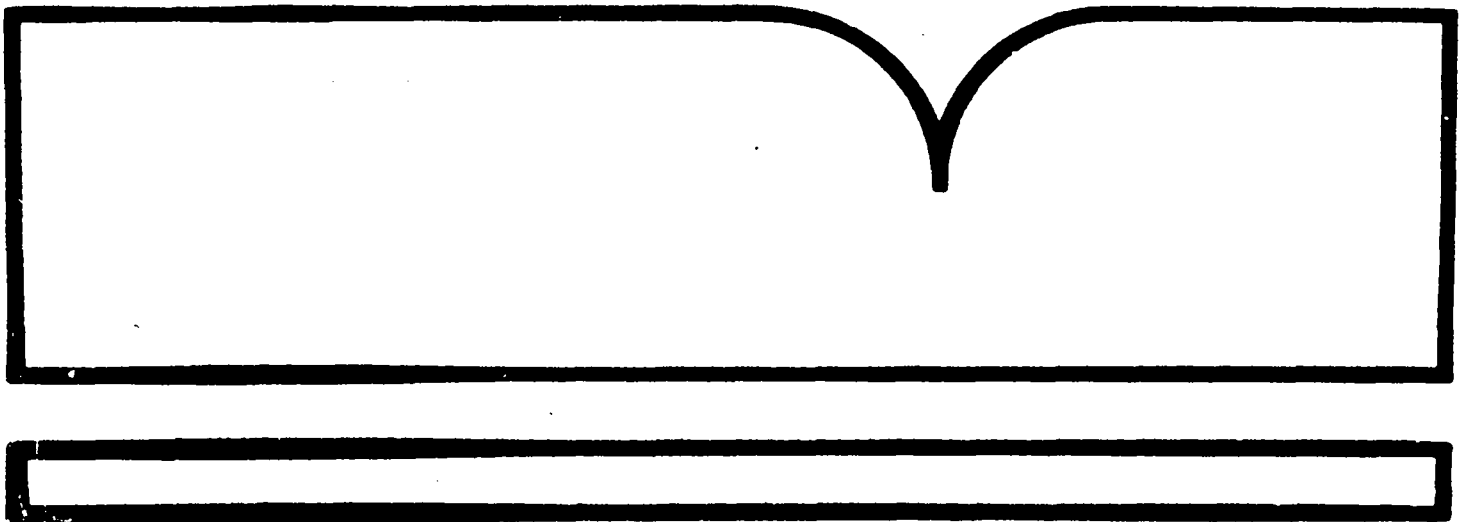Waste Incineration and
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WASTE INCINERATION AND EMISSION CONTROL TECHNOLOGIES

by

T. G. Brna and C. B. Sedman
Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

AIR AND ENERGY ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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16. ABSTRACT The paper gives results of a survey of available waste incineration and emission control technologies in the U.S., Japan, and Western Europe. Increasing concern over landfills as a waste management option and the decreasing availability of sites have focused attention on incineration for destruction of hazardous wastes and volume reduction of other wastes in the U.S. Incineration requires the control of air pollutant emissions, which can be minimized by combining in-furnace and post-combustion control technologies. Since future potential regulation of both hazardous air pollutants and acid rain precursors may cause extensive retrofit or early termination of existing waste incineration installations, planning for new or modified installations should recognize the various control technologies available in order to minimize future outlays if regulations are tightened.

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T. G. Brna
C. B. Sedman
Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
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## ABSTRACT

The increasing concern over landfills as a waste management option and the decreasing availability of sites have focused attention on incineration for destruction of hazardous wastes and volume reduction of other wastes in the U.S.  The use of incineration requires the control of air pollutant emissions, which can be minimized by combining in-furnace and post-combustion control technologies.  Since future potential regulation of both hazardous air pollutants and acid rain precursors may cause extensive retrofit or early termination of existing waste incineration installations, the planning for new or modified installations should recognize the various control technologies available in order to minimize future outlays if regulations are tightened.  A survey of available technologies in the U.S., Japan, and Western Europe is presented for consideration.

# INTRODUCTION

Generators of hazardous wastes, substantial volumes of non-hazardous wastes, or mixtures of both have several available disposal options, all of which promise to become increasingly expensive in the future. Long-term storage and landfilling have inherent liabilities and steadily increasing costs as available sites diminish and regulations drive up operating costs. Except for limited recycle/reuse opportunities, the majority of thermally destructible wastes will probably be incinerated in special purpose furnaces, or mixed with fossil fuels and/or larger volume combustible wastes and burned in conventional steam boilers or water-wall incinerators. In many cases, cogeneration of steam and electricity from waste combustion will be the most economically attractive long-term waste disposal option.

In reducing waste volume and destroying potentially hazardous components, air pollution is an unavoidable by-product. Nearly complete destruction (99.99%) of hazardous wastes by combustion is now required. However, trace quantities of products of incomplete combustion, especially dioxins and furans, are not currently regulated by the U.S. EPA. Further, high destruction efficiencies require high temperature and increased turbulence (good mixing). Both of these promote increased oxides of nitrogen ($NO_x$), which are acid rain precursors. Oxidation of fuel nitrogen, sulfur, and halogens produces additional $NO_x$ as well as sulfur oxides ($SO_x$) and acid gases, all suspected contributors to acid rain. Non-combustibles such as trace metals (especially mercury, lead, arsenic, and chromium) are all potentially emitted with fly ash.

