Waste Management Study of Foundaries Major Waste Streams: Phase II

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Waste Management Study of Foundries Major Waste Streams: Phase II

by
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The University of Alabama
and
American Foundrymen's Society, Inc.

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Waste Management Study of Foundries Major Waste Streams: Phase II

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Front cover:
From 2 to 3 cu. yards of dust and fume arising daily at 11 dust-producing points in the sand handling operations -- shakeout, conveyore and muller -- at Bay City Steel Castings Div. of American Hoist & Derrick Company are trapped in a Wheelabrator Turbex wet collector.
This report is part of HWRIC's Technical Report Series. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.
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LIST OF ABBREVIATIONS

BACT  Best Available Control Technology
CAAA  The Clean Air Act Amendments of 1990
ESP   Electrostatic Precipitator
LAER  Lowest Achievable Emission Rate
HAP   Hazardous Air Pollutant
MACT  Maximum Achievable Control Technology
MSDS  Material Safety Data Sheet
NR    Not Reported
PSD   Prevention of Significant Deterioration
USEPA The United States Environmental Protection Agency
ABSTRACT

Research on emission control and waste disposal is the number one priority within AFS. In an industry survey conducted by AFS, ten top areas of concern were outlined, headed by sand system waste and emissions from molding, pouring, melting and shakeout in iron and steel green sand foundries. The objective of the present program was to define the foundry waste streams and emissions, establish where the streams originate, and define their make-up. A primary driving force for this work is the Clean Air Act Amendments of 1990 which will set new regulations for air emissions from foundries for 189 hazardous air pollutants (HAP) by 1997.

The focus of the research was on the nature of the foundry waste streams in the form of air emissions from processes of coremaking, molding, pouring, and shakeout and to establish their origin and their makeup. Binder chemicals are a major potential contributor to emissions from coremaking and subsequent processes.

The Phase I report included a review of all available information. Sources were the technical literature, suppliers of chemicals to foundries, AFS workshops, USEPA Office of Air Quality Planning and Standards, technical meetings, and visits to foundries.

This Phase II report covers an extension of the research to include emission factors derived from the limited data available for the common binder systems. These data will be useful for making order-of-magnitude estimates of emissions. Also included is a brief discussion of treatment technologies currently available for air emissions, along with a list of vendors for such equipment.
1.0 BACKGROUND

Up to now, foundry waste emission concerns have emphasized sand, water, and particulate emissions. Concerns about emissions of air toxics have largely been focused on occupational health and safety. The Clean Air Act Amendments of 1990 (CAAA) require the control of emissions of toxic and hazardous materials to the air. The scope of a project which dealt with all types of emissions from foundries would be far too large for the current project. Therefore, this project dealt only with air emissions of toxic and hazardous chemicals subject to the CAAA.

This report does not address nonattainment area requirements. The preconstruction review requirements for major new sources or major modifications locating in areas designated nonattainment differ from prevention of significant deterioration (PSD) requirements. The emissions control requirement for nonattainment areas, lowest achievable emission rate (LAER), is defined differently than the best available control technology (BACT). This report discusses only the HAP's covered under Title III of the CAAA. Those foundries under LAER requirements will also have to look at the requirements under Title I; SO2, NOx, and CO. In addition some states have set lower emission limits for some compounds to trigger MACT than the CAAA. Thus, a small foundry (<50 employees) may easily pass all criteria under Title III, but still have to be concerned about state regulations or Title I.

The U. S. foundry industry is very diverse. A comprehensive study of air emissions from all the different types of foundries and binder systems is beyond the scope possible for this project. Grey iron, ductile iron and steel account for about 84 percent of the metal cast in 1990. In addition, EPA has chosen iron and steel foundries to be the first foundry types to come under compliance of the CAAA. Therefore, the emphasis for this project was air emissions from green sand iron and steel foundries. In particular, emphasis has been placed on core making, pouring, and shake-out. Metal preparation and melting have not been considered, as there are a number of current technologies for treating melting effluents (such as baghouses, etc.).

2.0 FOUNDRY EMISSION INVENTORY

Since the publication of the Phase I report, the total air emissions from a foundry were determined in a case study done by Euvrard and Jackson [6]. The foundry studied was a medium sized gray and ductile iron foundry, with two cupolas melting approximately 17,000 tons of metal a year. The plant used a green sand molding system and a variety of oil, hot box, and cold box resins. Resins used for the cores included oil, phenolic isocyanate, phenolic ester, and furan hot box.

The air emissions were divided into metals, semi-volatiles, and volatile organic compounds and were reported in tons per year. Table 1 shows all air emissions converted to tons of emission per ton of metal poured. Emissions of 25 tons per year of a combination of the HAP compounds will trigger MACT. Table 2 reports the amount of metal to be poured to trigger MACT based on a combination of HAP component emissions.

Once again, these are total foundry air emissions and not process specific. However, it was determined that 90% of the HAP metals came from over the cupolas, 54% of the semi-volatiles and 24% of the volatiles came from the shakeout area, and 16% of the organics, semi-volatile and volatile were from pouring and cooling.
Table 1. Total Air Emissions from an Iron Foundry

<table>
<thead>
<tr>
<th>Air Pollutant Emissions</th>
<th>PLANT TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(tons emission/ton metal poured)</td>
</tr>
</tbody>
</table>

**METALS**
- Aluminum: 4.4900e-05
- Antimony: 1.4176e-06
- Arsenic: 4.8824e-07
- Barium: 4.8235e-07
- Beryllium: 5.8824e-09
- Cadmium: 7.6471e-08
- Chromium: 1.1647e-06
- Cobalt: 1.0000e-07
- Copper: 9.5000e-06
- Iron: 6.6826e-04
- Lead: 6.8176e-06
- Magnesium: 5.3935e-05
- Manganese: 3.5552e-04
- Mercury: <1.6471e-07
- Molybdenum: 2.2941e-07
- Nickel: 4.1765e-07
- Selenium: 1.6471e-07
- Silver: 7.6471e-08
- Tin: 7.7706e-06
- Titanium: 9.0588e-07
- Zinc: 9.7412e-06

**TOTAL METALS**: 1.1621e-03

**TOTAL CAAA METAL HAPs**: 3.6634e-04

**PARTICULATE**: 6.5067e-03

**HYDROGEN CHLORIDE**: 2.5465e-05

**SULFUR OXIDES**
- Sulfur dioxide: 6.9676e-05
- Sulfur trioxide: 2.7841e-05
- Sulfuric acid: 1.8008e-04

**TOTAL SULFUR OXIDES**: 2.7759e-04

**OXIDES OF NITROGEN**: 1.5081e-04

**CARBON MONOXIDE**: 4.0428e-03
Table 1, Continued. Total Air Emissions from an Iron Foundry

<table>
<thead>
<tr>
<th>Air Pollutant Emissions</th>
<th>PLANT TOTAL (tons emission/ton metal poured)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SEMI-VOLATILE ORGANIC COMPOUNDS</strong></td>
<td></td>
</tr>
<tr>
<td>* Acenaphthene **</td>
<td>1.1765e-08</td>
</tr>
<tr>
<td>* Acenaphthene **</td>
<td>4.8824e-08</td>
</tr>
<tr>
<td>* Benzo (a) anthracene **</td>
<td>1.1765e-09</td>
</tr>
<tr>
<td>* Bis (2-ethylhexyl) phthalate</td>
<td>9.3294e-07</td>
</tr>
<tr>
<td>* Dibutylphthalate</td>
<td>1.9941e-07</td>
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<tr>
<td>* Diethylphthalate</td>
<td>4.7941e-07</td>
</tr>
<tr>
<td>* Di-n-octylphthalate</td>
<td>6.4706e-09</td>
</tr>
<tr>
<td>* Fluoranthene **</td>
<td>1.7647e-09</td>
</tr>
<tr>
<td>* Fluorene **</td>
<td>5.1765e-08</td>
</tr>
<tr>
<td>* Naphthalene</td>
<td>1.4824e-06</td>
</tr>
<tr>
<td>* Phenanthrene **</td>
<td>6.8235e-08</td>
</tr>
<tr>
<td>* Pyrene **</td>
<td>1.7647e-09</td>
</tr>
<tr>
<td>2,4-Dimethylphenol</td>
<td>1.6106e-06</td>
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<tr>
<td>* Phenol</td>
<td>1.0541e-06</td>
</tr>
<tr>
<td>* Cresols</td>
<td>1.8976e-06</td>
</tr>
<tr>
<td>* Methyleneanthalenes **</td>
<td>1.1229e-06</td>
</tr>
<tr>
<td><strong>TOTAL SEMI-VOLATILES</strong></td>
<td>8.9712e-06</td>
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<tr>
<td><strong>TOTAL CAAA SEMI-VOLATILE HAPs</strong></td>
<td>6.8747e-06</td>
</tr>
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</table>

**VOLATILE ORGANIC COMPOUNDS**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>2.1439e-05</td>
</tr>
<tr>
<td>* Benzene</td>
<td>8.2353e-09</td>
</tr>
<tr>
<td>* Bromoform</td>
<td>2.4882e-07</td>
</tr>
<tr>
<td>* 1,3-Butadiene</td>
<td>6.5235e-07</td>
</tr>
<tr>
<td>* 2-Butanone (MEK)</td>
<td>2.1871e-06</td>
</tr>
<tr>
<td>* Carbon Disulfide</td>
<td>1.2353e-08</td>
</tr>
<tr>
<td>* Chlorobenzene</td>
<td>5.8824e-10</td>
</tr>
<tr>
<td>* Chloroform</td>
<td>1.5276e-06</td>
</tr>
<tr>
<td>* Chloromethane (Methyl Chloride)</td>
<td>5.8824e-10</td>
</tr>
<tr>
<td>* 1,2-Dichloroethane (EDC)</td>
<td>4.1765e-08</td>
</tr>
<tr>
<td>1-Dichloroethane</td>
<td>6.4353e-07</td>
</tr>
<tr>
<td>* Dichloromethane</td>
<td>2.8824e-08</td>
</tr>
<tr>
<td>* Ethyl Butyl Cellusolve</td>
<td>&lt;1.1318e-06</td>
</tr>
<tr>
<td>* Ethylbenzene</td>
<td>1.4941e-07</td>
</tr>
<tr>
<td>* Formaldehyde</td>
<td>&lt;2.7059e-08</td>
</tr>
<tr>
<td>2-Hexanone</td>
<td>3.0000e-08</td>
</tr>
<tr>
<td>* 4-Methyl-2-Pentanone (MIBK)</td>
<td>5.1176e-07</td>
</tr>
<tr>
<td>* Styrene</td>
<td>7.0647e-07</td>
</tr>
<tr>
<td>* Tetrachloroethylene (PCE)</td>
<td>2.7912e-05</td>
</tr>
<tr>
<td>* Toluene</td>
<td>9.7588e-06</td>
</tr>
<tr>
<td>* 1,1,1-Trichloroethane (TCA)</td>
<td>4.0588e-08</td>
</tr>
<tr>
<td>* Trichloroethene (TCE)</td>
<td>1.0588e-07</td>
</tr>
<tr>
<td>Trichlorofluoromethane (F-11)</td>
<td>2.2471e-07</td>
</tr>
<tr>
<td>Trichlorotrifluoromethane (F-113)</td>
<td>3.7412e-07</td>
</tr>
<tr>
<td>* Vinyl Acetate</td>
<td>9.1418e-06</td>
</tr>
<tr>
<td>* Xylenes</td>
<td>9.8616e-05</td>
</tr>
</tbody>
</table>
Table 1, Continued. Total Air Emissions from an Iron Foundry

<table>
<thead>
<tr>
<th></th>
<th>Plant Emissions</th>
<th>Amount of Metal Poured</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL VOLATILES</td>
<td>1.7552e-04</td>
<td></td>
</tr>
<tr>
<td>TOTAL CAAA VOLATILE HAPs</td>
<td>1.5168e-04</td>
<td></td>
</tr>
<tr>
<td>FACILITY TOTAL CAAA HAPs</td>
<td>5.5036e-04</td>
<td></td>
</tr>
</tbody>
</table>

* Denotes CAAA HAP
** Denotes Polycyclic Organic Matter

Table 2. Summary of CAAA HAP Emissions from Foundry Audit

<table>
<thead>
<tr>
<th>Air Pollution Emissions</th>
<th>Plant Total Emission (Tons emission/ton metal poured)</th>
<th>Amount of Metal Poured (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL CAAA METALS HAPs</td>
<td>3.663e-04</td>
<td>6.824e+04</td>
</tr>
<tr>
<td>TOTAL CAAA SEMI-VOLATILES HAPs</td>
<td>6.875e-06</td>
<td>3.637e+06</td>
</tr>
<tr>
<td>TOTAL CAAA VOLATILE HAPs</td>
<td>1.517e-04</td>
<td>1.648e+05</td>
</tr>
<tr>
<td>FACILITY TOTAL CAAA HAPs</td>
<td>5.504e-04</td>
<td>4.542e+04</td>
</tr>
</tbody>
</table>

3.0 DEVELOPMENT OF EMISSION FACTORS

The emissions of HAP's from iron and steel foundries can generally be classified as metals or organics.

3.1 METALS

Emissions from melting furnaces are primarily volatile metals, which are generally controlled by particulate emission control devices. These emissions depend upon the type of scrap melted and on the type of melting furnace. The rate of metal emissions from electric and induction furnaces would be expected to be lower than from cupolas, for example. Many cupolas have particulate control devices on them, which reduces the net emission of metals. Any polymers, especially vinyl polymers, in the scrap may generate organic emissions, but the levels of organic emissions to be expected have not been quantified. Afterburners to control CO emissions in cupolas may also give sufficient control of many organic compound emissions. A study of emissions from melting operations was beyond the scope of the present study. Metal emissions from core and mold making, and shakeout are considered to be insignificant. Metal emissions from pouring depends on the alloy poured and the pouring temperature and are not included in this study.

3.2 ORGANIC COMPOUND EMISSIONS

The potential emissions of HAP's from production of cores and molds are generally volatile organic compounds that result from unreacted components of the resin, solvents, or catalysts. Forty-seven HAP's have been identified from the published literature on foundry air emissions, but many of these are at very low levels. Excluding metals, 38 potential HAP's were reported to be emitted, but of these only 16 have been identified in this study as being potentially emitted in any quantity larger than trace amounts in foundry operations. These HAP's have been identified by
type, but quantitative data on levels of emissions are very scarce and generally are not available.

The previous lists of HAP's are inclusive of emissions which may occur in several different locations in a foundry. It probably will be necessary to pinpoint more accurately which HAP's are emitted from each area of the plant. Therefore, some discussion will be made of the potential emissions from several areas of the plant.

3.2.1 Core and Mold Making Emissions

Actual published quantitative emission data taken in core rooms were not found. Emissions of HAP's in core and mold making up to now have been of concern mainly for occupational health and safety. The main reason for needing to know the level of emissions has been to determine ventilation requirements. Mosher [1] recently has compiled data from suppliers and manufacturers of binder chemicals to determine the fate of the ingredients put into the coremaking process. This document was prepared to assist foundries in filling out the EPA form R on emissions. The fate of the chemical ingredients was categorized as percent that was reacted and no longer existed after coremaking, percent unchanged in the process and remaining in the core, and percent evaporated to give an airborne emission. Therefore, these data can be used to give estimates of emissions from core and mold preparation areas. The Phase I report showed sample calculations of the amount of core sand usage that would result in 10 tons/year of emissions in core making for naphthalene, formaldehyde, and methanol evaporation emissions from three of the common binder systems that would be expected in the core room, when the binders are used at typical binder/sand ratios. This approach can be used to estimate emissions of HAP's from other binder systems.

