonstrated satisfactory results in controlling emissions of acid gases, particulates, and heavy metals. The same appears true of wet scrubbers, even though the specific operation of an upstream spray dryer for drying the liquid effluent from the wet scrubber may require additional operational experience and data for a final evaluation. Evidence that a spray dryer absorber followed by a fabric filter baghouse, operating at a flue gas temperature of 120–140°C (248–284°F), provides efficient removal of heavy metals has been reported. Recent developments, however, suggest that a wet

scrubber with additional subcooling of the flue gas may provide optimum control of emissions of some heavy metals and specifically that of gaseous mercury (Hg).

The results of some dry flue gas cleaning system tests suggest the capture of dioxins and furans by condensation and/or chemical reaction, even though the mechanism is not very well understood. Controversy still exists regarding whether the potential emissions of organics should be addressed as a combustion issue or a flue gas cleanup issue. However, it does appear prudent to limit the formation of organics in the combustor to preclude the need for their cleanup by downstream flue gas treatment and their subsequent disposal with scrubber residues. Finally, most recently the $NO_x$ emissions from the waste incinerator (which in some complicated manner seem to be inversely related to organic emissions) have undergone study, and potential control options via additives to the wet scrubber liquor/slurry have been identified. This may indicate that the wet scrubber, despite its relative complexity and high cost, can potentially offer novel advantages over semidry and dry systems. More operational experience and emission measurements are required, however, before the commercial wet $NO_x$ removal system can be evaluated conclusively.

It appears that the specification and selection of waste incinerator flue gas cleaning systems in Germany are done mostly on a site-specific basis, considering factors such as capital cost, operational costs, scrubber waste disposal options, compliance with current emission limits, and flexibility in terms of possible retrofit to any future emission limits. Developments over the last 5–10 years suggest that the identification of an optimum flue gas cleaning system design that efficiently meets all objectives from both economic and environmental perspectives at all locations and conditions probably is unrealistic. However, the waste incineration sector has undertaken a technologically refined approach to controlling its flue gas emissions that is aimed at meeting the demands of the marketplace as well as the community.

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