Given the potential for these classes of pollutants--trace hazardous organics, acid gases, trace heavy metals, and fly ash--the air pollution control strategy selected must have the capability of multi-pollutant control in order to minimize costly retrofit or upgrading to meet possible future regulations. The residues, although small in volume relative to unburned wastes, contain concentrated pollutants which must be disposed of in an environmentally safe manner, but residue disposal is not addressed here.

## CURRENT REGULATORY STATUS

Requirements of the individual states differ, and the U.S. lags behind other industrial nations in regulating emissions from waste combustion as shown

2

in Table 1. Local regulations or permit conditions
frequently determine the types of combustor and emission
controls required. In the U. S., for example, only
particulate matter is currently regulated by Federal
Standard, but typical permits at the local or state
level have limited carbon monoxide, $SO_x$, and $NO_x$ emiss-
ions, and more recently have covered trace metals,
hydrocarbons (particularly dioxins), and acid gases
(hydrochloric and hydrofluoric acids). Recent install-
ations in the U. S. have included technologies spec-
ifically targeted to reduce unburned hydrocarbons in
the furnace as well as tail-end processes to remove
acid gases, $SO_x$, and particulate matter. Particulate
matter controls are currently being permitted at 20 to
25% of the allowable emissions under current Federal
Standards, reflecting growing concern over trace metals
which tend to partition in the finer particles. One
recent U.S. installation has also included an in-furnace
reduction technique for reducing $NO_x$.[4]

In Western Europe, particularly West Germany,
similar technologies have been installed for nearly a
decade due to local permit requirements and national
standards which were recently set by Federal regulations
summarized in Table 1. Many of the technologies current-
ly offered in the U.S. and described later in this
paper are licensed from European vendors such as NIRO,
Flakt, and Deutsche Babcock. Japanese installations
have shown similar trends to those in Europe but add-
itionally feature an add-on, catalytic reduction step
for $NO_x$ removal, using Japanese technology developed
originally for steam electric generators.[5]

EMISSION CONTROL TECHNOLOGIES

In-Furnace Techniques

Of paramount concern is the destruction of combust-
ible and hazardous components which also diminish the
amounts of potentially hazardous products of incomplete
combustion, or toxic organics. A program is now under-
way within the U.S. EPA to develop combustion guidelines
for incinerators within the next year. The goals of
the program include establishing minimum time/tempera-
ture relationships for efficient combustion, air/fuel
mixing criteria, air injector designs, excess air and
turndown restrictions, startup and shutdown procedures,
and monitoring to verify compliance with these guide-
lines.

For $NO_x$ control, one in-furnace technique is curr-
ently in use in Japan and at one installation in the

3

TABLE 1. SELECTED EMISSIONS STANDARDS FOR WASTE INCINERATORS

| | U.S.[1] | California[2] | Connecticut[2] | Michigan[2] | West Germany[2,3] | Sweden[2] |
|---|---|---|---|---|---|---|
| Solid Particulate Matter, g/dscf (mg/m³) | 0.08 (200) | 0.01[a] (25) | 0.015 (37.5) | 0.015 (37.5) | 0.013[b] (32.5) | 0.01[c] (25) |
| Carbon Monoxide, ppm | --- | --- | --- | 113(24-hr avg) | 87 | --- |
| Hydrogen Chloride | --- | 30 ppmv (wet or dry scrubbers req'd) | 90% reduction | 90% | 17 ppmv (50 mg/Nm³) | 60 ppmv (BACT req'd)[d] |
| Sulfur Dioxide, ppm | --- | 30 | 170 | 86 | 38 (200 mg/Nm³) | New SO$_2$ limits reduce all acids significantly[3] |
| 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, mg/m³ | --- | --- | --- | --- | 20 | --- |
| Mercury + Cadmium + Thallium, mg/m³ (includes vapors) | --- | --- | --- | --- | 0.2 | --- |
| Gas Correction | 12% CO$_2$ dry | 12% CO$_2$ dry | 12% CO$_2$ dry | 12% CO$_2$ dry | 11% O$_2$ dry | --- |

[a] 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 vm.
[b] This is the local often applied limit, although the national limit is 0.02 gr/dscf (50 mg/Nm³).
[c] This limit and those below are from the Swedish Environmental Protection Board's "Temporary Emission Goals," July 1986.
[d] See GMTCRR 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.