3.2.2 Pouring and Cooling Emissions

Laboratory data on emissions from pouring and cooling for one hour for most common binder systems have been reported. Although the studies were made for workplace health and safety considerations, quantities of the major organic compounds emitted can be calculated from the data. The experiments were made to give a comparison among binder systems, and no parameter studies were made. The experimental conditions were well presented by Scott, Bates and James [10]. The casting was an irregular gear, which weighed approximately 40 kg with the gating system and riser. The sand weighed approximately 100 kg to give a sand-to-metal ratio of 2.5, except for the shell mold which had a sand-to-metal ratio of 0.9. The pouring temperature was 1450 °C. Emissions data were reported in concentrations (ppm), but with the specified gas flow rate of 1000 L/min through the stack the mass of emissions of each component can be calculated. They made measurements on 10 hot-box and no-bake binders, as well as for green sand and dry sand. Emory et al [5] used an identical setup to study nitrogen compound emissions from three hot-box and three no-bake binder systems. A third set of experiments, again using the same setup, was made by Archibald and Warren [2] on four cold-box binder systems. Their results were given in terms of milligrams of emission per gram of binder resin in the mold.

Tables 3 and 4 contain emission factors calculated from the data of Scott et al [10] and Archibald and Warren [2]. The factors are in terms of tons of emissions per ton of metal poured, and tons of emissions per ton of binder used. These factors should be used with a great deal of caution. First, the work of Scott et al [10] was published in 1977. The binders in use at that time are probably not the same as the binders carrying the same name today, and the normal usage level in a mold may also be quite different. The operating parameters were not varied in either of these studies. If the sand-to-metal ratios are different, the part being cast has a very different configuration, or the metal temperature is different, the effects of these variable changes on the emission factors are unknown.
### Table 3. HAP Emissions per Ton of Metal Poured for Common Binder Systems

**EMISSIONS, ton/ton metal poured**

<table>
<thead>
<tr>
<th>Binder System</th>
<th>Acrolein</th>
<th>Ammonia</th>
<th>Formaldehyde</th>
<th>Hydrogen Sulfide</th>
<th>Hydrogen Cyanide</th>
<th>Nitrogen Oxides</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Alkyd Isocyanate</td>
<td>3.60e-06</td>
<td>1.50e-06</td>
<td>4.35e-06</td>
<td>3.00e-07</td>
<td>7.20e-06</td>
<td>1.46e-05</td>
</tr>
<tr>
<td>2. Core Oil</td>
<td>2.40e-06</td>
<td>1.20e-06</td>
<td>3.00e-06</td>
<td>1.80e-06</td>
<td>2.70e-06</td>
<td>2.55e-06</td>
</tr>
<tr>
<td>3. Dry Sand</td>
<td>1.05e-06</td>
<td>1.95e-06</td>
<td>7.50e-07</td>
<td>4.35e-05</td>
<td>3.00e-06</td>
<td>7.65e-06</td>
</tr>
<tr>
<td>4. Furan Hot Box</td>
<td>6.00e-07</td>
<td>9.45e-04</td>
<td>4.50e-07</td>
<td>2.85e-06</td>
<td>1.65e-04</td>
<td>1.95e-05</td>
</tr>
<tr>
<td>5. Green Sand</td>
<td>1.50e-07</td>
<td>4.65e-06</td>
<td>3.00e-07</td>
<td>5.93e-05</td>
<td>8.40e-06</td>
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<td>NR</td>
<td>NR</td>
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<td>NR</td>
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<table>
<thead>
<tr>
<th>Binder System</th>
<th>Phenol</th>
<th>Sulfur Dioxide</th>
<th>Total Aldehydes</th>
<th>Benzene</th>
<th>Other Aromatics</th>
<th>Total HAPs</th>
</tr>
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<tbody>
<tr>
<td>1. Alkyd Isocyanate</td>
<td>4.50e-06</td>
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<td>8.85e-05</td>
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<td>3.30e-05</td>
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<td>2.25e-05</td>
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<td>2.55e-05</td>
<td>6.00e-06</td>
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<td>4.35e-05</td>
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<td>4.95e-05</td>
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<td>1.11e-03</td>
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<tr>
<td>12. Silicate-Ester</td>
<td>4.50e-06</td>
<td>3.90e-06</td>
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<td>9.00e-06</td>
<td>7.10e-05</td>
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*NR Not Reported*
Table 4. HAP Emissions per Ton of Resin Used for Common Binder Systems

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<thead>
<tr>
<th>Binder System</th>
<th>Acrolein</th>
<th>Ammonia</th>
<th>Formaldehyde</th>
<th>Hydrogen Sulfide</th>
<th>Hydrogen Cyanide</th>
<th>Nitrogen Oxides</th>
<th>EMISSIONS, ton/ton resin</th>
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</thead>
<tbody>
<tr>
<td>1. Alkyd Isocyanate</td>
<td>7.62e-05</td>
<td>3.17e-05</td>
<td>9.21e-05</td>
<td>6.35e-06</td>
<td>1.52e-04</td>
<td>3.08e-04</td>
<td>1.76e-05, 2.25e-05</td>
</tr>
<tr>
<td>2. Core Oil</td>
<td>2.40e-05</td>
<td>1.20e-05</td>
<td>3.00e-05</td>
<td>1.80e-05</td>
<td>2.70e-05</td>
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<td>1.43e-04</td>
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<td>3.08e-05</td>
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<td>3.08e-04</td>
<td>2.80e-04</td>
<td>9.23e-06</td>
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<td>1.23e-05</td>
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<td>4.92e-05</td>
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<td>5.80e-04</td>
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<td>5.00e-06</td>
<td>7.50e-06</td>
<td>9.75e-04</td>
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</tr>
<tr>
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<td>3.27e-05</td>
<td>3.82e-05</td>
<td>3.45e-05</td>
<td>5.45e-06</td>
<td>2.25e-05, 2.55e-05</td>
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<td>NR</td>
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<td>15. FRC Process</td>
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<td>NR</td>
<td>NR</td>
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<td>NR</td>
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<td>16. SO2 Process</td>
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</table>

<table>
<thead>
<tr>
<th>Binder System</th>
<th>Phenol</th>
<th>Sulfur Dioxide</th>
<th>Total Aldhydes</th>
<th>Benzene</th>
<th>Other Aromatics</th>
<th>Total HAPs</th>
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<td>1. Alkyd Isocyanate</td>
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<td>7.35e-04</td>
<td>3.30e-04</td>
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</tr>
<tr>
<td>3. Dry Sand</td>
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<td>5.20e-04</td>
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<td>1.00e-04</td>
<td>1.96e-02</td>
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<td>1.34e-03</td>
<td>2.77e-04</td>
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<td>1.32e-03</td>
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<td>4.73e-04</td>
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<td>2.75e-04</td>
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<td>8.60e-04</td>
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<td>2.90e-02</td>
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<td>NR</td>
<td>NR</td>
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<td>16. SO2 Process</td>
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<td>NR</td>
<td>2.85e-03</td>
<td>1.25e-02</td>
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</table>

* NR Not Reported
3.2.3 Shakeout

No emission factors were developed for shakeout. There were no adequate data in the literature for making estimates of shakeout emission. Obviously operating parameters such as metal temperature, cooling time, and sand-to-metal temperature will have an effect on shakeout emissions.

4.0 TREATMENT TECHNOLOGIES

4.1 SURVEY OF CURRENTLY AVAILABLE TECHNOLOGIES

In order to assess the current commercial availability of pollution control equipment, a letter was sent to each of 99 air pollution control equipment suppliers listed in the Foundry Management & Technology, October, 1992 WHERE-TO-BUY Directory Section. In the letter, the project was identified and information requested on equipment recommended for control of potential air pollutants from coremaking, pouring and shakeout, and sand reclamation processes. Specific requests were made for methods used for sizing equipment, operating parameters, and other factors of importance. Some 26 responses were received, with the majority offering air filtration and gas sampling equipment or services (Table 28). This information was reviewed in preparation of this report.

Table 5. Response to Survey on Current HAP Control Technology Recovery Technology Area

<table>
<thead>
<tr>
<th>Particulates</th>
<th>Gas</th>
<th>Hoods</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Responses</td>
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<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

* 3 responses dealt with sand reclamation processes

4.2 TREATMENT EQUIPMENT AND PROCESSES

In the past several decades, industry has directed its attention toward the protection of the environment. There are five control strategies followed in order to reduce and/or eliminate pollutant emissions. They include elimination of the operation entirely or in part, recycling, modification of the operation, relocation of the operation, applications of control technologies, and combinations of the above. This section deals solely with the use of control technologies.

Before selecting air pollution control equipment, several environmental, engineering, and economic factors must be considered. They are as follows:

Environmental, Economic and Engineering Factors

1. Equipment location
2. Available space
3. Ambient conditions
4. Availability of adequate utilities
The following section gives descriptions of several different control systems. The first section deals with control of gaseous pollutants and the second with the control of particulates.

4.3 TREATMENT PROCESSES

The objective in any treatment process is to bring the gas or liquid containing the particulates or chemical species in contact with a medium (air, water, etc.) so as to remove these species. Gas-liquid contacting processes that involve several components in the gas phase, similar to the foundry emissions, include transfer of one or more species from the gas to a liquid (absorption or scrubbing) or vice-versa (stripping). Some important aspects concerning the behavior of gas-liquid systems and relevant terms used to explain the state of such systems are noted below:

1. The gas in equilibrium with a liquid must be saturated with that liquid.

2. A limited number of intensive system variables may be arbitrarily specified (Gibbs Phase Rule) but the remaining variables must then be evaluated using equilibrium relationships for the distribution of components between the two phases.

3. The partial pressure of a vapor at equilibrium in a gas mixture containing one or more condensable components cannot exceed their respective pure component vapor pressures at the system temperature. Any attempt to increase the partial pressure of the component (by adding more vapor to the gas phase or increasing the total pressure) would lead to condensation of that component.

The techniques available for treating foundry emissions are abundant and the criteria that are important for such an operation should be based on the following:

1. Particle size distribution (including shape and density).
2. Efficiency of the equipment and emission reductions required.
3. Allowable pressure drop vs. required flow rate of gas processed.
4. Capital and operating costs of equipment.
5. Ease of treatment of dirty liquid or solids generated

Among the various collection devices such as spray towers, condensers, cyclone scrubbers, and electrostatic precipitators that are available - a venturi scrubber proves to be a good choice for the treatment of foundry emissions. Inertial impact is the primary collection mechanism for this type of removal. Water is injected upstream of the venturi throat and the curtain of water is broken up by the gas stream into drops which collect the dust. Venturi scrubbers are considered to be highly efficient for small particles similar to foundry emissions (between 0.001 to 100 microns) and there is no particle reentrainment. In spite of its higher efficiency scrubbers do not function well where plume rise is important since a wet plume has little buoyancy.

4.3.1 Absorption

Absorption is a process which removes one or more components from a gas stream by treatment with a liquid [3]. The necessary condition for the removal of components from a gas stream is the solubility of these components in the absorbing liquid. The two most commonly used absorbers are packed and plate towers. In packed towers, the gas moves up through the packing while the liquid flows down the tower. Plate towers, on the other hand, use trays for the liquid to flow across and then down to the next tray, while the gas moves up through perforations in the tray. The design of these towers must be based on the principles of diffusion, equilibrium, and mass transfer [3]. The main objective of the design is to provide a large interfacial area to bring the gas into contact with the liquid.

The efficiency of the tower depends on several factors including a) solubility of the component in a given solvent, b) concentration, c) temperature, d) flow rates of the gas and liquid streams, e) constant surface area, and f) efficiency of solvent regeneration (if the solvent is recycled) [8]. Under ideal conditions, efficiencies of 99+ % can be obtained with absorption.

Absorbers are commonly used for inorganic vapors [8]. If used for organic vapors one may be faced with the following problems. First, the solvent for a particular component may be hard to find or identify. The component must be soluble in the solvent and the solvent should be easily regenerated for recycling. Second, the effluent must be disposed of in an environmentally safe way. Finally, the outlet gas concentrations normally will be small which may lead to unrealistic tower heights, contact times, and high liquid-gas flow rates [8].

This report will not go into a discussion of design equations. They can be found in mass transfer books such as Treybal, Mass Transfer Operations; and Henley & Seader, Equilibrium-Stage Separation Operations in Chemical Engineering.

The following table is a list of some advantages and disadvantages of absorption towers [3].

Advantages

1. Relatively low pressure drop.
2. Standardization in fiberglass-reinforced plastic (FRP) construction permits operation in highly corrosive atmospheres.
3. Capable of achieving relatively high mass-transfer efficiencies.
4. Increasing the height and/or type of packing or number of plates can improve mass transfer without purchasing a new piece of equipment.
5. Relatively low capital cost.
6. Relatively small space requirements.
7. Ability to collect particulates as well as gases.

Disadvantages

1. May create liquid disposal problem.
2. Product collected wet.
3. Particulates deposition may cause plugging of the bed or plates.
4. When FRP construction is used, it is sensitive to temperature.
5. Relatively high maintenance costs.

4.3.2 Adsorption

Adsorption is a process in which certain components of a gas are transferred to the surface of a solid adsorbent. Adsorption is useful in air pollution control because it concentrates gaseous pollutants, thus facilitating their disposal [11]. It is used for industrial applications such as odor control, or recovery of volatile solvents [4].

There are two types of adsorption, physical and chemical. Physical adsorption is the result of intermolecular forces of attraction between the solid and the substance being adsorbed [12]. This process is reversible, which allows recovery of the adsorbed material. When the attractive forces between the solid and the gas are stronger than those between the molecules of the gas itself, the gas will condense on the surface of the solid. This process is accompanied by the release of heat, which usually is larger than the latent heat of vaporization of the sorbed material. The forces holding the sorbed material to the solid can be overcome by the addition of heat or lowering the pressure, allowing regeneration of the adsorbent.

Chemical adsorption is the result of chemical interaction between the gas and solid [12]. Chemisorption is characterized by the following characteristics: a) energy released is greater than that of physical adsorption, b) the process is irreversible, c) the rate increases with a rise in temperature, d) it is more highly selective than physical adsorption, e) the capacity of the adsorbent is limited to that of the active sites on its surface. Chemical adsorption is not a feasible process if the recovery of the material is desired or if the adsorbent is to be regenerated for re-use.

There are several different solid adsorbents. The most widely used are activated carbon and molecular sieves. Descriptions and physical properties of different adsorbents can be found in Buonicore & Davis, *Air Pollution Engineering Manual*; Cooper & Alley, *Air Pollution Control A Design Approach*, and Rao, *Environmental Pollution Control Engineering*.

Adsorption takes place in fixed, moving, and fluidized beds [3]. A fixed bed adsorber is fitted with perforated screens to support the adsorbent [9]. The moving bed adsorbers move the adsorbent in and out of the adsorption zone. Finally, the fluidized bed adsorbers contain a number of shallow fluidized beds of activated adsorbent. Design equations for these different beds can be found in mass transfer books, such as Treybal, *Mass Transfer Operations* and Sherwood, Pigford and Wilke, *Mass Transfer*. 
The following is a list of advantages and disadvantages of the adsorption process [3]:

Advantages

1. Recovery of the sorbed material may be possible.
2. Excellent control and response to process changes.
3. No chemical disposal problem when pollutant is recovered and returned to the process.
4. Capability of systems to provide fully automatic, unattended operation.
5. Capability to reduce gaseous vapor contaminants from process streams to extremely low levels.

Disadvantages

1. Product recovery may require an exotic, expensive distillation (or extraction) scheme.
2. Adsorbent progressively deteriorates in capacity as the number of cycles increases.
3. Adsorbent regeneration requires a steam or vacuum source.
4. Relatively high capital cost.
5. Prefiltering of gas stream may be required to remove any particulate capable of plugging the adsorbent bed.
6. Cooling of the gas stream may be required to get the usual range of operation (less than 120 °F).
7. Relatively high steam requirements to desorb high molecular-weight hydrocarbons.
8. Generally applicable to the removal of small amounts of pollutants.

4.3.3 Combustion

Combustion is a process in which organics are converted to carbon dioxide and water by rapid oxidation. Combustion, also known as incineration, can be used for odor control, and to destroy toxic compounds [4]. This process can achieve 95 to 99 percent efficiencies [8]. There are three combustion processes used to destroy organic contaminants: 1) flaring, 2) thermal incineration, 3) catalytic incineration [7].

Time, temperature, and turbulence, the three T's, govern the speed and completeness of combustion [7]. The oxygen must come into intimate contact with the combustible material at a sufficient temperature for a sufficient length of time for the reaction to be completed. Incomplete reactions may result in the formation of aldehydes, organic acids, and carbon monoxide.