U.S. Known as Thermal $DeNO_x$, it involves injecting ammonia in the upper furnace to achieve selective reduction of $NO_x$ (see Figure 1).[4] The ammonia/$NO_x$ reactions are extremely sensitive to temperature so that the injection location must be carefully selected. Also there is generally some slip of ammonia (i.e., ammonia which does not react with $NO_x$).
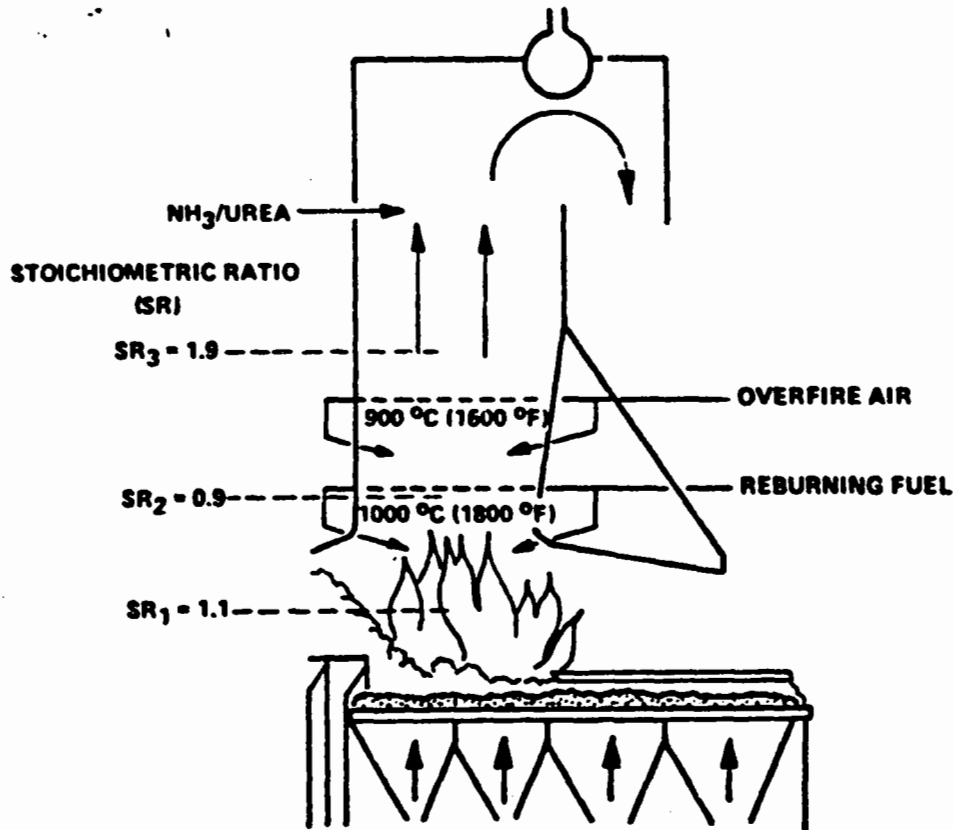


NH3/UREA

STOICHIOMETRIC RATIO
(SR)

$SR_3 = 1.9$

900 °C (1600 °F)

OVERFIRE AIR

$SR_2 = 0.9$

1000 °C (1800 °F)

REBURNING FUEL

$SR_1 = 1.1$

Figure 1. Reburning and thermal $DeNO_x$ applied to a waste incinerator.

Another promising $NO_x$ control concept is reburning with an auxiliary fuel such as natural gas. The process could potentially be applied to waste incinerators as shown in Figure 1. The individual stoichiometric ratio ($SR_i$) terms in this figure refer to the air/fuel stoichiometric ratio (SR) with SR less than 1.0 representing fuel-rich conditions. Enough reburning fuel should be injected at a location low in the furnace to create a hot, slightly oxygen-starved zone. The overfire air is injected above the reburning zone to complete the combustion process. Reburning can be combined with ammonia or urea injection to optimize $NO_x$ reduction. In addition

5

to $NO_x$ reduction, reburning has the potential for destroying organic compounds due to the high flame temperature and high concentration of flame radicals existing in the reburning zone.[6]

## Particulate Matter Control

Particulate matter control for solid waste combustors is practiced in all technologically advanced countries. The dominant system in the U. S. is the electrostatic precipitator (ESP), accounting for about 75% of all systems. With ESPs, very low emission levels are achievable; < 45 mg/Nm$^3$ (< 0.02 gr/dscf) at high ratios of collector plate surface area to gas flow volume; i.e., in the range of 170 min./m (52 min./ft) or greater.

Wet scrubbers (venturis) are relatively ineffective for particle control, removing 80 to 95% at normal operation. Very high pressure losses are required to remove fine particles, and the erosion and corrosion potential in acidic gas streams make the venturi a poor choice from economic and reliability perspectives.

Fabric filters are seldom used unless upstream sorbent injection is practiced, because of the perceived failures caused by hot gases, spark carryover, or sticky particles. However, fabric filters are capable of control to < 45 mg/Nm$^3$ without the operational upsets due to varying fuel and ash composition that adversely affect 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, but an alkali sorbent (or control of liquid pH to 5 or higher) is necessary for substantial $SO_2$ control. Totally dry sorbents require substantial residence time in the gas for effective acid gas control. Injection of sorbent into a duct must be complemented by a fluid-bed reactor, humidification, a fabric filter dust collector, or combinations of these to be effective. Figures 2 and 3 illustrate typical dry sorbent injection systems in use in Western Europe.

Spray drying or semi-dry injection of sorbent is more effective than dry injection, with increasing acid gas control as the approach to saturation temperature is decreased, either by waste heat recovery or water injection/humidification. The most effective control

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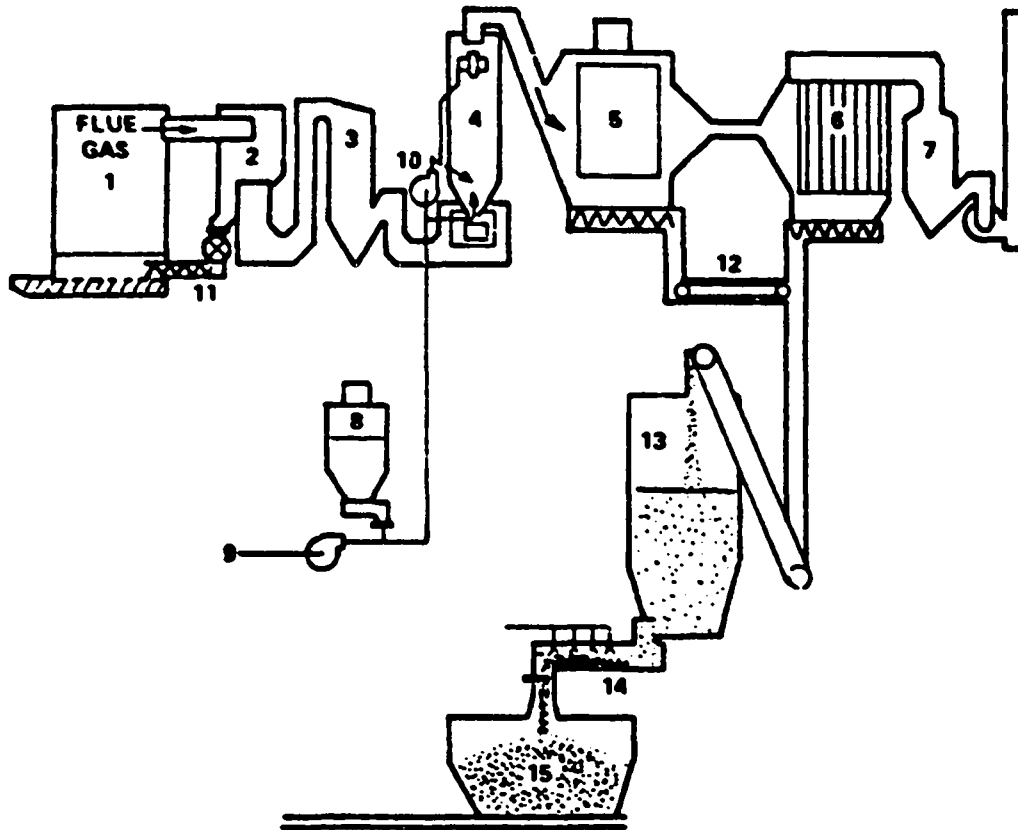
1. FURNACE AND BOILER
2. PRECOLLECTOR
3. WASTE HEAT BOILER NO. 1
4. REACTOR
5. ELECTROSTATIC PRECIPITATOR
6. FABRIC FILTER
7. WASTE HEAT BOILER NO. 2
8. LIME SILO

9. LIME FEEDING
10. LIME RECIRCULATION
11. COARSE DUST CONVEYING
12. FINE DUST CONVEYING
13. DUST SILO
14. DUST HUMIDIFIER
15. DUST BIN

Figure 2. Dry absorption system, Malmo, Sweden.

of acid gases is by alkali scrubbers operating at
saturation (wet scrubbing), but this has to be weighed
against the amount of waste water generated and its
treatment. Figure 4 illustrates a typical spray dryer
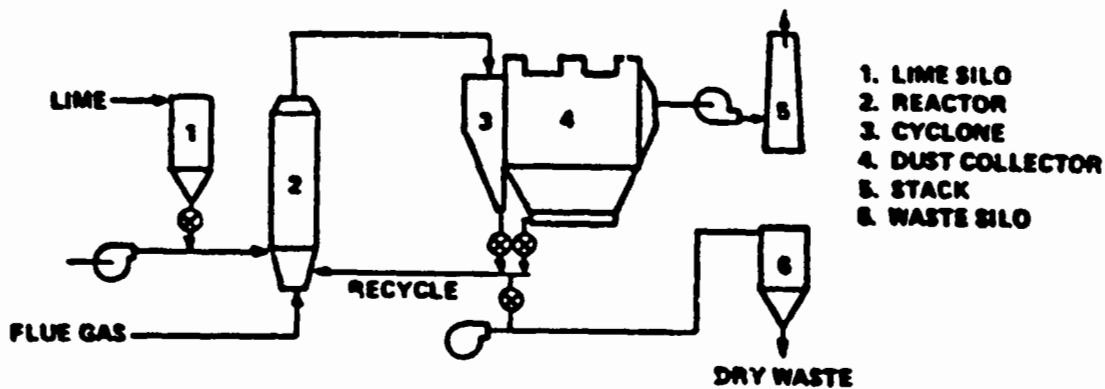system for acid gas removal.

**1. LIME SILO**
**2. REACTOR**
**3. CYCLONE**
**4. DUST COLLECTOR**
**5. STACK**
**6. WASTE SILO**

Figure 3.  Circulating fluid-bed absorption (dry) process.



**1. LIME FEEDER**
**2. LIME SLAKER**
**3. FEED TANK**
**4. HEAD TANK**
**5. SPRAY ABSORBER**
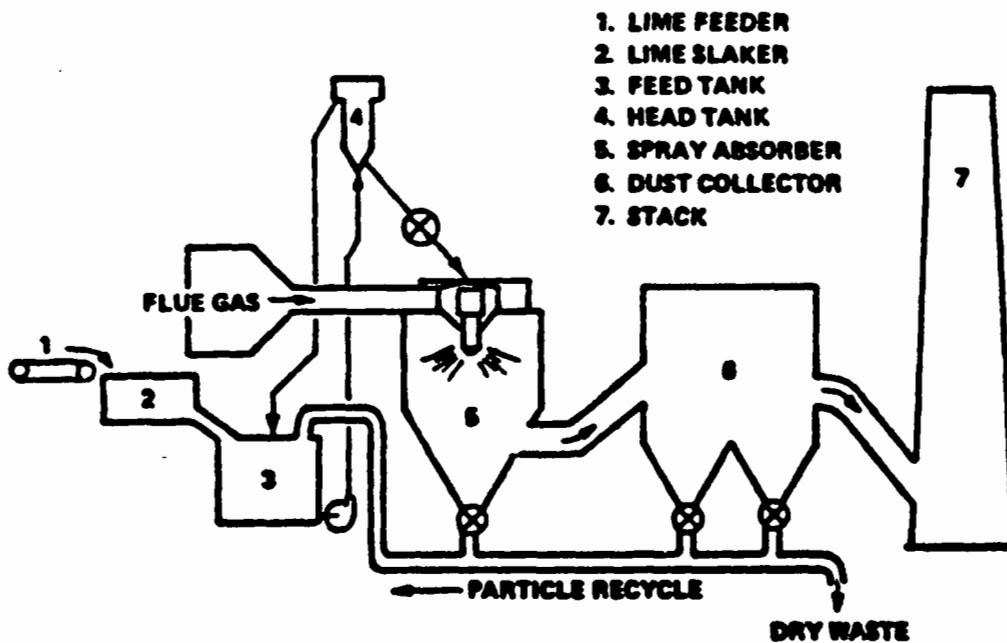**6. DUST COLLECTOR**
**7. STACK**