Flares and thermal incineration are characterized by a flame, while catalytic incineration is flameless. In catalytic incineration, a metallic catalyst is used to produce oxidation.

Flares are usually applied when the heating value of the gases cannot be recovered economically [8]. They are commonly used to control process upsets and accidental releases. They are most widely used to dispose of hydrocarbons [7]. There are three common types of flares: 1) elevated, 2) ground level, 3) burning pits [9].

Thermal incineration is used for a wide but low range of organic vapor concentrations [3]. They consist of burners, which ignite the fuel and organic vapor, and a chamber, which provides appropriate residence time for the oxidation process. The concentration of gas to be treated must be below the lower explosive limit. The feed is usually preheated since the reaction occurs at
elevated temperatures. Following is a list of some operating ranges: Temperature-1200 to 1500 °F; Time-0.2 to 1.0 seconds; and gas velocity-10 to 50 ft/s. High velocities are needed to prevent settling of particulates (if any) and minimize dangers of flashback and fire hazards. The advantage of thermal incinerators is that energy can usually be recovered in some form.

In catalytic incineration, the waste stream passes over a catalyst bed [7]. For simple reactions, the effect of the presence of a catalyst is to 1) increase the reaction rate, 2) permit the reaction to occur, and 3) reduce the reactor volume. Conditions for operation are lower than those of thermal incineration. Gas is delivered at a velocity between 10 to 30 ft/s and a much lower temperature, between 650 to 800 °F. Catalytic incineration is more sensitive to pollutant characteristics. The design is generally less expensive than thermal incinerators [8]. Commonly, metals from the platinum family are used for the catalyst due to their ability to combust at low temperatures [7].

Following is a list of advantages and disadvantages of combustion processes [3].

Advantages

1. Simplicity of operation.
2. Capability to provide steam generation or heat recovery in other forms.

Disadvantages

1. Relatively high operating cost.
2. Potential for flashback and subsequent explosion hazard.
3. Catalyst poisoning.
4. Incomplete combustion can create potentially worse pollution problems (NOx, SOx).

4.3.4 Condensation

Condensation is a process which changes a vapor into a liquid. It is frequently applied as a preliminary air pollution control device to remove concentrated vapors from a gas stream before the gas reaches more expensive equipment, such as an absorber [8]. Condensation is accomplished by either lowering the temperature or increasing the pressure. However, increasing the pressure is often economically infeasible. Efficiencies of 50 to 90 percent can be reached using condensation [8], however, the effectiveness depends directly upon the vapor pressure or volatility of the compounds being condensed.

Metallurgical dusts and fumes have a range of particle diameters from 0.001 to 100 microns. Particulate controls are used in many foundries, and condensible vapor components may condense on solid particles and be trapped in these collection devices. Therefore, particulate collection may reduce somewhat the emissions of low-volatility HAP’s. When considering the level of emissions from an air pollution control device, one should remember that the partial pressure of a component in a gas stream cannot exceed the vapor pressure of that component. Thus, if a gas stream is cooled, some of the less volatile components may condense.

There are two common types of condensers used for air pollution control: contact and surface [7]. Contact condensers bring the gas stream into direct contact with the cooling fluid, where the vapors condense and mix with the coolant. Three common types of contact condensers are spray, jet, and barometric, which are usually more flexible and have better efficiencies than surface condensers. They also have the following advantages: 1) they can be used to produce a
vacuum, therefore, creating a draft to remove odorous vapors, 2) they are usually simpler and less expensive than surface condensers, and 3) they usually have considerable odor-removing capacity. However, the principle disadvantage is their large water requirement.

Surface condensers are used for recovery, control and/or removal of trace impurities or contaminants [7]. In the surface-type condenser the vapor does not contact the coolant. The coolant is placed in the tubes while the vapor condenses in the shell portion of the condenser. Three types of surface condensers are the tube-and-shell, fin fan, and tubular. The advantages of the surface condenser are as follows: salable condensate can be recovered; water, used as the coolant, can be reused; and surface condensers require less water and produce 10 to 20 times less condensate. On the other hand, they are more expensive and require more maintenance than the contact condensers.

Design equations can be found in Kern, Process Heat Transfer; and Buonicore & Davis, Air Pollution Engineering Manual.

The following is a list of advantages and disadvantages of the use of a condenser [3].

Advantages

1. Pure product recovery (in the case of surface condensers).
2. Water used in surface condensers does not contact the contaminated gas stream and can be used after cooling.

Disadvantages

1. Relatively low removal efficiencies for gaseous contaminants.
2. Coolant requirements may be extremely expensive.

Estimation of Vapor Pressure:

Because the effectiveness of condensation for removing components from an air stream is directly related to the volatility of the compounds, calculations of vapor pressures were made for compounds of interest. The vapor pressures of the various chemical emissions from Foundry Molds were estimated at two temperatures (100 and 200°F) by using an integrated form of the Clausius-Clapeyron equation. These temperatures were chosen because they should cover the range of expected temperatures for particulate treatment devices which treat ambient air from the various parts of the foundry. Each species of the emissions has an appropriate form of equation which estimates vapor pressure that agrees well with the observed vapor pressures in literature. The following are the three forms of expressions used from The Properties of Gases & Liquids by Reid et al:
\[ \ln\left(\frac{P_{vp}}{P_c}\right) = (1-x)^{-1} [Ax + Bx^{1.5} + Cx^3 + Dx^6] \quad --- \quad (1) \]

where \( x = 1 - \frac{T}{T_c} \)

\[ \ln P_{vp} = A - \frac{B}{T} + C \ln T \quad --- \quad (2) \]

\[ \ln P_{vp} = A - \frac{B}{[T+C]} \quad --- \quad (3) \]

where

- \( P_{vp} = \) Vapor pressure, in bars
- \( P_c = \) Critical pressure, in bars
- \( T_c = \) Critical temperature, in degrees Kelvin
- \( T = \) Temperature, in degrees Kelvin
- \( A, B, C, & D = \) Constants

Listed below are the equations used for each of the chemical species.

<table>
<thead>
<tr>
<th>Equation 1</th>
<th>Equation 2</th>
<th>Equation 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. m-Xylene</td>
<td>13. Hydrogen Cyanide</td>
<td></td>
</tr>
<tr>
<td>4. o-Xylene</td>
<td>14. Sulfur Dioxide</td>
<td></td>
</tr>
<tr>
<td>6. Acetaldehyde</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. n-Butyraldehyde</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Propionaldehyde</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Phenol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Formaldehyde</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 6. Pure Component Vapor Pressures and Equilibrium Mole Fractions at 100°F[1] and 200°F[2]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ammonia</td>
<td>46.997</td>
<td>141.790</td>
<td>4.638e-04</td>
<td>1.399e-03</td>
</tr>
<tr>
<td>2. Hydrogen Sulfide</td>
<td>58.668</td>
<td>134.395</td>
<td>5.790e-04</td>
<td>1.326e-03</td>
</tr>
<tr>
<td>3. Hydrogen Cyanide</td>
<td>8.315</td>
<td>43.630</td>
<td>8.207e-05</td>
<td>4.306e-04</td>
</tr>
<tr>
<td>4. Sulfur Dioxide</td>
<td>22.765</td>
<td>78.244</td>
<td>2.247e-04</td>
<td>7.722e-04</td>
</tr>
<tr>
<td>5. Nitrogen Oxides</td>
<td>380.074</td>
<td>486.480</td>
<td>3.751e-03</td>
<td>4.801e-03</td>
</tr>
<tr>
<td>10. Phenol</td>
<td>0.002</td>
<td>0.041</td>
<td>1.550e-08</td>
<td>4.011e-07</td>
</tr>
<tr>
<td>11. Benzene</td>
<td>0.222</td>
<td>1.494</td>
<td>2.189e-06</td>
<td>1.474e-05</td>
</tr>
<tr>
<td>12. Toluene</td>
<td>0.071</td>
<td>0.601</td>
<td>6.999e-07</td>
<td>5.936e-06</td>
</tr>
<tr>
<td>13. m-Xylene</td>
<td>0.022</td>
<td>0.247</td>
<td>2.218e-07</td>
<td>2.435e-06</td>
</tr>
<tr>
<td>14. o-Xylene</td>
<td>0.018</td>
<td>0.209</td>
<td>1.796e-07</td>
<td>2.061e-06</td>
</tr>
<tr>
<td>15. Naphthalene</td>
<td>0.001</td>
<td>0.018</td>
<td>6.987e-09</td>
<td>1.731e-07</td>
</tr>
</tbody>
</table>

While condensation has not been widely used as an air pollution control method in the metal casting industry, other equipment such as venturi scrubbers and bag houses are common. Compounds which are emitted in hot operations, such as pouring, cooling, and shakeout will condense to form a smoke or fume that may be trapped in a bag-house or scrubber. The data on equilibrium partial pressures presented in Table 6 can be used to estimate the emissions of condensible compounds from particulate collection devices. If the mole fraction of a component is less than the listed values, the component will not condense. If, however, the mole fraction of a component exceeds the values listed, the component will condense and will be collected in a particulate collection device if the condensate has a large enough particle size. It is very common for condensate to collect on solid particles, so that the chance of collection of a fume in conjunction with other particulates is enhanced.

4.3.5 Cyclone Separators

Cyclone separators are used for the control of medium-sized and coarse particulates [3]. They have a low purchase cost, no moving parts, and can be made to withstand harsh conditions [4]. The efficiency of a cyclone is not as high as other particulate collection devices [3]. For this reason, cyclones are usually used as a precleaner for other particulate control devices.
Gas enters the cyclone near the top, then it is forced in a downward spiral because of its shape and tangential entry [4]. As the gas spirals down, centrifugal force and inertial forces cause the particles to move outward, collide with the wall and slide down to be collected. Near the bottom, the gas reverses its downward spiral and moves up in a tighter spiral and exits out the top of the cyclone. There are three categories of cyclones: high efficiency, conventional, and high throughput.

The efficiency depends on the particle size and cyclone design [4]. Efficiency may be 98% for particles greater than 5 microns but drops off to 90% for particles greater than 15 to 20 microns. As the efficiency of the cyclone increases so does the operating cost due to a high pressure drop. When the gas flow is high, several cyclones may be used in series or parallel [11]. Using them in series will increase the overall efficiency, but there will be a significant pressure drop. Cyclone separator design equations can be found in Buonicore and Davis, Air Pollution Engineering Manual; and Cooper and Alley, Air Pollution Control A Design Approach.

The following are the advantages and disadvantages of cyclones [3].

**Advantages**

1. Low cost of construction.
2. Relatively simple equipment with few maintenance problems.
3. Relatively low operating pressure drop in the range of approximately 2 to 6 inches water column.
4. Temperature and pressure limitations imposed only by the materials of construction used.
5. Dry collection and disposal.
6. Relatively small space requirements.

**Disadvantages**

1. Relatively low overall particulate collection efficiencies.
2. Inability to handle tacky materials.
3. Operating cost increase with increasing efficiency.

**4.3.6 Fabric Filtration**

One of the most frequently used technologies for airborne particulate control is fabric filtration or baghouses. They operate by pumping the dirty gas into the baghouse, where the particulates accumulate on the bags. The dust is allowed to build up on the bags until the pressure drop begins to become excessive, then the bags are cleaned. The build up of the cake is usually what determines the efficiency of the process.

Baghouses are least efficient for collecting particulates between 0.1 to 0.3 \( \mu \text{m} \) in diameter [8], however, particles larger or smaller than this can be collected with an efficiency of 99% or greater. The efficiency is largely insensitive to the physical characteristics of the gas and dust, and, depending on the fabric cleaning method, to the inlet dust loading.

There are three types of baghouses: 1.) reverse-air, 2.) shaker, and 3.) pulse-jet [4]. The reverse air baghouse feeds the gas/dust stream up through the bottom of the bags, in which the dusts collect on the inside of the bags. The dust builds up until the pressure drop gets too high, and then the clean gas flow is reversed back through the bags. This reversal knocks the filter cake
off the bags and the solid collects in the bottom in the hopper. They are usually constructed with several different bag compartments to allow continuous running while some of the bags are being cleaned. The reverse air cleaning process is gentle, therefore, the bags have a long life span.

Shaker baghouses operate in the same way as the reverse air type. The difference comes from the manner in which they are cleaned. The filter cake on the inside of the bags is mechanically shaken off the bags. The shaking motion can be vertical, horizontal, or a combination of both [3]. The one condition that absolutely has to be met during cleaning is that there be no positive direction flow. For this reason, as with the reverse air baghouses, they are designed with several compartments to allow a continuous operation during cleaning. The shaking of the bags tend to decrease their life span.

The third type of baghouse, pulse jet, employs high pressure compressed air to back flush the bags [3]. This method creates a shock wave, that travels down the bag knocking dust off. This cleaning technique is fast, only lasting a fraction of a second. Therefore, this process does not require that the baghouse be divided into separate compartments. Another difference between the pulse jet and the others is that the bags are closed at the bottom and open at top, hence, the dust collects on the outside of the bags. Internal frames, called cages, support the bags to prevent them from collapsing while they are in use. Once again the pulse jet action is harsher on the bags, shortening their life span.

The design equations for baghouses can be found in Buonicore and Davis, Air Pollution Engineering Manual, and Cooper and Alley, Air Pollution Control A Design Approach.

The following is a list of the advantages and disadvantages of baghouses [3].

Advantages
1. Extremely high collection efficiency on both coarse and fine (submicron) particulates.
2. Relatively insensitive to gas stream fluctuation. Efficiency and pressure drop are relatively unaffected by large changes in inlet dust loadings for continuously cleaned filters.
3. Filter outlet air may be recirculated within the plant in many cases (for energy conservation).
4. Collected material is recovered dry for subsequent processing or disposal.
5. No problems with liquid waste disposal, water pollution, or liquid freezing.
6. Corrosion and rusting of components are usually not problems.
7. There is no hazard of high voltage, simplifying maintenance and repair and permitting collection of flammable dusts.
8. Use of selected fibrous or granular filter aids (precoating) permits the high-efficiency collection of submicron smokes and gaseous contaminants.
9. Filter collectors are available in a large number of configurations, resulting in a range of dimensions and inlet and outlet flange locations to suit installation requirements.
10. Relatively simple operation.

Disadvantages
1. Temperatures much in excess of 550 °F require special refractory mineral or metallic fabrics that are still in the development stage and can be very expensive.
2. Certain dusts may require fabric treatments to reduce dust seeping or, in other cases, assist in the removal of the collected dust.
3. Concentrations of some dusts in the collector may represent a fire or explosion hazard if a spark or flame is admitted by accident. Fabrics can burn if readily oxidizable dust is being collected.

4. Relatively high maintenance requirements (bag replacement, etc.).

5. Fabric life may be shortened by elevated temperatures and in the presence of acid or alkaline particulate or gas constituents.

6. Hygroscopic materials, condensation of moisture, or tarry adhesive components may cause crusty caking or plugging of the fabric or require special additives.

7. Replacement of fabric may require respiratory protection for maintenance personnel.

8. Medium pressure-drop requirements, typically in the range of 4 to 10 inches water column.

4.3.7 Electrostatic Precipitators (ESP)

ESP's induce a charge on the particle in the gas stream that causes the particles to accumulate on collector plates. Once collected on the plates, the particulates are knocked off and transferred to a hopper. They are less sensitive to the size of the particles but very sensitive to aerosol density and electrical resistivity of the particle [8]. Drift velocity of the particle is influence by this resistivity. The overall efficiency will experience a decrease if there is a low drift velocity due to a high resistivity.

The operation of an ESP consists of forcing the particle through a corona to give them an electric charge [3]. A corona is an action in which the voltage applied to the electrodes cause the gas between the electrodes to break down electrically. Then an electric field, caused by high voltage electrodes, force the particle to the collector plates. There are five common type of ESP's: 1.) plate-wire, 2.) flat-plate, 3.) tubular, 4.) wet, and 5.) two-stage.

In plate-wire ESP's, the gas flows between parallel plates of sheet metal and high voltage electrodes, passing each wire in sequence as it flows through the unit [3]. The units may be tall, however, they also allow many flow lanes to operate and are able to handle large volumes of gasses. The electrodes are commonly given a negative polarity because a negative corona supports a higher voltage than a positive corona before sparking. A charging zone is established by the ions, generated in the corona, following electric field lines from the wires to the collecting plates.