Figure 4.  Spray absorption (semi-dry) process.

Combined semi-dry/dry scrubbers control acid gases
perhaps more effectively than once-through spray drying
and are probably similar in effectiveness to spray dry-
ing with recycle, depending on the approach to saturation
temperature.  Combined semi-dry/wet systems, such as
spray dryer/venturi(s) combinations, are potentially
the most effective systems for acid gas control but
become increasingly complex as the number of targeted

8

pollutants increases. Table 2 summarizes the above dis-
cussion. The reader is cautioned that the reagent
requirements and solid/liquid wastes produced are not
considered, and this table only reflects the systems as
operated. Any of these techniques may be enhanced by
more reactive sorbents or operation at more favorable
temperatures. Figures 5 and 6 illustrate the combina-
tion semi-dry/dry and semi-dry/wet scrubbing systems.

TABLE 2.  EFFECTIVENESS OF ACID GAS CONTROLS (% REMOVAL)

| Control System | Pollutant | | |
| | HCl | HF | $SO_2$ |
|---|---|---|---|
| Dry Injection + Fabric Filter (FF)[a] | 80 | 98 | 50 |
| Dry Injection + Fluid-Bed Reactor + ESP[b] | 90 | 99 | 60 |
| Spray Dryer + ESP | 95+ | 99 | 50-70 |
| (Recycle)[c] | (95+) | (99) | (70-90) |
| Spray Dryer + Fabric Filter | 95+ | 99 | 70-90 |
| (Recycle)[c] | (95+) | (99) | (80-95) |
| Spray Dryer + Dry Injection + ESP or FF[d] | 95+ | 99 | 90+ |
| Wet Scrubber[e] | 95+ | 99 | 90+ |
| Spray Dryer + Wet Scrubber(s) + ESP or FF[e] | 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 temperature at the exit of the control device.


    In summary, effective control of acid gases is
possible with dry, semi-dry, and wet scrubbers. HCl
and HF are relatively easy to control, while $SO_2$ control
is more difficult and is favored by wet or semi-dry
systems with lower flue gas temperatures. Although not
discussed due to lack of data, very effective sulfur
trioxide control seems possible with a spray dryer.

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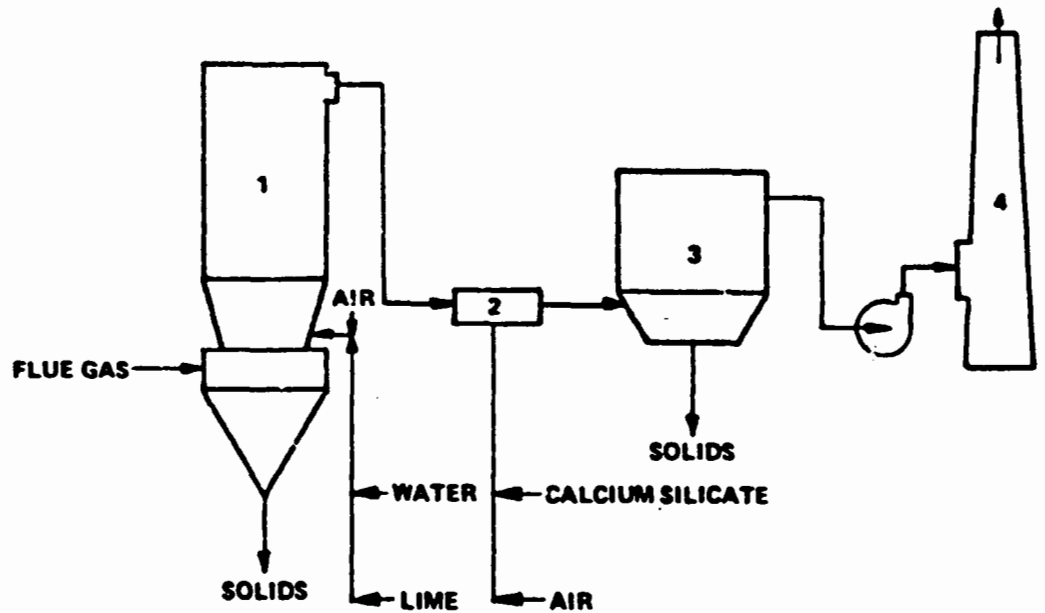
1. QUENCH REACTOR (SPRAY DRYER)
2. DRY VENTURI
3. BAGHOUSE
4. STACK

Figure 5.   Semi-dry/dry scrubber.[7]


Should $SO_3$ control also become a concern, systems which
contact the gas with wet or dry sorbent prior to a par-
ticulate control device should be encouraged.  This
approach is suggested because, after alkali scrubbing,
$SO_3$ apparently becomes an aerosol and is amenable to
capture.  Control systems with particle collectors up-
tream of the scrubber have historically reported poor
$SO_3$ control effectiveness.