Flat-plate ESPs operate on the same principles as plate-wire ESPs [3]. The difference is that they use flat plates instead of wires. They are able to increase the average electric field, however, they are not able to generate coronas. Therefore, the coronas are generated using electrodes placed ahead of and sometimes behind the flat plate collecting zones.

Tubular ESPs have the electrodes running along the axis of the tube [7]. The tubes can be formed as circular, square, or hexagonal honeycombs, with the gas flowing either upward or downward. The high voltage electrodes operate at one voltage for the entire length of the tube and the current varies along length as the particulates are removed from the system.

Wet ESPs are any of the above configurations with wet walls instead of dry [3]. Water may be applied intermittently or continuously to wash the walls. The advantages of a wet ESP are there are no back coronas or problems with reentrainment when knocking the particulates off the wall.

A two-stage ESP is a series device while those described above are parallel in nature [3]. The discharge electrode precedes the collector electrodes, and in indoor applications is operated
with a positive polarity to limit ozone production. They are usually used for gas flows of 50,000 cfm and less. Two-stage ESPs are considered a separate and unique device as compared to large high gas volume single stage ESPs.

The design procedure and equations for an ESP can be found in Buonicore and Davis, Air Pollution Engineering Manual, and Cooper and Alley, Air Pollution Control A Design Approach.

The advantages and disadvantages of ESPs are listed below [3].

Advantages

1. Extremely high particulate collection efficiencies can be attained.
2. Dry collection and disposal.
3. Low pressure drop.
4. Designed for continuous operation with minimum maintenance requirements.
5. Relatively low operating costs.
6. Capable of operation under high pressure (to 150 psi) or vacuum conditions.
7. Capable of operation at high temperatures (to 1300 °F).
8. Relatively large gas flow rates can be effectively handled.

Disadvantages

1. High capital cost.
2. Very sensitive to fluctuations in gas stream conditions (flow rates, temperatures, particulate and gas composition and particulate loadings).
3. Certain particulates are difficult to collect due to extremely high or low resistivity characteristics.
4. Relatively large space requirements for installation.
5. Explosion hazard when treating combustible gases and/or collecting combustible particulates.
6. Special precautions required to safeguard personnel from the high voltage.
7. Ozone is produced by the negatively charged electrode during gas ionization.
8. Relatively sophisticated maintenance personnel required.

4.3.8 Wet Scrubbers

Wet scrubbers remove particulates from a gas stream by trapping the particles in liquid droplets and then separating the droplets from the gas stream [3]. They can be used for the following conditions: 1.) contaminant cannot be removed easily in a dry form, 2.) soluble gases are present, 3.) soluble or wettable particulates are present, 4.) contaminant will undergo some subsequent wet process, 5.) pollution control equipment must be compact, 6.) contaminants more safely handled wet than dry. The particulates are captured in the liquid droplets by one of the following mechanisms: impaction, interception, and diffusion.

The goal of the scrubber is to cause the particle to become trapped in a water droplet and then be removed from the gas stream [3]. The size of the particle removed is determined by the size of the liquid droplets. The smaller particles will be trapped in the smaller droplets. If the droplets are densely packed, there will be higher probability of capturing the particles. The scrubber must be designed properly to ensure that the droplets are densely packed with the proper droplet sizes. A successful scrubber will be able to create and control droplet dispersion effectively. Commonly, there are five types of wet scrubbers in use: 1.) venturi, 2.) mechanically aided, 3.) pump aided, 4.) wetted filter type, and 5.) tray or sieve.
Venturi scrubbers consist of a converging section, throat, and diverging section [3]. The scrubbing liquid can be injected in a variety of ways including at the throat zone, at the gas inlet, and upward against the gas flow. They are usually considered to be a high energy particulate control device. They operate by converting the static pressure to kinetic energy in order to shear the scrubbing liquid into fine droplets.

Mechanically aided scrubbers create droplet dispersion by the use of a whirling mechanical device (usually a fan wheel or disk) [3]. The scrubbing liquid is injected into the mechanical device and mechanical energy is added to the system to break the liquid into fine droplets. Typically, the scrubber itself uses lower fan energy but the collection energy comes from a supplemental, device equipment. Therefore, the entire system would have to be considered in deciding the energy requirements.

Pump aided scrubbers introduce the liquid in a variety of ways including countercurrent to the gas, in the same direction as the gas, and at an angle [3]. They use atomized sprays to control the dispersion of the droplets. The energy input comes from the pressurized liquid stream and they are considered more efficient than fan aided scrubbers. Some different types of pump aided scrubbers are spray chambers, cyclone spray chambers, and orifice scrubbers [4].

Wetted filter scrubbers force the liquid and gas to go through small openings where a filtration process occurs [3]. The particulates temporarily stick to the filter. These type scrubbers are best suited for low particulate loadings.

Tray or sieve scrubbers accelerate the gas stream through small orifices on the tray [3]. The kinetic energy is used to create a froth in the liquid and the particulate is injected into the liquid stream.

Once again, design equations can be found in Buonicore and Davis, Air Pollution Engineering Manual; and Cooper and Alley, Air Pollution Control A Design Approach.

The following are the advantages and disadvantages of wet scrubbers [3].

Advantages

1. No secondary dust sources.
2. Relatively small space requirements.
3. Abilities to collect gases as well as particulates.
4. Ability to handle high-temperature, high-humidity gas streams.
5. Low capital cost (if wastewater treatment system is not required).
6. For some processes, the gas stream is already at high pressures (so pressure drop considerations may not be significant).
7. Ability to achieve high collection efficiencies on fine particulates (however, at the expense of pressure drop).

Disadvantages

1. May create water disposal problem.
2. Product is collected wet.
3. Corrosion problems are more severe than with dry systems.
4. Steam plume opacity and/or droplet entrainment may be objectionable.
5. Pressure drop and horsepower requirements may be high.
6. Solids build up at the wet-dry interface may be a problem.
7. Relatively high maintenance costs.

5.0 FIELD INFORMATION ON POTENTIAL AIR EMISSIONS OF HAP’S FROM IRON AND STEEL FOUNDRY BINDERS AND OTHER CHEMICALS

Potential air emissions of HAP’s from binders and other chemicals used in iron and steel foundries were assessed from information obtained from the technical literature, suppliers, MSDS’s, foundry contacts, and from AFS educational workshops.

5.1 SUPPLIER CONTACTS

Suppliers of chemicals to foundries were contacted by form letter and asked to submit information on binder chemical emissions. Phone calls to four major binder manufacturers also yielded applicable information. Material Safety Data Sheets (MSDS) were obtained from these manufacturers. One supplier provided information by binder type and process, while another provided information with only by binder type. Two other suppliers did not respond. Several iron foundries were also contacted for information but only a few responded.

5.2 WORKSHOPS

One of the investigators attended an AFS workshop on coremaking at the AFS training center in Chicago in April, 1992. The workshop provided valuable information from the instructors and attendees. Notes taken from the school were used to make a chart with several different binders and their emissions. Much of this information was included in the binder process descriptions discussed above.

5.3 FOUNDRY VISITS

Visits have been made to six major foundries in Alabama to discuss current process information and extent of data available on air emissions of hazardous air pollutants from coremaking, pouring, and shakeout operations.

6.0 OTHER ACTIVITIES

6.1 USEPA COORDINATION

Several trips have been made to Durham, NC to coordinate activities with USEPA’s Office of Air Quality Planning and Standards. James H. Maysilles, the EPA Project Officer, is our designated contact for the project. The EPA contractor for developing the Background Information Document is Research Triangle Institute, also in Durham.

6.2 QUESTIONNAIRE DEVELOPMENT

A questionnaire was developed to help foundries to begin to assess air emission potentials for the different processes. Worksheets were prepared for scrap pretreatment, melt furnace, core room, molding, pouring, shakeout, and sand reclaiming. The questionnaire was tested on several foundries in Alabama, but contact with USEPA’s Office of Air Quality Planning and Standards indicated that their screening information request (the "short form"), and maximum achievable control technology (MACT) standards development information request (the "long form"), were to
be issued shortly. To prevent confusion between the documents, we suspended work on our version and concentrated on coordinating our efforts with the USEPA in developing the questionnaire and in helping the foundryman understand and fill out the required forms.

6.3 PAPERS AND PRESENTATIONS

The following presentations have been made in conjunction with this project:


Marvin D. McKinley, Irvin A. Jefcoat, William J. Herz, and Chris Frederick, "Air Emissions from Foundries: A Survey of Currently Available Information from the Literature, Suppliers, and Foundrymen”, Presented at the 97th Casting Congress & CASTEXPO ’93, Chicago, IL, April, 1993. Paper has been accepted for publication in AFS Transactions.


7.0 CONCLUSIONS

The data in the literature on organic HAP emissions are of two types: (1) identification of chemical types and their concentrations in the workplace needed for worker health and safety, and (2) emissions during pouring and cooling. There are no emission data reported for shakeout. The pouring and cooling emissions were made for a single type of casting using the same metal-to-sand ratio and gray iron. Most data were reported either as concentrations in the gas or in milligrams of HAP per gram of binder resin. Emission factors were calculated from the literature data in terms of tons emission per ton of resin or per ton of metal poured for 16 binder systems from pouring and cooling, but much of the data were taken a long time ago and do not reflect improvements in binders or current usage levels. Even though some of the data may be out of date, they are the only published data available. It is clear that many small and medium-sized foundries will not have emissions at levels which will trigger MACT. The numbers presented here can be viewed as "worst-case" for purposes of estimating the impact of the CAAA on a particular foundry. While these emission factors allow calculation of order of magnitude estimates of emissions, they do not give the effect of parameters on the emission level. It is not clear that reporting the data as either ton HAP/ton of resin or ton HAP/ton of metal poured is valid if the sand-to-metal ratio changes. There are no data at different metal temperatures, so that emission factors based on this literature cannot be used for steel casting. Since shakeout may occur at a different part of the plant, and because pyrolysis products may be trapped in the sand before shakeout, the effect of cooling time on shakeout emissions is needed. It is apparent that additional research is needed to determine the important parameters that control HAP emissions.

While laboratory data on emissions are needed for parameter studies, these data must be supplemented by plant measurements for validation. A research program which includes both laboratory data and plant testing is needed.

Treatment technologies currently available for reducing HAP emissions were briefly covered in this report. There is a conflict between control of concentration of HAP’s in the ambient air in
the foundry for worker health and safety and the effective collection and treatment of emissions to the air. For worker health and safety, a large volume of air is normally pulled through the plant. This large volume of air makes concentrations low and amount of gas to be treated high, which is detrimental to gas treatment for HAP emission control. It appears that most small (<50 employees) and medium (50 to 500 employees) foundries will emit HAP's at a level below the threshold amounts specified by the CAAA. The large foundries (>500 employees), however, appear to be likely to exceed the thresholds. It appears that the first approach to emission control should be reduction of emissions through process and binder changes, and that controls to capture emissions other than particulate controls may be prohibitively expensive.
BIBLIOGRAPHY


APPENDIX

VENDORS OF AIR EMISSION CONTROL EQUIPMENT
VENDORS:


ABSORBERS: GAS

1. Analytichem International Inc.--Harbor City, CA
2. Adsorbents & Dessicants Corp. of America--Los Angeles, CA
3. Divesified Vacuum Technology, Inc.--Colorado Springs, CO
4. Ultrapure Systems Inc.--Colorado Springs, CO
5. Micrographic Technology, Inc.--Denver, CO
6. Entrolete, Inc.--New Haven, CT
7. ABB/ASEA Brown Boveri Inc.--Stamford, CT
8. Patterson Process Equipment Div., Patterson Pump Co.--Toccoa, GA
9. Flex-Kleen Corporation--Chicago, IL
10. Trema North America Inc.--Reisterstown, MD
11. Sphinx Adsorbents Inc.--Springfield, MA
12. Monroe Environmental Corp.--Monroe, MI
13. Iroquis Industries Inc.--Muskegon, MI
14. Missouri Boiler & Tank Co.--St. Louis, MO
15. Sigri Corporation--Bedminster, NJ
16. RaySolv Inc.--Bound Brook, NJ
17. Advanced Industrial Technology Corp.--Lodi, NJ
18. Ambient Engineering Inc.--Matawan, NJ
19. Allied Group--Mendham, NJ
20. Hydronics Engineering Corp.--Midland Park, NJ
21. York, Otto H., Co. Inc.--Parsippany, NJ
22. Ergenics Inc.--Ringwood, NJ
25. Clean Gas Systems Inc.--Farmingdale, NY (516-756-2474 Ext. 91)
26. Ducon Environmental Systems--Farmingdale, NY
27. Emtrol Corp.--Hauppauge, NY (516-582-9700)
29. Chemipulp/Jenssen Div.--Watertown, NY
30. Harrison Plastic Systems--Aurora, OH
31. Midwest Filtration Co.--Hamilton, OH
32. Nutter Engineering Div., Patterson-Kelley--Tulsa, OK
33. Air Products & Chemicals--Allentown, PA
34. GE Company, GE Environmental Services--Lebanon, PA
35. CTC Industrial Servics, Inc.--Memphis, TN
36. BS & B Engineering Co., Inc.--Houston, TX
37. Ershings, Inc.--Belligham, WA

TOWERS: ABSORPTION

1. Ecodyne Cooling Tower Services--Santa Rosa, CA
2. Monroe Environmental Corp.--Monroe, MI
3. Duall Div. Met-Pro Corporation--Owosso, MI
4. Anel Industries, Inc.--Winona, MI
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<td>ECO Equipment FEP Inc.</td>
<td>PQ, Anjou, Canada</td>
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SCRUBBERS: AIR

2. Beco Corporation-- Benton, AR
3. Tigg Corp.-- Heber Springs, AR (800-925-0011)
4. Advance Fiberglass, Inc.-- Little Rock, AR (800-342-7367)
5. Jaeger Aerospace Engineering-- Costa Mesa, CA
6. ACME Fiberglas, Inc.-- Hayward, CA (510-538-3440)
7. Air Chem Systems Inc.-- Huntington Beach, CA
8. Campbell, J.A., Company-- Long Beach, CA (310-424-0455)
9. Joy Technologies, Inc., Western Precipitation Div.-- Monrovia, CA
10. Calvert Environmental-- San Diego, CA (619-272-0050)
11. Aqua Craft, Inc.-- San Francisco, CA (415-637-0322)
12. Environmental Corrections, Inc.-- Sun Valley, CA
13. TFI International-- Commerce City, CO
14. Air Sentry, Inc.-- Denver, CO (800-878-7897)
15. Interal Corp.-- Englewood, CO (303-773-0753 Ext.300)
16. Quality Plating Services, Inc.-- Bristol, CT (203-582-7518)
17. M & S Engineering & Mfg. Co., Inc.-- Broad Brook, CT
18. Entoletier, Inc.-- New Haven, CT (203-787-3575)
19. ABB/ASEA Brown Boveri, Inc.-- Stamford, CT (800-626-4999)
20. Industrial Plastic Systems, Inc.-- Lakeland, FL (813-646-8551)
22. Savage Industries-- Tucker, GA
23. Amerex, Inc.-- Woodstock, GA (404-928-0970)
25. Bact Engineering Inc.-- Arlington Heights, IL
26. Flex-Kleen Corporation-- Chicago, IL (312-648-5300)
27. Bisco Enterprise-- Franklin Park, IL (708-671-4466)
28. Nokorrode, Inc.-- Mundelein, IL
29. Quad Environmental Technologies Corp.-- Northbrook, IL
30. ARI Technologies, Inc.-- Palatine, IL (708-359-7810)
31. Amquip Inc.-- Hammond, IN
32. Snodgrass, Brad, Inc.-- Indianapolis, IN
33. AAF/Snydergeneral Corp.-- Louisville, KY (502-637-0011)
34. Fisher-Klosterman, Inc.-- Louisville, KY (502-776-1505)
35. Vanaire-- Louisville, KY (502-491-3553)
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44. Clarkson Controls & Equipment Co.-- Detroit, MI (313-255-9110)
45. Uni-Wash, Incorporated-- Harbor Springs, MI (616-347-5005 Ext.20)
46. CMI-Schneible-- Holly, MI (313-634-8211)
47. Centri-Spray Corp.-- Livonia, MI
48. Haden Management Corp.-- Madison Heights, MI
49. Haden Schweitzer Corp.-- Madison Heights, MI
50. Monroe Environmental Corp.-- Monroe, MI (800-922-7707)
51. Monroe Welding & Engineering Co.-- Monroe, MI
52. Duall Div. Met-Pro Corporation-- Owosso, MI
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58. Anel Industries, Inc.-- Winona, MS
59. Monsanto Enviro-Chem Systems Inc.-- St. Louis, MO
60. Willow Springs Mfg., Ltd.-- Willow Springs, MO (417-469-2792)
62. Eastern Cyclone Industries, Inc.-- Fairfield, NJ
63. DR Technology, Inc.-- Freehold, NJ
64. Environmental Dynamics Corp.-- Kresson, NJ (609-768-1100)
65. North American Pollution Control Systems, Inc.-- Linden, NJ (800-752-0237)
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87. Zelcron Industries Inc. c/o Ducon Environmental Systems Div.-- Melville, NY (800-394-4990)
88. Swemco, Inc.-- New York, NY (212-645-0440)
89. KCH Services, Inc. Dept. N-- Forest City, NC
90. Harrison Plastic Systems-- Aurora, OH
91. Ceilcote, Air Pollution Control Div. Master Builders Inc.-- Berea, OH (216-243-0700)
92. Air Plastics, Inc.-- Cincinnati, OH
93. Effox, Inc.-- Cincinnati, OH
94. Kleinfeldt, R.F., Co., Inc.-- Cincinnati, OH
95. Aquatech Inc.-- Cleveland, OH
97. Barnebey & Sutcliffe Corp.-- Columbus, OH (614-258-9501)
98. R. L. Industries, Inc.-- Fairfield, OH (800-846-2735)
99. Volk Environmental Technology-- Mansfield, OH
100. Volk, Mike, Co., Inc.-- Mansfield, OH
101. ACDC Inc.-- Milford, OH (513-248-1820)
102. Vorti-Siv Div. of M M Industries, Inc.-- Salem, OH
103. Apacs, Inc.-- Sylvania, OH
104. Ecolotreat Process Equipment Corp.-- Toledo, OH (419-729-5443)
105. U.S. Waste Control-- Ardmore, OK (800-546-2182)
106. Custom Fiberglass Mfg.-- Oklahoma City, OK
107. Tech-Mark Inc./Enviro-Pak Div.-- Clackamas, OR
108. Ketema Inc., Schutte & Koerting Div.-- Bensalem, PA
109. Ceco Filters, Inc.-- Conshohochken, PA (215-825-8585)
110. C & E Plastics-- Georgetown, PA
111. GE Company, GE Environmental Services, Inc.-- Lebanon, PA
112. Jones & Hunt, Inc.-- Orwigsburg, PA
113. Pennsylvania Engineering Corp., Engineering Construction Div.-- Pittsburgh, PA
114. Wheelabrator Air Pollution Control-- Pittsburgh, PA (800-394-0992)
115. Global Environmental Corp.-- Plumsteadville, PA (800-220-1533)
117. E S T Corp.-- Quakertown, PA (215-538-7000)
118. Luftrol, Inc.-- Warminster, PA
119. Hansen Engineering, Inc.-- West Alexander, PA (412-484-7551)
120. Augusta Fiberglass, Inc.-- Blackville, SC (803-284-2246)
121. Spartan Tanks, Inc.-- Spartanburg, SC
122. ABB Environmental Systems (Industrial), Knoxville, TN
123. Chemco Engineering, Inc.-- Belton, TX (817-771-1966)
124. CJM Custom Steel Fabrication Environmental Tech.-- Denton, TX (800-548-2182)
125. Dyna-Therm Corp.-- Houston, TX (713-444-9759)
126. Winston Mfg. Corp.-- Longview, TX
127. Unisorb Corp.-- South Houston, TX (713-943-3753)
128. Centrifix Corp.-- Woodlands, TX (713-363-4868)
129. Tri Dim Filter Corp.-- Louisa, VA (703-967-2600)
130. GPI Corp.-- Schofield, WI (715-359-6123 Ext.25)
131. Vaportek, Inc.-- Sussex, WI
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55. North American Pollution Control Systems, Inc.-- Linden, NJ (800-752-0237)
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63. Sonic Environmental Systems-- Parsippany, NJ (201-882-9288)
64. York, Otto H., Co., Inc. (World Headquarters)-- Parsippany, NJ (800-524-1543)
65. Hollow Shapes, Inc.-- Pompton Plains, NJ
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72. Croll-Relynolds Co., Inc.-- Westfield, NJ (908-232-4200)
73. C O H Norcarb Inc.-- Brewster, NY
74. Beltran Associates, Inc.-- Brooklyn, NY (718-338-3311)
75. Cortech Plastics Inc.-- Buffalo, NY
76. Brucar Process Systems, Inc.-- Deer Park, NY
77. Primary Plastics Inc.-- Endwell, NY
78. Clean Gas Systems Inc.-- Farmingdale, NY (516-756-2474 Ext.91)
79. Ducon Environmental Systs-- Farmingdale, NY (516-420-4900)
80. Heat Systems Inc.-- Farmingdale, NY (800-645-9846)
81. Emtrol Corp.-- Hauppaug, NY (516-582-9700)
82. Leroy Plastics, Inc.-- Leroy, NY (716-768-8159)
83. Descon International Inc.-- Lindenhurst, NY (516-226-7766)
84. Zelcron Industries Inc. c/o Ducon Environmental Systems Div.-- Melville, NY (800-394-4900)
85. M.K. Plastics Corp.-- Mooers, NY (518-236-7949)
86. Bayfield Enterprises Inc.-- New York, NY (212-684-3589)
87. Swemco, Inc.-- New York, NY (212-645-0440)
88. Burgess-Manning, Inc., Sub. of Nitram Energy, Inc.-- Orchard-Park, NY
89. PKG Equipment Inc.-- Rochester, NY (716-436-4650)
90. KCH Services, Inc. Dept. N-- Forest City, NC
91. Filtajet Dust Control Dept. T-- Salisbury, NC
92. Kar-Del Plastics, Inc.-- Ashland, OH
93. Harrison Plastic Systems-- Aurora, OH
94. Magnum Plastics, Inc.-- Aurora, OH (216-562-9200)
95. Ceilcote, Air Pollution Control Div. Master Builders Inc.-- Berea, OH (216-243-0700)
96. United States Manufacturers Resource of Pro-Fab Mfg. Inc.-- Bedford, OH (216-232-3584)
97. Interstate Plastics Div. of Wester, Inc.-- Bremen, OH
98. Protectoplas Co.-- Burton, OH
99. Air Plastics, Inc.-- Cincinnati, OH
100. Effox, Inc.-- Cincinnati, OH
101. Kleinfeldt, R.F., Co., Inc.-- Cincinnati, OH
104. R. L. Industries, Inc.-- Fairfield, OH (800-846-2735)
105. Harrison Machine & Plastics Corp.-- Hiram, OH
106. United States Plastic Corp.-- Lima, OH (419-228-2242)
107. Volk Environmental Technology-- Mansfield, OH
108. Vanguard Plastics-- Mantua, OH
109. ACDC Inc.-- Milford, OH (513-248-1820)
110. Process Environmental Systems, Inc.-- North Ridgeville, OH
111. Vorti-Siv Div. of M M Industries, Inc.-- Salem, OH
112. Ecolotreat Process Equipment Corp.-- Toledo, OH (419-729-5443)
113. Neundorfer Inc.-- Willoughby, OH
114. Ketema Inc., Schutte & Koerting Div.-- Bensalem, PA
115. Ceco Filters, Inc.-- Conshohocken, PA (215-825-8585)
116. C & E Plastics-- Georgetown, PA
117. Met-Pro Corp. Systems Division-- Harleysville, PA
118. Goodhart Sons, Inc.-- Lancaster, PA (717-656-2404)
119. GE Company, GE Environmental Services, Inc.-- Lebanon, PA
120. Keystone Metal & Machine Co., Inc.-- Millersville, PA (717-464-2204)
121. Beco Engineering Co.-- Oakmont, PA
122. Jones & Hunt, Inc.-- Orwigsburg, PA
123. Pennsylvanian Engineering Corp., Engineering Construction Div.-- Pittsburgh, PA
124. Wheelabrator Air Pollution Control-- Pittsburgh, PA (800-394-0992)
125. Global Environmental Corp.-- Plumsteadville, PA (800-220-1533)
127. Luftrol, Inc.-- Warminster, PA
128. Hansen Engineering, Inc.-- West Alexander, PA (412-484-7551)
129. Ambi, Inc.-- Lincoln, RI
130. Plasfab, Inc.-- Warwick, RI
131. Augusta Fiberglass, Inc.-- Blackville, SC (803-284-2246)
132. Spartan Tanks, Inc.-- Spartanburg, SC
133. Chemco Engineering, Inc.-- Belton, TX (817-771-1966)
134. CJM Custom Steel Fabrication Environmental Tech.-- Denton, TX (800-548-2182)
135. Corr Tech, Inc.-- Houston, TX (800-752-7054)
136. Dyna-Therm Corp.-- Houston, TX (713-444-9759)
137. Emissions Technology, Inc.-- Houston, TX (713-448-0135)
138. I.C.P. Industries, Inc.-- Houston, TX (713-641-6401)
139. Process Specialties, Inc.-- Houston, TX (713-448-7177)
140. Unisorb Corp.-- South Houston, TX (713-943-3753)
141. Centrifix Corp.-- Woodlands, TX (713-363-4868)
142. Tri Dim Filter Corp.-- Louisa, VA (703-967-2600)
143. Precisioneering Ltd.-- Scarborough, ON Canada
144. AC Plastiques Canada, Inc.-- Les Cedres, PQ Canada

SCRUBBERS: GAS

2. Tigg Corp.-- Heber Springs, AR (800-925-0011)
3. Jaeger Aerospace Engineering-- Costa Mesa, CA
4. ACME Fiberglass, Inc.-- Hayward, CA (510-536-3440)
5. Cryogenic Industries Inc.-- Irvine, CA (714-261-1219)
6. Campbell, J.A., Company-- Long Beach, CA (310-424-0455)
7. Virotrol, Inc.-- Loomis, CA
8. Joy Technologies, Inc., Western Precipitation Div.--Monrovia, CA
9. Cryoquip Inc.-- Murrieta, CA
10. Delatech Inc.-- Napa, CA
11. Calvert Environmental-- San Diego, CA (619-272-0050)
13. Stearns Catalytic World Corp.-- Denver, CO
14. Entoletter, Inc.-- New Haven, CT (203-787-3575)
15. ABB/ASEA Brown Boveri, Inc.-- Stamford, CT (800-626-4999)
16. Industrial Gas Systems-- Palm Coast, FL (904-445-4200)
17. Wittmann-Hasselberg, Division of Wittmann Company, Inc., The-- Palm Coast, FL (904-445-4200)
18. Warren Engineering-- Atlanta, GA (404-843-8333)
19. Tampella Power Corp. Dept HG-- Marietta, GA (800-394-8871)
20. Thyssen Rheinstahl Technik Co. Dept. TRTCO-- Marietta, GA
22. Amerex, Inc.-- Woodstock, GA (404-928-0970)
23. Buchbinder-- Alsip, IL
25. Fiberbasin, Inc.-- Chicago, IL (312-622-4343)
26. Flex-Kleen Corporation-- Chicago, IL (312-648-5300)
27. Aarmqup Inc.-- Hammond, IN
28. AAF/Snydergeneral Corp.-- Louisville, KY (502-637-0011)
29. Fisher-Klosterman, Inc.-- Louisville, KY (502-776-1505)
30. Vanaire-- Louisville, KY (502-491-3553)
31. Precision Industries Inc.-- Baton Rouge, LA
32. Danzer Metal Works Co., The-- Hagerstown, MD
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<th>Company</th>
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<td>33.</td>
<td>Telpac Company, Ltd.-- Boston, MA</td>
<td>(617-523-0948)</td>
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<td>Koch Process Systems, Inc.-- Westborough, MA</td>
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<td>Monroe Environmental Corp.-- Monroe, MI (800-922-7707)</td>
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<td>Duall Div. Met-Pro Corporation-- Owosso, MI</td>
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<td>37.</td>
<td>Tri-Mer Corp.-- Owosso, MI (517-723-7838 Ext.77)</td>
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<td>Anel Industries, Inc.-- Winona, MS</td>
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<td>Monsanto Enviro-Chem Systems Inc.-- St. Louis, MO</td>
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<td>Willow Springs Mfg., Ltd.-- Willow Springs, MO (417-469-2792)</td>
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<td>Sigri Corporation-- Bedminster, NJ (908-231-3100)</td>
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<td>42.</td>
<td>Spectra Gases, Inc.-- Irvington, NJ (800-932-0624)</td>
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<td>North American Pollution Control Systems, Inc.-- Linden, NJ (800-752-0237)</td>
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<td>Advanced Industrial Technology Corp.-- Lodi, NJ (201-265-1414)</td>
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<td>S &amp; S Industrial Corp.-- Marifton, NJ</td>
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<td>Ambient Engineering Inc.-- Matawan, NJ (908-566-8686)</td>
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<td>Hydronics Engineering Corp.-- Midland Park, NJ</td>
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<td>Bioclimatic, Inc.-- Moorestown, NJ (800-962-5594)</td>
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<td>Mikropul Environmental Systems-- Morris Plains, NJ (201-606-5900)</td>
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<td>Sonic Environmental Systems-- Parsippany, NJ (201-882-9288)</td>
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<td>51.</td>
<td>York, Otto H., Co., Inc. (World Headquarters)-- Parsippany, NJ</td>
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<td>Research-Cottrell Companies-- Somerville, NJ (908-685-4000)</td>
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<td>Omni Coil, Inc.-- Southampton, NJ</td>
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<td>Omni Fabricators Inc.-- Southampton, NJ (609-859-3900)</td>
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<td>Aer-X-Dust Corp.-- Tennent, NJ</td>
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<td>Airpol, Inc.-- Teterboro, NJ (201-288-7070)</td>
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<td>Advanced Oxidation Systems, Inc.-- Wayne, NJ (201-628-0309)</td>
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<td>Croll-Reynolds Co., Inc.-- Westfield, NJ (908-232-4200)</td>
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<td>Perkins, P.W., Co., Inc.-- Woodstown, NJ (609-769-3525)</td>
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<td>C O H Norcarb Inc.-- Brewster, NY</td>
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<td>Arrow Tank Co., Inc.-- Buffalo, NY</td>
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<td>Cortech Plastics Inc.-- Buffalo, NY</td>
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<td>Metal Cladding, Inc.-- Buffalo, NY</td>
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<td>Clean Gas Systems Inc.-- Farmingdale, NY (516-756-2474 Ext.91)</td>
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<td>Ducon Environmental Systems-- Farmingdale, NY (516-420-4900)</td>
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<td>Heat Systems Inc.-- Farmingdale, NY (800-645-9846)</td>
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<td>Emtrol Corp.-- Hauppaugae, NY (516-582-9700)</td>
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<td>Rosenwach Tank Co., Inc.-- Long Island City, NY</td>
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<td>Zelcron Industries Inc. c/o Ducon Environmental Systems Div.-- Melville, NY (800-394-4990)</td>
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<td>71.</td>
<td>Pyro Industries Inc.-- Mineola, NY</td>
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<td>Swemco, Inc.-- New York, NY (212-645-0440)</td>
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<td>Burgess-Manning, Inc., Sub. of Ntram Energy, Inc.-- Orchard Park, NY</td>
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<td>Chemipulp/Jenssen Div.-- Watertown, NY</td>
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<td>KCH Services, Inc. Dept. N-- Forest City, NC</td>
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<td>Harrison Plastic Systems-- Aurora, OH</td>
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<td>Babcock &amp; Wilcox, Power Generation Group, Customer Parts &amp; Service Dept. TR-- Barberton, OH (800-354-4400)</td>
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<td>Air Plastics, Inc.-- Cincinnati, OH</td>
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<td>Effox, Inc.-- Cincinnati, OH</td>
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<td>Volk Environmental Technology-- Mansfield, OH</td>
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<td>82.</td>
<td>ACDC Inc.-- Milford, OH (513-248-1820)</td>
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<td>Vorti-Siv Div. of M M Industries, Inc.-- Salem, OH</td>
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<td>Nutter Engineering Div., Patterson-Kelly</td>
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<td>85</td>
<td>Filter Fab Mfg. Corp.-- Aliquippa, PA</td>
<td>(412-375-6927)</td>
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<td>Ketema Inc., Schutte &amp; Koerting Div.--</td>
<td>Bensalem, PA</td>
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<td>87</td>
<td>Kinney, S.P., Engineers, Inc.-- Carnegie</td>
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<td>Ceco Filters, Inc.-- Conshohocken, PA</td>
<td>(215-825-8585)</td>
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<td>GE Company, GE Environmental Services, Inc.--</td>
<td>Lebanon, PA</td>
<td>(800-732-0340)</td>
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<td>90</td>
<td>Matheson Instruments-- Montgomeryville, PA</td>
<td>(800-732-0340)</td>
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<td>Jones &amp; Hunt, Inc.-- Orwigsburg, PA</td>
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<td>Hall-Woolford Tank Co., Inc.-- Philadelphia, PA</td>
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<td>Pennsylvania Engineering Corp., Engineering Construction Div.-- Pittsburgh, PA</td>
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<td>94</td>
<td>Wheelabrator Air Pollution Control-- Pittsburgh, PA</td>
<td>(800-394-0992)</td>
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<td>95</td>
<td>Global Environmental Corp.-- Plumsteadville, PA</td>
<td>(800-220-1533)</td>
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<td>E S T Corp.-- Quakertown, PA (215-538-7000)</td>
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<td>Luftrol, Inc.-- Warminster, PA</td>
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<td>ACS Industries, Inc.-- Woonsocket, RI (800-343-2257)</td>
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<td>Spartan Tanks, Inc.-- Spartanburg, SC</td>
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<td>ABB Environmental Systems (Industrial), Knoxville, TN</td>
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<td>Peerless Mfg. Co.-- Dallas, TX</td>
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<td>BS &amp; S Engineering Co., Inc.-- Houston, TX</td>
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<td>Dyna-Therm Corp.-- Houston, TX (713-444-9759)</td>
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<td>Emissions Technology, Inc.-- Houston, TX (713-448-0135)</td>
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<td>Keco Research &amp; Development, Inc.-- Houston, TX</td>
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<td>Process Specialties, Inc.-- Houston, TX (713-448-7177)</td>
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<td>Smith Industries, Inc.-- Houston, TX</td>
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<td>King Tool Co.-- Longview, TX</td>
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<td>PPC Industries-- Longview, TX</td>
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<td>Winston Mfg. Corp.-- Longview, TX</td>
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<td>Unisorb Corp.-- South Houston, TX (713-943-3753)</td>
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<td>Centrifix Corp.-- Woodlands, TX (713-363-4688)</td>
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<td>113</td>
<td>Tri Dim Filter Corp.-- Louisa, VA (703-967-2600)</td>
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<td>114</td>
<td>GPI Corp.-- Schofield, WI (715-359-6123 Ext.25)</td>
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<td>115</td>
<td>Wells-Hall Fabrication &amp; Construction, Ltd.-- Edmonton, AB Canada</td>
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1. Tigg Corp.-- Heber Springs, AR (800-925-0011)
2. Active-Carb-- Canoga Park, CA (800-424-2049)
3. Adsorvents & Desiccants Corp. of America-- Los Angeles, CA (800-228-4124)
4. Anderson Industrial Products, Inc.-- East Berlin, CT (203-828-9262)
5. Solvay Performance Chemicals Inc.-- Greewich, CT (203-629-7900)
6. Pneumatic Products Corp.-- Ocala, FL (904-237-1220 Ext. 320)
7. Trema North America, Inc.-- Reisterstown, MD (800-833-2925)
8. Magic Sorb.-- Danvers, MA
9. Remedial Systems Inc.-- Foxboro, MA (800-394-5622)
10. Koby Incorporated-- Marlboro, MA (508-481-8348)
11. Sphinx Adsorbents, Inc.-- Springfield, MA (413-736-5020)
12. D-Mark, Inc.-- Mount Clemens, MI (800-343-3610)
13. Southeastern Fibers, Inc.-- St. Paul, MN (800-833-2472)
17. Chromex Corp, Interflo Div.-- Brooklyn, NY (800-468-3735)
18. Mystic Display Co., Inc.-- Brooklyn, NY (800-334-7954)
19. Airtek-- Buffalo, NY (716-692-6111)
20. Multiform Dessicants, Inc.-- Buffalo, NY (716-883-8900)
21. Clean Gas Systems Inc.-- Farmingdale, NY (516-756-2474 Ext. 91)
22. Ducon Environmental Systems-- Farmingdale, NY (516-420-4900)
23. Zelcron Industries Inc. c/o Ducon Environmental Div.-- Melville, NY (800-394-4990)
24. Flanders Filters Inc.-- Washington, NC (919-945-8081)
25. Andersons Industrial Products Div.-- Maumee, OH (419-893-5050)
27. Met-Pro Corp., Systems Division-- Harleysville, PA
28. Calgon Carbon Corp.-- Pittsburgh, PA (800-422-7266)
29. Parker Systems, Inc.-- Norfolk, VA (800-666-0006)
30. North Valley Industries Inc.-- Omak, WA
31. Drummond Welding & Steel Works Ltd.-- PQ Longueuil, Canada