## Post-Combustion $NO_x$ Control

Probably the most difficult and expensive pollutant
to control is $NO_x$, primarily due to unreactive NO which
comprises 95% or more of the total uncontrolled $NO_x$.  The
most effective control is selective catalytic reduction
(SCR) which currently must be preceded by acid gas and
heavy metals control to be effective   If the thermal
penalties are acceptable, then SCR c*  *emove 80-90% of
$NO_x$ with a $NH_3/NO$ molar ratio of 1.0 _ * about 5 ppmv $NH_3$
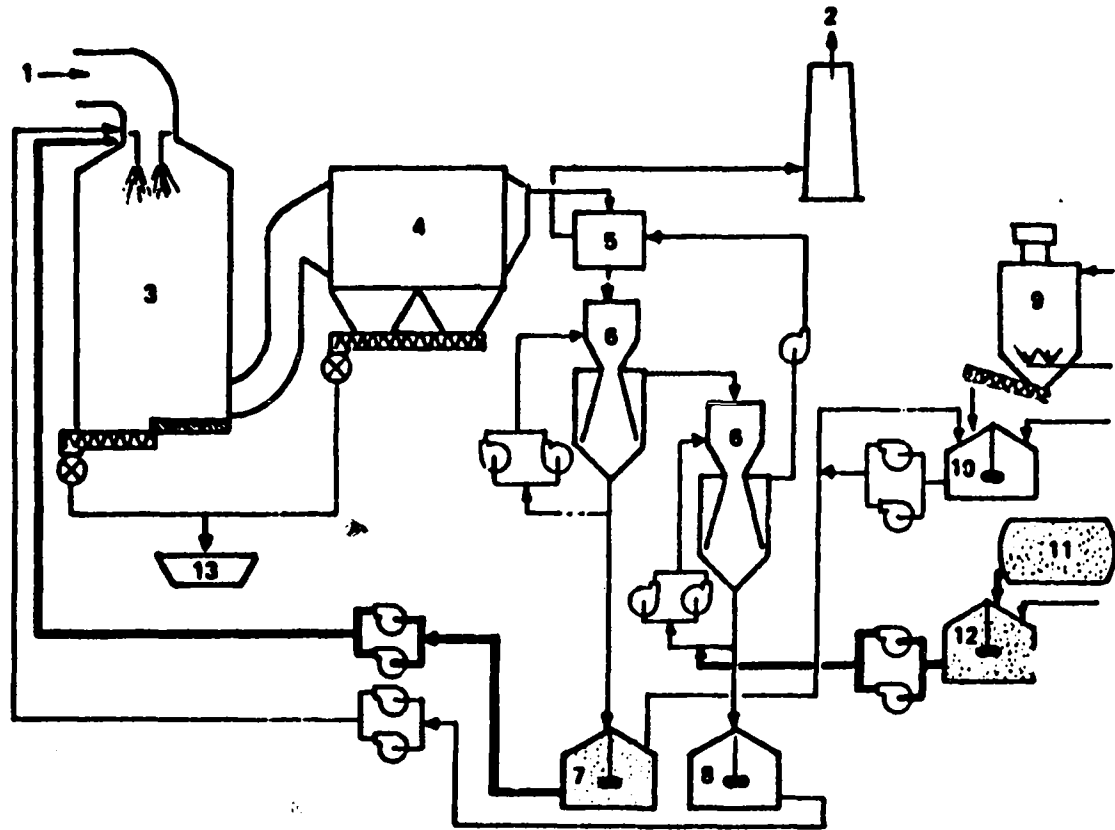
1. FLUE GAS
2. EXHAUST GAS
3. SPRAY DRYER
4. ELECTROSTATIC PRECIPITATOR OR FABRIC FILTER
5. GAS-GAS HEAT EXCHANGER
6. VENTURI SCRUBBER
7. NEUTRALIZATION TANK

8. SLUDGE TANK
9. LIME SILO
10. LIME SLAKER
11. SODIUM HYDROXIDE STORAGE
12. SODIUM AIR TANK
13. DRY WASTE

Figure 6.  Semi-dry/wet scrubber.

slip. Use of special lower temperature, HCl-resistant
catalysts in the future can make SCR even more attrac-
tive.[5] Potentially less effective and more complicated
$NO_x$ control may be achieved by an oxidation step inte-
grated into sodium- or magnesium-based wet scrubbing.
Due to the liquid waste potential, this may be best
applied to the combination semi-dry/wet scrubber system
shown in Figure 6, and $NO_x$ control of 30 to 50% would
be expected. Figure 7 illustrates SCR as applied to
incineration flue gas in Japan.

### Post-Combustion Organic Pollutant Control

Control of dioxins and furans, as well as other
trace organic compounds, is not well understood because
the mechanism of capture is not known. Likely, conden-
sation and capture as a particle is significant, and
attack and capture by caustic reagents is also probable.
These capture phenomena are best addressed by lowering
flue gas temperatures, subjecting flue gas to caustic
sorbent, and collecting the product in a highly effic-
ient particle collector. Limited data show that spray
drying followed by fabric filtration is very effective
for organic vapor control and superior to the spray
drying/ESP system. Also lower flue gas temperatures
favc increased control of organics. Reference 8 is
a good discussicn of these observations. The results
are summarized in Table 3, where CDD refers to chlor-
inated dibenzo-para-dioxins and CDF to chlorinated
dibenzofurans.[8]

Limited data have been collected on control device
efficiencies for dioxins and furans, with only outlet
concentrations being reported for most tests. Unfort-
unately, test data and methodologies are lacking to
compare the effectiveness of various control systems
for organic pollutants. However, the superiority of a
sorbent on a fabric filter for control is evident from
Table 3. The data shown were based on tests in a
single pilot plant, and thus should be used with
caution.[9]

### Heavy Metals Control

The control of heavy metals is similar to organic
pollutant control in that effective control of par-
ticles and low flue gas temperatures are major factors.
Sorbents, however, are not suspected to play a major
role. 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. Figure 8 illustrates various heavy metals
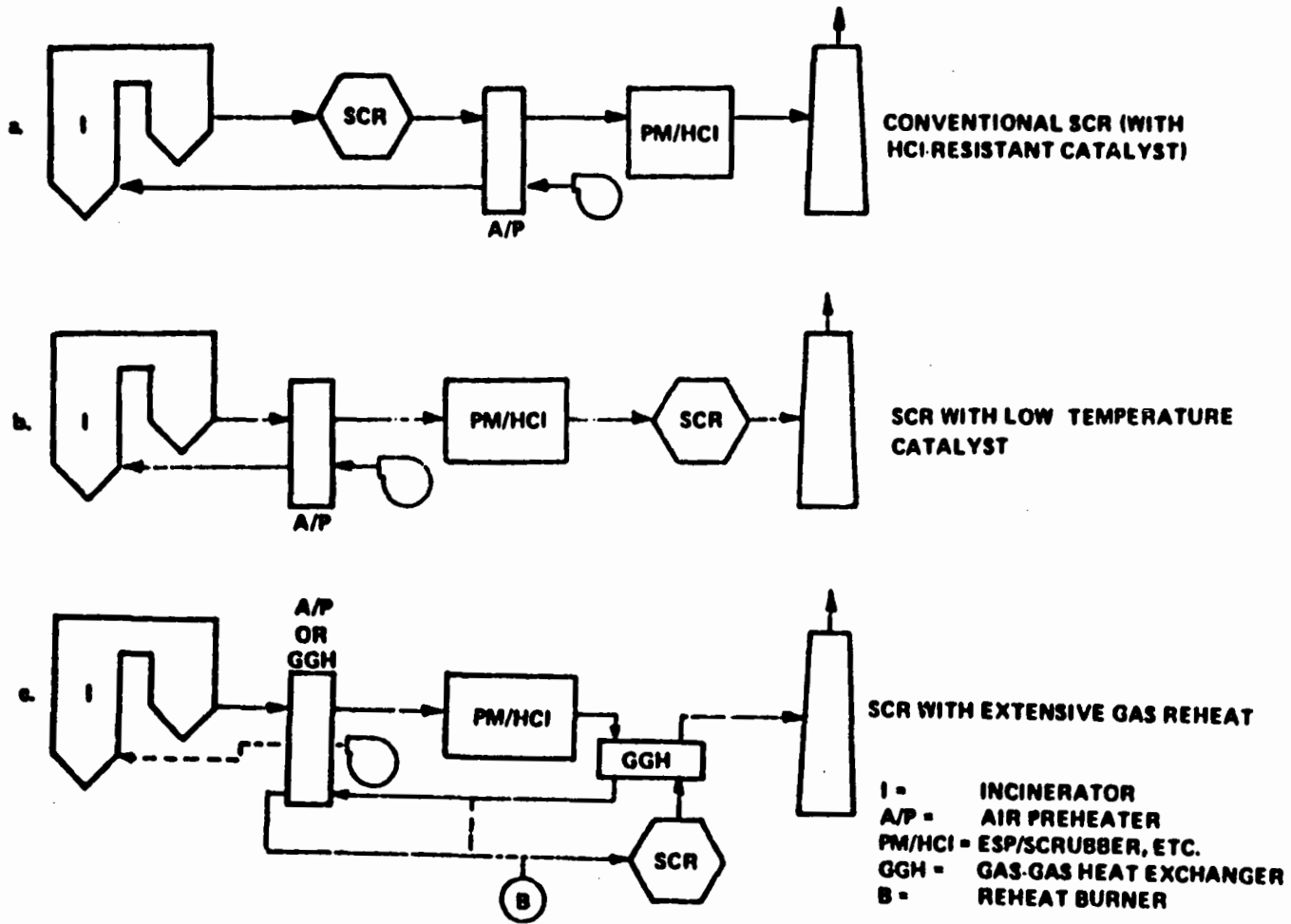as they appear in flue gas and their relative

12

a.    CONVENTIONAL SCR (WITH HCI-RESISTANT CATALYST)

b.    SCR WITH LOW TEMPERATURE CATALYST

c.    SCR WITH EXTENSIVE GAS REHEAT

| | |
|---|---|
| I = | INCINERATOR |
| A/P = | AIR PREHEATER |
| PM/HCI = | ESP/SCRUBBER, ETC. |
| GGH = | GAS-GAS HEAT EXCHANGER |
| B = | REHEAT BURNER |