**ADSORBERS: ACTIVATED CARBON**

1. Tigg Corp.-- Heber Springs, AR (800-925-0011)
2. Magic Sorb-- Danvers, MA
3. Prekins, P.W., Co., Inc.-- Woodstown, NJ (609-769-3525)
### Combustion

#### Flares: Waste Gas

1. Hirt Combustion Engineers-- Montebello, CA (213-728-9164)
2. Sur-Lite Corp.-- Santa Fe Springs, CA (310-693-0796)
4. Pilgrim Steel Co.-- Glassboro, NJ
5. Almetek Industries, Inc.-- Hackettstown, NJ
6. Flaregas Corp.-- Spring Valley, NY
7. LFG Specialties Inc.-- Cleveland, OH (216-891-0305)
8. It-McGill Pollution Control Systems, Inc.-- Tulsa, Ok (916-748-0700)
9. Zeeco, Inc.-- Tulsa, OK (918-258-8551)
10. Zink, Inc.-- Tulsa, OK
12. NAO, Inc.-- Philadelphia, PA (800-523-3495)
13. Flare Industries Inc.-- Austin, TX
14. Allied Flare, Inc.-- Houston, TX (713-332-1000)
15. Kaldair Inc., Div. of BP America-- Houston, TX (800-526-3247)
16. Stackmatch Flare Ignition, Inc.-- Plano, TX (800-623-9260)

#### Incinerator Systems

1. BDP Thermal Systems Inc.-- San Carlos, CA (800-222-5575)
3. Andersen 2000, Inc.-- Peachtree City, GA (800-241-5424)
4. CIL Incineration Systems, Inc.-- Blaine, MN (612-784-6052)
5. Thermal Process Construction Co., Inc.-- Dover, NJ (201-361-5900)
7. Enercon Systems Inc.-- Elyria, OH (216-323-7080)
8. It-McGill Pollution Control Systems Inc.-- Tulsa, OK (918-748-0700)
9. Zeeco, Inc.-- Tulsa, OK (918-258-8551)
10. T-Thermal-- Conshohocken, PA (215-828-5400)
11. Seco/Warwick Corp.-- Meadville, PA (814-724-1400)
12. Vulcan Iron Works, Inc.-- Wilkes-Barre, PA (717-822-2161)
13. National Incinerator, Inc.-- Corsicana, TX (903-872-4651)
14. Noell, Inc.-- Herndon, VA (703-793-6500)

#### Incinerators

1. Consolidated Engineering Co.-- Kennesaw, GA (800-486-6836)
2. Brule, C.E. & E., Inc.-- Blue Island, IL (708-388-7900)
3. Detrick, M.H. Co.-- Mokena, IL (800-335-3751)
4. Thermal Process Construction Co., Inc.-- Dover, NJ (201-361-5900)
5. JWP Air Technologies-- Mountainside, NJ (908-789-2700)
7. Stelter & Brinck, Inc.-- Harrison, OH (800-568-9703)
8. T-Thermal-- Conshohocken, PA (215-828-5400)
9. NAO, Inc.-- Philadelphia, PA (800-523-3495)
Engineers-- Pittsburgh, PA (412-281-5222)
13. Pennram Products Division-- Williamsport, PA (717-368-1033)
14. AKI Systems, Inc.-- Tomball, TX (713-351-7945)
15. Epon Industrial Systems, Inc.-- Woodlands, TX (800-447-7872)

INCINERATORS: CATALYTIC

1. Etter Engineering Co., Inc.-- Cheshire, CT
2. CVM Corp.-- Wilmington, DE (302-654-7070)
3. Catalytic Products International-- Lake Zurich, IL (708-438-0334)
4. Dedert Corp.-- Olympia Fields, IL (708-747-7000)
5. ARI Technologies, Inc.-- Palatine, IL (708-359-7810)
6. Gancia-Cote & Co.-- Detroit, MI
7. Moco Thermal Industries-- Romulus, MI (313-728-6800)
8. Glenro, Inc.-- Paterson, NJ (800-922-0106)
10. CSM Environmental Systems, Inc.-- Brooklyn, NY (718-522-7000)
11. Camet Co.-- Hiram, OH (216-569-3245)
12. Johnson Matthey, Environmental Products Div.-- Wayne, PA (215-341-8535)
13. AKI Systems, Inc., An Astrotech International Co.-- Tomball, TX (713-351-7945)
15. Thermo Electron Wisconsin, Inc.-- Kaukauna, WI (414-766-7200)
16. Anguil Environmental Systems, Inc.-- Milwaukee, WI
17. Patterson Industries (Canada) Ltd.-- On, Scarborough, Canada (800-336-1110 Ext. 1078)

INCINERATORS: FUME

1. Coen Co., Inc.-- Burlingame, CA
2. Smith Environmental Corp.-- Duarte, CA
3. H E M C Environmental Management-- Irvine, CA (714-727-1217)
4. Hirt Combustion Engineers-- Montebello, CA (213-728-9164)
5. Smith Engineering Co.-- Ontario, CA
6. Keith Co., Inc.-- Pico Rivera, CA
7. Bayco Div. of V.S.B.-- Sacramento, CA (916-924-8061)
8. "Burney" The Burner-- San Bernardino, CA
9. Alzeta Corp.-- Santa Clara, CA (408-727-8282)
10. Sur-Lite Corp.-- Sante Fe Springs, CA (310-693-0796)
11. In-Process Technology, Inc.-- Sunnyvale, CA (408-745-1066)
12. Marquardt Environmental Systems-- Van Nuys, CA
13. Interel Corp.-- Englewood, CO (303-733-0753 Ext.300)
15. ABB/ASEA Brown Boveri, Inc.-- Stamford, CT (800-626-4999)
16. Peabody Engineering Corp.-- Stamford, CT
17. CVM Corp.-- Wilmington, DE (302-654-7070)
18. Simonds Mfg. Corp.-- Auburndale, FL
19. Industrial Equipment & Engineering Co.-- Orlando, FL
20. International Incinerators-- Columbus, GA
21. Consolidated Engineering Co.-- Kennesaw, GA (800-486-6836)
22. Brule, C.E. & E., Inc.-- Blue Island, IL (708-388-7900)
23. Eisenmann Corporation-- Crystal Lake, IL (815-456-4100)
24. Basic Environmental Engineering, Inc.-- Glen Ellyn, IL
25. Enders-Process Equipment Corp.-- Glen Ellyn, IL (708-469-3787)
26. Catalytic Products International-- Lake Zurich, IL (708-438-0334)
27. Dedert Corp.-- Olympia Fields, IL (708-747-7000)
28. Ari Technologies, Inc.-- Palatine, IL (708-359-7810)
29. Kelair Products Inc.-- Spring Grove, IL (815-675-2728)
30. Precision Quincy Corp.-- Woodstock, IL (815-338-2675)
31. Combustion Systems, Inc.,-- Cambay, IN
32. Koch, George, Sons, Inc.-- Evansville, IN (812-426-9600)
33. Precision Industries Inc.-- Baton Rouge, LA
34. F & E Stokers, Inc., Stokers Div.-- Baltimore, MD
35. Wolverine Corporation-- Merrimac, MA (508-346-4541)
36. Wickberg, B.G., Co., Inc.-- North Quincy, MA (617-328-9200)
37. Process Heating Corp.-- Shrewsbury, MA (508-842-5200)
38. Ferrara, N., Inc.,-- Somerset, MA (508-679-2440)
39. Airtech Systems Corp.-- Stoughton, MA (617-344-0467)
40. Clarkson Controls & Equipment Co.-- Detroit, MI (313-255-9110)
41. Gancia-Cote & Co.-- Detroit, MI
42. Jensen Oven Co., Inc.-- Farmington, MI (800-783-OVEN)
43. Haden Management Corp.-- Madison Heights, MI
44. Hade-Schweiter Corp.-- Madison Heights, MI
45. Bigelow-Liptak Corp.-- Plymouth, MI
46. Durr Industries Inc.-- Plymouth, MI (313-459-6800)
47. Moco Thermal Industries-- Romulus, MI (313-728-6800)
48. Euthenergy Systems, Inc.-- Sanford, MI
49. Combustion Technologies, Inc.-- Troy, MI
50. CIL Incineration Systems Inc.-- Blaine, MN
51. North Atlantic Technologies, Inc.-- Bloomington, MN (612-888-8553)
52. Atlas Incinerators, Inc.-- Minneapolis, MN
53. Johnston Mfg. Co.-- Minneapolis, MN
55. Finishing Technologies, Inc.-- Chesterfield, MO
56. BBC Industries, Inc.-- Fenton, MO
57. Thermal Process Construction Co., Inc.-- Dover, NJ (201-361-5900)
58. North American Pollution Control-- Linden, NJ (800-752-0237)
59. Van-Packer Co.-- Manahawkin, NJ (609-597-8080)
60. REECO (Regenerative Environmental Equipment Co., Inc.)-- Morris Plains, NJ (201-538-8585)
61. JWP Air Technologies-- Mountainside, NJ (908-789-2700)
62. Somerset Technologies, Inc.-- New Brunswick, NJ
63. Glenro, Inc.-- Paterson, NJ (800-922-0106)
64. HED Industries, Inc.-- Ringoes, NJ
65. Pereny Equipment Div., HED Industries, Inc.,-- Ringoes, NJ
66. Airpol, Inc.-- Teterboro, NJ (201-288-7070)
68. Ducon Environmental Systems-- Farmingdale, NY (516-420-4900)
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<td>Des Champs Laboratories Inc.</td>
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<td>Consumat Systems, Inc.</td>
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<td>109</td>
<td>International Waste Industries</td>
<td>Vienna, VA</td>
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<td>111</td>
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<td>Catalytic Combustion Corp.</td>
<td>Bloomer, WI</td>
<td>715-568-2882 Ext.22</td>
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<td>113</td>
<td>Thermo Electron Wisconsin, Inc.</td>
<td>Kaukauna, WI</td>
<td>414-766-7200</td>
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<td>114</td>
<td>Anquil Environmental Systems</td>
<td>Milwaukee, WI</td>
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**INCINERATION: VOLATILE ORGANIC COMPOUNDS**

1. Hirt Combustion Engineers-- Montebello, CA (213-728-9164)
2. Alzeta Corp.-- Santa Clara, CA (408-727-8282)
3. In-Process Technology, Inc.-- Sunnyvale, CA (408-745-1066)
4. Marquardt Environmental Systems-- Van Nuys, CA
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<td>Interel Corp.--</td>
<td>Englewood, CO</td>
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<td>6.</td>
<td>ABB/ASEA Brown Boveri, Inc.--</td>
<td>Stamford, CT</td>
<td>(800-626-4999)</td>
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<td>CVM Corp.--</td>
<td>Wilmington, DE</td>
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<td>Consolidated Engineering Co.--</td>
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<td>Enders-Process Equipment Corp.--</td>
<td>Glen Ellyn, IL</td>
<td>(708-469-3787)</td>
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<td>Wolverine Corporation--</td>
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<td>Wickberg, B.G., Co., Inc.--</td>
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<td>Ferrara, N., Inc.--</td>
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<td>Jensen Oven Co., Inc.--</td>
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<td>(800-783-OVEN)</td>
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<td>Thermal Process Construction Co., Inc.--</td>
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<td>North American Pollution Control--</td>
<td>Linden, NJ</td>
<td>(800-752-0237)</td>
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<td>REECO (Regenerative Environmental Equipment Co., Inc.--</td>
<td>Morris Plains, NJ</td>
<td>(201-538-8585)</td>
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<td>JWP Air Technologies--</td>
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<td>Glenro, Inc.--</td>
<td>Paterson, NJ</td>
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<td>Feco Environmental, Div of Feco Engineered Systems, Inc.--</td>
<td>Cleveland, OH</td>
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<td>23.</td>
<td>Surface Combustion Inc.--</td>
<td>Maumee, OH</td>
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<td>It-McGill Pollution Control Systems, Inc.--</td>
<td>Tulsa, Ok</td>
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<td>25.</td>
<td>Kleenair Products Co., Inc.--</td>
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<td>26.</td>
<td>Advanced Valve Design--</td>
<td>Allentown, PA</td>
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<td>Selas Fluid Processing Corp.--</td>
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<td>NAO, Inc.--</td>
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<td>AKI Systems, Inc.--</td>
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<td>Allis Mineral Systems, Inc.--</td>
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<td>Anquil Environmental Systems--</td>
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CONDENSERS: GAS

1. Johansing Iron Works-- Alameda, CA
2. Associated Vacuum Technology, Inc.-- Covina, CA
3. REPCO Engineering, Inc.-- Montebello, CA (310-725-3973)
4. Wiegmann & Rose, Sub. of Xchanger Mfg. Corp.-- Richmond, CA
5. Turbotec Products Inc., Div. of Thermodynetics-- Windsor, CA (800-394-1633)
6. Kennedy Tank & Mfg. Co., Inc.-- Indianapolis, IN
7. Holt Corp.-- Saugus, MA (617-233-8808)
8. Super Radiator Coils-- Minneapolis, MN (612-922-3330)
9. Heatcraft Inc.-- Grenada, MS
10. Atlantic Detroit Diesel Allison Inc.-- Lodi, NJ
11. Edwards Engineering Corp.-- Pompton Plains, NJ (800-526-5201)
13. Omni Coil, Inc.-- Southampton, NJ (609-859-3955)
14. Omni Fabricators, Inc.-- Southampton, NJ (609-859-3900)
15. Croll-Reynolds Co., Inc.-- Westfield, NJ (908-232-4200)
16. Enerfin Inc.-- Albany, NY
17. Rubican Industries Corp.-- Brooklyn, NY
18. Bos-Hatten, Inc.-- Buffalo, NY (716-662-6540)
20. Gaston County Fabrication-- Stanley, NC (704-822-5000)
21. Ambassador Heat Transfer Co.-- Cincinnati, OH
22. Unifin International Div. of Keeprite Inc.-- Cincinnati, OH (519-451-0230)
25. Ecodyne MRM, Inc.-- Massillon, OH
27. Stokes Vacuum, Inc.-- Philadelphia, PA
28. Struthers Walls Corp.-- Warren, PA
29. Frick Co.-- Waynesboro, PA
30. F.E.S., Inc.-- York, PA
31. Refrigeration Valve & System Corp.-- Bryan, TX
32. Process Specialties, Inc.-- Houston, TX (713-448-7177)
33. Super Radiator Coils (Richmond Virginia Div.)-- Richmond, VA (804-794-2887)
34. Chil-Con Products Ltd.-- Brantford, ON Canada
35. Enerfin Inc.-- Boucherville, PQ Canada (514-449-3430)

CONDENSERS: VAPOR

1. Johansing Iron Works-- Alameda, CA
2. Associated Vacuum Technology, Inc.-- Covina, CA
3. REPCO Engineering, Inc.-- Montebello, CA (310-725-3973)
4. Energy Research & Generation Inc.-- Oakland, CA
5. Wiegmann & Rose, Sub. of Xchanger Mfg. Corp.-- Richmond, CA
6. Turbotec Products Inc., Div. of Thermodynetics-- Windsor, CA (800-394-1633)
7. Bailey Refrigeration Co., Inc.-- North Miami, FL
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<td>Koolant Koolers, Inc.</td>
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<td>45.</td>
<td>Ambassador Heat Transfer Co.</td>
<td>Cincinnati, OH</td>
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<td>46.</td>
<td>Central Fabricators, Inc.</td>
<td>Cincinnati, OH</td>
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<td>47.</td>
<td>Ellis &amp; Watts Company</td>
<td>Cincinnati, OH</td>
<td>(513-752-9000)</td>
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<td>49.</td>
<td>Ecodyne MRM, Inc.</td>
<td>Massillon, OH</td>
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<td>50.</td>
<td>Waste Heat Technologies, Inc.</td>
<td>Wadsworth, OH</td>
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<td>51.</td>
<td>G.E.A. Rainey Corp.</td>
<td>Catooasa, OK</td>
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<td>52.</td>
<td>Harris Thermal Transfer Products, Inc.</td>
<td>Newberg, OR</td>
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<td>53.</td>
<td>Industrial Process Equipment Corp.</td>
<td>Arnold, PA</td>
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<td>56.</td>
<td>Sentinel Process System, Inc.</td>
<td>Hatboro, PA</td>
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<td>57.</td>
<td>Baeuerle &amp; Morris, Inc.</td>
<td>King of Prussia, PA</td>
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58. Stokes Vacuum, Inc.-- Philadelphia, PA
59. Resorcon, Inc., A Niagara Blower Co.-- Pittsburgh, PA (412-825-8400)
60. Harris Tube Pulling & Mfg. Inc.-- Ooltewah, TN (615-238-4814)
61. Krueger Engineering & Mfg. Co., Inc.-- Houston, TX
62. Process Specialties, Inc.-- Houston, TX (713-448-7177)
63. Straus Systems Inc.-- Houston, TX
64. Super Radiator Coils (Richmond Virginia Div.)-- Richmond, VA (804-794-2887)
65. Perfex Industrial Products-- Milwaukee, WI (414-546-2880)

BAGHOUSES

2. Beco Corporation-- Benton, AR
4. Pacific Engineering Systems Co.-- Anaheim, CA
5. Murphy-Rodgers, Inc.-- Huntington Park, CA
6. Food Engineering Service-- Inwindale, CA
7. Wire Technology Corp.-- Los Angeles, CA
8. PSP Industries-- Milpitas, CA
9. Joy Technologies, Inc., Western Precipitation Div.-- Monrovia, CA
10. Air Sentry, Inc.-- Denver, CO (800-878-7897)
11. Interel Corp.-- Englewood, CO (303-733-0753 Ext.300)
12. Warwick Mfg. & Equipment Co.-- Bridgeport, CT
13. GE Company-- Fairfield, CT (800-626-2004)
14. National Filter Media Corp.-- Hamden, CT
15. ABB/ASEA Brown Boveri, Inc.-- Stamford, CT (800-626-4999)
17. AFL Industries, Inc.-- Riviera Beach, FL (407-844-5200)
18. Advanced Metal & Welding Corp.-- Atlanta, GA
19. Transac, Inc.-- Macon, GA (800-841-4982)
20. Amerex, Inc.-- Woodstock, GA (404-928-0970)
21. Dustvent, Inc.-- Addison, IL
22. Flex-Kleen Corporation-- Chicago, IL (312-648-5300)
23. Great Lakes Filter, Filpaco Div.-- Chicago, IL (312-722-2200)
24. Meyer, Wm. W., & Sons, Inc.-- Skokie, IL (708-673-0312)
25. Turn Key Engineering Inc.-- Vincennes, IN (800-878-8534)
26. Deter Company, Inc.-- Burgin, KY (606-748-5262)
27. AAF/Snydergeneral Corp.-- Louisville, KY (502-637-0011)
29. Dixie Air Engineering Co.-- Baltimore, MD
30. Dovco Industrial Fabrication, Inc.-- Baltimore, MD
31. Environmental Elements Corp.-- Baltimore, MD
32. Trema North America, Inc.-- Reisterstown, MD (800-833-2925)
33. Alpha Environmental Services, Inc.-- Boston, MA (617-787-0282)
34. Wickberg, B.G., Co., Inc.-- North Quincy, MA (617-328-9200)
35. Aget Mfg. Company-- Adrian, MI (800-832-2438 Ext. 99)
36. Great Lakes Filter, Div of Acme Mills Co.-- Detroit, MI (313-894-1950)
37. Forrest Brothers Inc.-- Gaylord, MI (517-732-8220)
38. Specified Design Corp.-- Grand Blanc, MI
39. Duall Div. Met-Pro Corporation-- Owosso, MI
40. Beckert & Hiester Inc.-- Saginaw, MI (800-332-4031 Ext. 12)
41. Filco Filtration Systems, Inc.-- Eden Prairie, MN
42. Nol-Tec Systems, Inc.-- Forest Lake, MN
43. General Resource Corp.-- Hopkins, MN
44. Contamination Control Corp.-- Maple Plain, MN
45. Gerber Industries Inc.-- Minneapolis, MN
46. Torit/Day Div., Donaldson Co. Inc.-- Minneapolis, MN (800-365-1331 Ext. 204)
47. Monotech of Mississippi-- Iuka, MS
48. BHA Group, Inc.-- Kansas City, MO
49. Mac Equipment Inc.-- Kansas City, MO
50. Standard Havens Div.-- Kansas City, MO
51. Filtration Systems Products, Inc.-- St. Louis, MO (314-721-2888)
52. Willow Springs Mfg., Ltd.-- Willow Springs, MO (417-469-2792)
53. Universal Filters, Inc.-- Asbury Park, NJ
54. Sternvent Co., Inc.-- Bogota, NJ
55. Joule Engineering Corp.-- Edison, NJ
56. Kleisser, G.A.-- Edison, NJ
57. Environmental Dynamics Corp.-- Kresson, NJ (609-768-1100)
58. Miller, Franklin, DeLumper-Mixer Div.-- Livingston, NJ (800-932-0599)
59. Sterling Net Co., Inc.-- Montclair, NJ (800-342-0316)
60. National Filter Media Corp. Air Pollution Control Div.--Moorstown, NJ
61. Mikropul Environmental Systems-- Morris Plains, NJ (201-606-5900)
62. Air Kinetics, Inc.-- Morristown, NJ
63. Belco Technologies Corp.-- Parisippany, NJ
64. Sonic Environmental Systems-- Parisippany, NJ (201-882-9288)
65. Research-Cottrell Companies-- Somerville, NJ (908-685-4000)
66. United Process Control, Inc.-- Somerville, NJ
67. CAP Technologies Inc.-- Stirling, NJ
68. Airpol, Inc.-- Teterboro, NJ (201-289-7070)
69. Deiden Industries Ltd.-- Brooklyn, NJ
70. Ducon Environmental Systems--Farmingdale, NY (516-420-4900)
71. Emtral Corp.-- Hauppauge, NY (516-582-9700)
72. Zelcron Industries Inc. C/O Ducon Environmental Systems--
    Melville, NY (800-394-4990)
73. Cors-Ible, Inc.-- Moravia, NY
74. Regenair Industries Inc.-- Rouses Point, NY (518-297-6966)
75. P & S Filtration Inc.-- Skaneateles Falls, NY
76. Griffin Environmental Co., Inc.-- Syracuse, NY (315-451-5300)
77. Dustex Corp.-- Charlotte, NC (704-588-2030)
78. Pneumatik Corp., Environmental Air Systems Div.-- Charlotte, NC (704-399-7441)
79. Eakes Building Group Inc.-- Greensboro, NC
80. Eakes Metal Fabricators, Inc.-- Greensboro, NC (800-348-0884)
81. Filtajet Dust Control Dept. T-- Salisbury, NC
82. Staclean Diffuser Co. Dept. T-- Salisbury, NC (800-438-3850)
83. Classic Systems Inc. Dept. T-- Statesville, NC
84. Nordfab Products, Inc.-- Thomasville, NC
85. Nordfab Systems, Inc.-- Thomasville, NC (919-889-5599)
86. Feco/Forsyth Inc.-- Winston Salem, NC (919-721-1500)
87. Diversified Specialty Enterprises, Inc.-- Canal Fulton, OH
88. Advanced Standard Products, Div. of Noral, Inc.-- Cleveland, OH (800-348-2345)
89. Sly W.W., Mfg. Co.-- Cleveland, OH (216-238-2000)
90. Barnebey & Sutcliffe Corp.-- Columbus, OH (614-258-9501)
91. Metals Trades, Inc.-- Columbus, OH
92. United McGill Corp.-- Columbus, OH (614-443-0192)
93. Volk Environmental Technology-- Mansfield, OH
94. E-Tech, Inc.-- Tulsa, OK (918-665-1930)
95. Aeropulse, Inc.-- Bensalem, PA (800-544-7393)
96. Fuller Company-- Bethlehem, PA (215-264-6222)
97. Johnson March System, Inc.-- Iryland, PA
98. GE Company, GE Environmental Services, Inc.-- Lebanon, PA
    Malvern, PA (800-TALK-JOY)
100. Pennsylvania Engineering Corp., Engineering Construction Div.--Pittsburgh, PA
101. Vulcan Engineering Co.-- Pittsburgh, PA
102. Wheelabrator Air Pollution Control-- Pittsburgh, PA (800-394-0992)
103. Global Environmental Corp.-- Plumsteadville, PA (800-220-1533)
104. Palladino Metal Fabrication, Inc.-- Pottstown, PA (800-788-8284)
105. Fabrication Specialists Co., Inc.-- Reading, PA
106. Free Flow, Inc.-- Blaine, TN
107. Esstee Mfg. Co., Inc.-- Cleveland, TN (615-472-6529)
108. Todd Mfg. Co., Inc.-- Cleveland, TN (615-476-5559)
109. ABB Environmental Systems-- Knoxville, TN
110. GMW, Inc.-- Memphis, TN (901-276-4593)
111. Hagan, Vince, Co., The-- Dallas, TX
112. Consolidated Fluidflo Inc.-- Houston, TX
113. PPC Industries-- Longview, TX
114. Monotech Corp.-- San Antonio, TX
115. Noell, Inc.-- Herndon, VA (703-793-6500)
116. Des Champs Laboratories, Inc.-- Natural Bridge, VA (703-291-1111)
117. Eastern Control Systems, Inc.-- Richmaond, VA
118. Midwesco Filter Resources Inc.-- Winchester, VA
119. Dan-Dee Equipment, Inc.-- Honey Creek, WI
120. Ruemelin Mfg. Co., Inc.-- Milwaukee, WI (414-962-6500)
121. Kreemer Tool & Mfg. Co. Ltd.-- ON, Brampton, Canada
122. Cantech Environmental Systems, Inc.-- ON, Mississuaga, Canada