Figure 7.   SCR options for municipal incinerators.

theoretical concentrations (vapor pressures) as a function of flue gas temperature.[9]

TABLE 3. SPRAY DRYER CONTROL OF SELECTED ORGANIC POLLUTANTS[9]

Control System (% Removal)

| Compound | 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 |

From Figure 8, it can be deduced that decreasing the flue gas temperature below 200°C (392°F) and high efficiency particulate collection should result in a very large reduction of metals, except for mercury (Hg), arsenates $(As_2O_3)_2$, and selenium ($SeO_2$ and $Se_6$). Corresponding reductions of these compounds proceed dramatically as temperatures are lowered. With the metals at their saturation temperatures, each is expected to be reduced by 90% for each additional temperature drop of 11 to 17°C (20 to 30°F). If this temperature effect is true, then wet scrubbing or wet/dry scrubbing which operates at saturation [~40°C (104°F)] should be highly effective for total heavy metals control, while most dry and semi-dry systems should be just as effective for practically all metals except mercury, arsenic, and selenium. The dry and semi-dry systems should achieve some capture of mercury, arsenic, and selenium, with the degree of capture increasing with decreasing flue gas temperature.

14
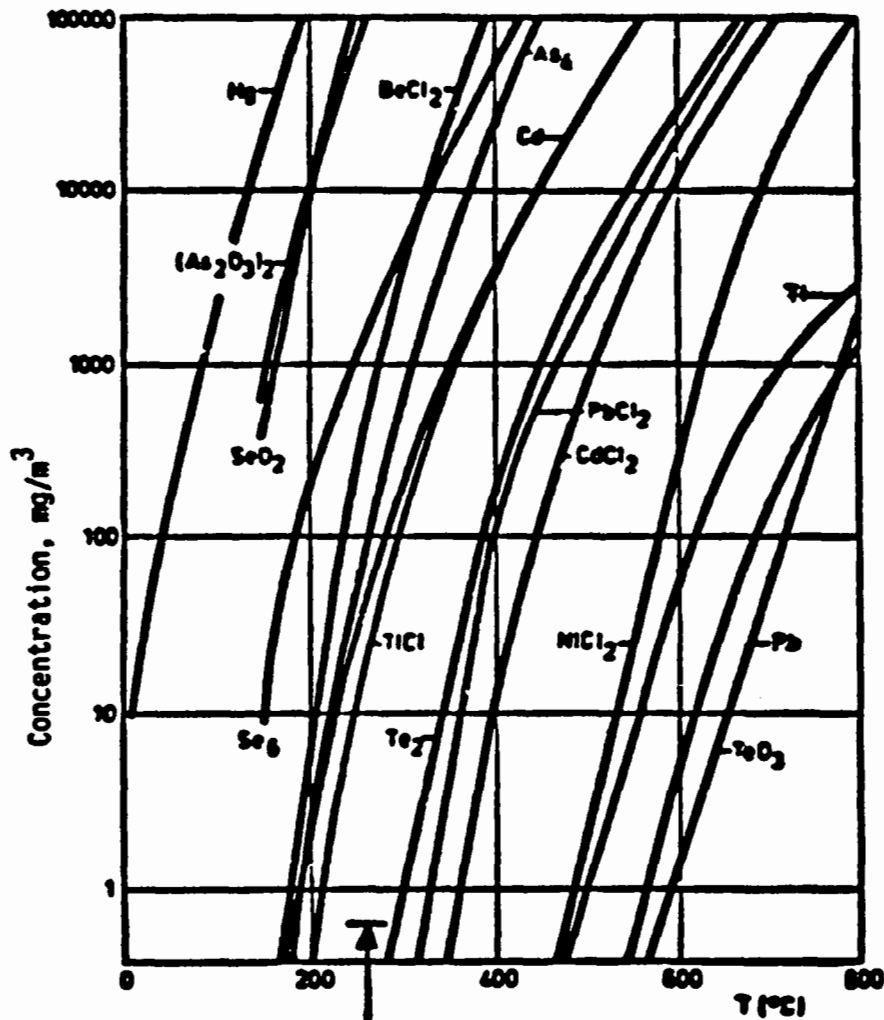
Measured Hg concentrations in raw gas.

Figure 8. Saturation points of metal and metal compounds. [9]

Reported metals control data generally show 95-98%
control or greater for most heavy metals except mercury.
Vapor-phase mercury control has been reported as: 75 to
85% control with spray dryer plus baghouse; and 35 to 45%
control with spray dryer plus ESP.[9] This is important in
that vapor control is possible with fabric filters and
ESPs, although limited data show the former to be clearly
superior. Wet scrubbers would appear to be ideal for
mercury control, but the collection of mercury vapors via
condensation and capture is not well documented. There-
fore, the choice of the most effective mercury control
is still the subject of controversy (see Reference 3).

## SUMMARY

In destroying wastes by incineration, several classes
of air pollutants are emitted which will likely
require control or at least consideration for control
by permitting agencies. The pollutants include trace
hazardous organics, acid gases, trace heavy metals,
and particulate matter. Various in-furnace and
post-combustion technologies are available to control
these pollutants, but the degree of control complexity
increases with the number of pollutants to be con-
trolled. Operators of existing incinerators should
be aware of these technologies for possible future
retrofit requirements, while those planning incinera-
tion projects should design these facilities to embrace
as many of the concepts described as practical, in
order to meet permit requirements with minimum delay.

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