CYCLONES

1. Brown International Corp.-- Covina, CA
2. Lakos, Laval Corp.-- Fresno, CA (209-255-1601)
3. South Valley Mfg., Inc.-- Gilroy, CA
4. Krebs Engineers-- Menlo Park, CA (415-325-0751)
5. ITW Irathane Systems-- Colorado Springs, CO (800-397-5434)
6. Dorr-Oliver Incorporated-- Milford, CT (800-547-7809)
7. Linatex Corp. of America-- Stafford Springs, CT
9. Carpco, Inc.-- Jacksonville, FL (904-353-3681)
10. Advanced Metal & Welding Corp.-- Atlanta, GA
11. Roberts & Schaefer Co.-- Chicago, IL (312-236-7292)
12. Meyer, Wm. W., & Sons, Inc.-- Skokie, IL (708-673-0312)
13. Cerline Ceramic Corp.-- Anderson, IN (317-649-7222)
14. California Pellet Mill Co.-- Crawfordsville, IN (317-362-2600)
15. Thombert Inc.-- Newton, IA
16. Champion Div. of California Pellet Mill Co.-- Waterloo, IA
17. Premier Pneumatics, Inc.-- Salina, KA
19. Dynadyne, Inc.-- Phoenix, MD
20. Trema North America, Inc.-- Registerstown, MD (800-833-2925)
21. P.X. Engineering, Inc.-- Boston, MA (617-269-6200)
22. Polytech Filtration Systems, Inc.-- Sudbury, MA (508-443-4901)
23. Aget Mfg. Company-- Adrian, MI (800-832-2438 Ext. 99)
24. Forrest Brothers Inc.-- Gaylord, MI (517-732-8220)
25. Monian Corp.-- Kalamazoo, MI (616-382-6348)
26. Beckert & Hiester Inc.-- Saginaw, MI (800-332-4031 Ext. 12)
27. ITW Irathane Systems Inc.-- Hibbing, MN (800-397-5434)
28. Gerber Industries Inc.-- Minneapolis, MN
29. Mac Equipment Inc.-- Kansas City, MO
30. Hydroflow Inc.-- Salem, NH (603-898-3388)
31. Rhone-Poulenc Tech-Sep-- Princeton, NJ (609-987-5046)
32. CAP Technologies Inc.-- Stirling, NJ
33. Clean Gas Systems Inc.-- Farmingdale, NY (516-756-2474 Ext. 91)
34. Ducon Environmental Systems-- Farmingdale, NY (516-420-4900)
35. Emtral Corp.-- Hauppauge, NY (516-582-9700)
36. Zelcron Industries Inc. C/O Ducon Environmental Systems--
   Melville, NY (800-394-4990)
37. Marstech-- New City, NY
38. Eakes Building Group Inc.-- Greensboro, NC
39. Eakes Metal Fabricators, Inc.-- Greensboro, NC (800-348-0884)
40. Wilbanks International, A Division of Coors Ceramics Co.-- Hillsboro, OR
41. Unicast Inc.-- Easton, PA
42. Andritz Sprout-Bauer T-- Muncy, PA (717-546-8211)
43. Pleiger Plastics Company-- Washington, PA (800-394-5608)
44. Puhl, G.F., Co., Inc.-- Goodlettsville, TN
45. Bailey-Parks Urethane, Inc.-- Memphis, TN (800-238-7638)
46. Allied Industries-- Houston, TX (713-676-6000)
47. Flexibox Inc.-- Houston, TX
48. Quality Solids Separation Co.-- Houston, TX (800-962-0370)
49. PPC Industries-- Longview, TX
50. National Metals Industries-- Salt Lake City, UT
51. Spokane Metal Products-- Spokane, WA (800-541-3601)
52. Blower Application Co., Inc.-- Germantown, WI (414-255-5580)
53. Warman International, Inc.-- Madison, WI (608-221-2261)
54. Maritime Welding Ltd.-- NB, Bathurst, Canada
1. Beco Corporation-- Benton, AR
2. STI-- Hayward, CA
3. STI/Environecs, Inc.-- Hayward, CA
4. Scientific Technologies Inc.-- Hayward, CA (510-471-9717)
5. Joy Technologies, Inc., Western Precipitation Div.-- Monrovia, CA
6. GE Company-- Fairfield, CT (800-626-2004)
7. Aerology, Inc.-- Old Saybrook, CT (203-399-7941)
8. Miles Pharmaceuticals-- West Haven, CT
9. McMillan Optical Company-- Murdock, FL (813-627-0100)
10. Car-Mon Products, Inc.-- Elgin, IL (708-695-9000)
11. AAF/Snydergeneral Corp.-- Louisville, KY (502-637-0011)
13. Dovco Industrial Fabrication, Inc.-- Baltimore, MD
14. Environmental Elements Corp.-- Baltimore, MD
15. Powmatic Eltron Inc.-- Finksburg, MD
16. U.S. Automation Co.-- Detroit, MI
17. Specified Design Corp.-- Grand Blanc, MI
18. Shape Corp.-- Grand Haven, MI
19. D-Mark, Inc.-- Mount Clemens, MI (800-343-3610)
20. R.S.E. Inc.-- New Baltimore, MI (313-725-0192)
21. Air Quality Engineering, Inc.-- Minneapolis, MN (612-544-4426)
22. Sonatron Corp.-- Bellmawr, NJ
23. Air Clean Co.-- Elizabeth, NJ
24. North American Pollution Control Systems Inc.-- Linden, NJ (800-752-0237)
25. Ambient Engineering, Inc.-- Matawan, NJ
27. Mikropul Environmental Systems-- Morris Plains, NJ (201-606-5900)
28. Belco Technologies Corp.-- Parsippany, NJ
29. Sonic Environmental Systems-- Parsippany, NJ (201-882-9288)
30. Research-Cottrell Companies-- Somerville, NJ (908-685-4000)
31. Airpol, Inc.-- Teterboro, NJ (201-288-7070)
32. Magnetic Specialties, Inc.-- Trenton, NJ
33. Croll-Reynolds Co. Inc.-- Westfield, NJ (908-232-4200)
34. Beltran Associates, Inc.-- Brooklyn, NY (718-338-3311)
35. Metal Cladding, Inc.-- Buffalo, NY
37. Babcock & Wilcox, Power Generation Group, Customer Parts & Service Dept.-- Barberton, OH (800-354-4400)
38. Ceilcote, Air Pollution Control Div. Master Builders Inc.-- Berea, OH (216-243-0700)
39. Air Plastics, Inc.-- Cincinnati, OH
40. Effox, Inc.-- Cincinnati, OH
41. United Air Specialists, Inc.-- Cincinnati, OH (513-891-0400)
42. Superior Roll Forming Co., Inc.-- Cleveland, OH (216-524-5040)
43. United McGill Corp.-- Columbus, OH (614-443-0192)
44. ACDC Inc.-- Milford, OH (513-248-1820)
45. CMC Environmental-- Valley View, OH
46. Neundorfer Inc.-- Willoughby, OH
47. Spirex Corp.-- Youngstown, OH
48. Laubeck Corp.-- Carbondale, PA (717-282-4344)
    Malvern, PA (800-TALK-JOY)
50. Universal Air Precipitator Corp.-- Monroeville, PA (800-326-8406)
51. Wheelabrator Air Pollution Control-- Pittsburgh, PA (800-394-0992)
52. Plymoth-- Willow Grove, PA
53. ABB Environmental Systems-- Knoxville, TN
54. Dresser Industries, Inc.-- Dallas, TX
55. CRS Enterprises, Inc.-- Fairfax Station, VA
56. Joy Mfg. Co., Canada, Ltd.-- ON, Kitchener, Canada

**SRUBBERS: DUST**

1. Beco Corporation-- Benton, AR
2. Advance Fiberglass, Inc.-- Little Rock, AR (800-342-7367)
3. Jaeger Aerospace Engineering-- Costa Mesa, CA
4. ACME Fiberglass, Inc.-- Hayward, CA (510-538-3440)
5. Air Chem Systems Inc.-- Huntington Beach, CA
6. Joy Environmental Equipment Co.-- Monrovia, CA
7. Joy Technologies, Inc., Western Precipitation Div.-- Monrovia, CA
8. Calvert Environmental-- San Diego, CA (619-272-0050)
9. Interel Corp.-- Englewood, CO (303-773-0753 Ext.300)
10. M & S Engineering & Mfg. Co., Inc.-- Broad Brook, CT
11. Entoletter, Inc.-- New Haven, CT (203-787-3575)
12. ABB/ASEA Brown Boveri, Inc.-- Stamford, CT (800-626-4999)
13. Air Purification System-- Tucker, GA (404-292-7195)
14. Savage Industries-- Tucker, GA
15. Hako Minutemen-- Addison, IL (708-627-6900)
16. Advanced Air Technology, Inc.-- Arlington Heights, IL (708-394-9553 Ext.23)
17. Flex-Kleen Corporation-- Chicago, IL (312-648-5300)
18. Nikro Industries Inc.-- Villa Park, IL (708-530-0558 Ext.255)
19. Snodgrass, Brad, Inc.-- Indianapolis, IN
20. AAF/Snydergeneral Corp.-- Louisville, KY (502-637-0011)
22. Danzer Metal Works Co., The-- Hagerstown, MD
23. Trema North America, Inc.-- Reisterstown, MD (800-833-2925)
24. Bay Shore Steel Co.-- Bay Shore, MI (616-347-1160)
25. Haden Schweitzer Corp.-- Madison Heights, MI
26. Monroe Environmental Corp.-- Monroe, MI (800-922-7707)
27. Duall Div. Met-Pro Corporation-- Owosso, MI
28. Tri-Mer Corp.-- Owosso, MI (517-723-7838 Ext.77)
29. Beckert & Hiester Inc.-- Saginaw, MI (800-332-4031 Ext.12)
30. CIL Incineration Systems, Inc.-- Blaine, MN
31. Multi-Clean-- St. Paul, MN
32. Anel Industries, Inc.-- Winona, MS (601-283-1540)
33. Monsanto Enviro-Chem Systems Inc.-- St. Louis, MO (314-275-5700)
34. Environmental Dynamics Corp.-- Kresson, NJ (609-768-1100)
35. North American Pollution Control Systems, Inc.-- Linden, NJ (800-752-0237)
36. Advanced Industrial Technology Corp.-- Lodi, NJ
37. Champion Trading Corp.-- Marlboro, NJ

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38. S & S Industrial Corp.-- Marlton, NJ
39. Ambient Engineering, Inc.-- Matawan, NJ
40. Atlantic Plastics & Fiberglass Co.-- Middletown, NJ
41. Hydronics Engineering Corp.-- Midland Park, NJ
42. Bioclimatic, Inc.-- Moorestown, NJ (800-962-5594)
43. Mikropul Environmental Systems-- Morris Plains, NJ (201-606-5900)
44. Belco Technologies Corp.-- Parsippany, NJ
45. York, Otto H., Co., Inc. (World Headquarters)-- Parsippany, NJ
46. Aer-X-Dust Corp.-- Tennent, NJ
47. Airpol, Inc.-- Teterboro, NJ (201-288-7070)
48. Advanced Oxidation Systems, Inc.-- Wayne, NJ (201-628-0309)
49. Croll-Reynolds Co., Inc.-- Westfield, NJ (908-232-4200)
50. Clean Gas Systems Inc.-- Farmingdale, NY (516-756-2474 Ext.91)
51. Ducon Environmental Systems-- Farmingdale, NY (516-420-4900)
52. Emtral Corp.-- Hauppauge, NY (516-582-9700)
53. Zelcron Industries Inc. c/o Ducon Environmental Systems Div.-- Melville, NY (800-394-4990)
54. Swemco, Inc.-- New York, NY (212-645-0440)
55. KCH Services, Inc. Dept. N-- Forest City, NC
56. Filtajet Dust Control Dept. T-- Salisbury, NC
57. Kar-Del Plastics, Inc.-- Ashland, OH
58. Magnum Plastics, Inc.-- Aurora, OH (216-562-9200)
59. Air Plastics, Inc.-- Cincinnati, OH
60. Effox, Inc.-- Cincinnati, OH
61. Kleinfeldt, R.F., Co., Inc.-- Cincinnati, OH
63. Volk Environmental Technology-- Mansfield, OH
64. ACDC Inc.-- Milford, OH (513-248-1820)
65. Ecolotreat Process Equipment Corp.-- Toledo, OH (419-729-5443)
66. Aeropulse, Inc.-- Bensalem, PA (800-544-7393)
67. Ketema Inc., Schutte & Koerting Div.-- Bensalem, PA
68. Jones & Hunt, Inc.-- Orwigsburg, PA
69. Pennsylvania Engineering Corp., Engineering Construction Div.-- Pittsburgh, PA
70. E S T Corp.-- Quakertown, PA (215-538-7000)
71. Luftrol, Inc.-- Warminster, PA
72. Dyna-Therm Corp.-- Houston, TX (713-444-9759)
73. Winston Mfg. Corp.-- Longview, TX
74. Tri Dim Filter Corp.-- Louisa, VA (703-967-2600)

SCRUBBERS: VENTURI

1. Joy Technologies, Inc., Western Precipitation Div.-- Monrovia, CA
2. Calvert Environmental-- San Diego, CA (619-272-0050)
3. Interel Corp.-- Englewood, CO (303-773-0753 Ext.300)
4. M & S Engineering & Mfg. Co., Inc.-- Broad Brook, CT
5. Andersen 2000, Inc.-- Peachtree City, GA (800-241-5424)
6. Amerex, Inc.-- Woodstock, GA (404-928-0970)
7. Advanced Air Technology, Inc.-- Arlington Heights, IL (708-394-9553 Ext.23)
8. Koch Engineering Co., Inc.-- Wichita, KS
9. Precision Industries Inc.-- Baton Rouge, LA
10. Danzer Metal Works Co., The-- Hagerstown, MD

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11. Trema North America, Inc.-- Reisterstown, MD (800-833-2925)
12. Koch Process Systems, Inc.-- Westborough, MA
13. Monroe Environmental Corp.-- Monroe, MI (800-922-7707)
14. Anel Industries, Inc.-- Winona, MS
15. Fox Valve Development Corp.-- Dover, NJ (201-328-1011)
16. DR Technology, Inc.-- Freehold, NJ
17. North American Pollution Control Systems, Inc.-- Linden, NJ (800-752-0237)
18. Advanced Industrial Technology Corp.-- Lodi, NJ
19. Ambient Engineering Inc.-- Matawan, NJ (908-566-6866)
20. Hydronics Engineering Corp.-- Midland Park, NJ
22. Airpol, Inc.-- Teterboro, NJ (201-288-7070)
23. Advanced Oxidation Systems, Inc.-- Wayne, NJ (201-628-0309)
25. Ward Automation Inc.-- Buffalo, NY (716-856-6966)
27. Ducon Environmental Systems-- Farmingdale, NY (516-420-4900)
28. Heat Systems Inc.-- Farmingdale, NY (800-645-9846)
29. Emtrol Corp.-- Hauppauge, NY (516-582-9700)
30. Zelcron Industries Inc. c/o Ducon Environmental Systems Div.-- Melville, NY (800-394-4990)
31. Swemco, Inc.-- New York, NY (212-645-0440)
32. Air Plastics, Inc.-- Cincinnati, OH
33. Effox, Inc.-- Cincinnati, OH
34. ACDC Inc.-- Milford, OH (513-248-1820)
35. Ketema Inc., Schotte & Koerting Div.-- Bensalem, PA
36. Jones & Hunt, Inc.-- Orwigsburg, PA
37. Global Environmental Corp.-- Plumsteadville, PA (800-220-1533)
38. EST Corp.-- Quakertown, PA (215-538-7000)
39. Luftrol, Inc.-- Warminster, PA
40. Hansen Engineering, Inc.-- West Alexander, PA (412-484-7551)
41. Augusta Fiberglass, Inc.-- Blackville, SC (803-284-2246)
42. Chemco Engineering, Inc.-- Belton, TX (817-771-1966)
43. Dyna-Therm Corp.-- Houston, TX (713-444-9759)
44. GPI Corp.-- Schofield, WI (715-359-6123 Ext.25)

SCRUBBERS: WET

2. Saracco Mfg. Corp.-- Larkspur, CA
3. Joy Environmental Equipment Co.-- Monrovia, CA
4. Joy Technologies, Inc., Western Precipitation Div.-- Monrovia, CA
5. Entoletter, Inc.-- New Haven, CT (203-787-3575)
6. Flex-Kleen Corporation-- Chicago, IL (312-648-5300)
7. ARI Technologies, Inc.-- Palatine, IL (708-359-7810)
9. Trema North America, Inc.-- Reisterstown, MD (800-833-2925)
10. Beckert & Hiester Inc.-- Saginaw, MI (800-332-4031 Ext.12)
11. Atlas Incinerators, Inc.-- Minneapolis, MN
12. Ceilcote, Air Pollution Control Div. Master Builders Inc.-- Berea, OH (216-243-0700)
13. Ketema Inc., Schutte & Koerting Div.—Bensalem, PA