METALS BEHAVIOR DURING MEDICAL WASTE INCINERATION

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ABSTRACT

Medical waste contains toxic metals such as lead, cadmium, and mercury. Consequently, the incineration of medical waste may result in the emissions of trace metals into the environment, if incinerators are not properly designed and operated. EPA's Risk Reduction Engineering Laboratory initiated a study in 1988 to document what is known about medical waste treatment, particularly in the area of medical waste incineration. This paper is to summarize the findings from this study regarding the behavior of metals in incineration processes. Highlights of these findings are as follows:

- Lead and cadmium are the two most-often-found metals in medical waste.
- Metals can partition into different phases (gas, liquid or solid) but cannot be destroyed during incineration.
- There are several potential pathways that metals follow to reach the environment. They exit incinerators with sifting, bottom ash, fly ash, scrubber waste, and flue gas.
- Data on the capture efficiency of metals by air pollution control equipment used at medical waste incinerators is very limited.
- Wet scrubbers generally capture cadmium moderately well but normally perform poorly in removing chromium and lead. Fabric filter systems efficiently capture all metals.

INTRODUCTION

It has been well known that medical waste contains toxic metals such as lead, cadmium, and mercury. These metals will only change forms (chemical and physical states) but will not be destroyed during incineration. They can be emitted from incinerators on small particles capable of penetrating deep into human lungs. Thus, the emission of trace amounts of heavy metals from medical waste incinerators is one of the major concerns to those who are involved in medical waste management. A clear understanding of metals behavior in medical waste incinerators is critically needed.

EPA's Risk Reduction Engineering Laboratory initiated a study in 1988 to document what is known about medical waste treatment, particularly in the area of medical waste incineration. Potential toxic metal emissions from medical waste incineration was one of main subjects studied. This paper is to summarize the findings of that study.

METAL SOURCES

Researchers at the University of California at Davis conducted a study to identify the sources of toxic metals in medical wastes (Hickman, 1987). The research effort focused on lead and cadmium because they were the two most-often-found metals in medical waste. They concluded that plastics in the waste contributed most to the presence of these two metals. Cadmium is a component in common dyes and thermo- and photo-stabilizers used in plastics. Lead was found in many materials including plastics, paper, inks, and electrical cable insulation. However, the primary source of lead appeared to be plastics. Like cadmium, lead is used to make dyes and stabilizers which protect plastics from thermal and photo-degradation. It is ironic to note that the dyes made from lead and cadmium are used to color plastic bags. Thus, part of the lead and cadmium emissions could be due simply to the "red bags" that infectious waste is placed in.

Under the hazardous waste program of the Resource Conservation and Recovery Act of 1976, EPA has identified ten (10) metals of most concern from 40 CFR 261 Appendix VIII. Four of the ten metals are classified as carcinogenic and the other six metals are considered to be toxic. The EPA's Carcinogen Assessment Group has estimated the carcinogenic potency for humans exposed to low levels of carcinogens. An assigned "Unit Risk" indicates the relative health threat of the metals. Unit Risk (UR) is the incremental risk of developing cancer to an individual exposed for a lifetime to ambient air containing one microgram of the compound per cubic meter of air. Inhalation is the only exposure pathway considered in determining UR.

Toxicity data are used to define concentrations for the six toxic metals below which they are not considered dangerous. Ambient concentrations should not exceed this concentration. The EPA has defined the maximum toxic concentration, or Reference Air Concentration (RAC), for each metal. If ground level concentrations of any of these metals exceeds its RAC, adverse health effects are likely. The Unit Risk of the four carcinogenic metals and the RAC of the six toxic metals are listed in Tables 1 and 2 (EPA, 4/91).

EMISSION PATHWAYS

A majority of metal emissions is in the form of solid particulate matter and a minority is in vapor form. It was generally concluded that particulate emissions from the incineration of medical wastes are determined by three major factors:

(1) Suspension of noncombustible inorganic materials;

(2) Incomplete combustion of combustible materials (these materials can be organic or inorganic matter); and

(3) Condensation of vaporous materials (these materials are mostly inorganic matter).

The ash content of the waste feed materials is a measure of the noncombustible portion of the waste feed and represents those materials which do not burn under any condition in an incinerator. Emissions of noncombustible materials result from the suspension or entrainment of ash by the combustion air added to the primary chamber of an incinerator. The more air added, the more likely that noncombustibles become entrained. Particulate emissions from incomplete combustion of combustible materials result from improper combustion control of the incinerator. Condensation of vaporous materials results from noncombustible substances that volatilize at primary combustion chamber temperatures with subsequent cooling in the flue gas. These materials usually condense on the surface of other fine particles.

Figure 1 shows the transformation of mineral matter during combustion of metals-containing waste. The Figure is self-explanatory. There are several potential pathways to the environment that metals may follow. Most metals remain in the bottom ash. A small fraction of the ash (on a weight basis) is entrained by the combustion gases and carried out of the primary chamber as fly ash. Volatile metals may vaporize in the primary combustion chamber and leave the bottom ash. These metals recondense to form very small particles as the combustion gases cool. Some of the entrained ash and condensed metals are captured in the air pollution control equipment (APCE). The rest enters the atmosphere. Four key variables affecting the vaporization of metals are (EPA, 4/91):

- Chlorine concentration in the waste;
- Temperature profiles in the incinerator;
- Metal species concentration in the waste; and
- Local oxygen concentration.

CURRENT CONTROL PRACTICE

Two strategies are used to minimize metals emissions: (1) The primary chamber is operated at conditions which do not promote vaporization or entrainment of metals; and (2) Any metals which do escape can be captured in the APCE, if present. The parameters usually used to control the escape of metals from the primary chamber are the primary chamber temperature and gas velocity. The key APCE parameters used are specific to the device which is utilized.

(1) Combustion control: Most operating medical waste incinerators are simple single-chamber units with an afterburner located in the stack. The ability of batch incinerators to control metals emissions is limited because only the temperature in the stack is usually monitored.

Most new incinerators are starved-air units. The primary chamber is designed to operate at low temperatures and low gas flow rates. This minimizes the amount of materials entrained or vaporized.

To ensure that metal emissions are minimized, operators must maintain the primary chamber at the temperatures and gas flow rates for which it was designed. Usually the only parameter that system operators can directly control is feed rate. High feed rates can lead to high temperatures and high gas velocities. Thus, many operators carefully control the feed rate. The feed rate is reduced when primary temperatures increase.

(2) APCE control: When metals reach the APCE, they are present in one of three forms. Non-volatile metals are on large entrained particles. Metals which have vaporized and recondensed are usually present on fly ash particles with diameters less than 1 micron. Extremely volatile metals are present as vapors. Table 3 summarizes the ability of common APCE to control these different metal forms. The Table is based on data and worst case predictions. Wet scrubbers are often used to minimize the temperature of the flue gases. Use of low temperatures ensure that all metal vapors have condensed. As indicated in Table 3, vapors are much more difficult to capture than particles (EPA, 4/91).

EMISSION DATA

Figure 2 compares the concentration of arsenic (chosen merely for illustrative purposes) in flue gases before any APCE, and in emitted gases for a variety of incinerators. As shown, a wide variety of flue gas cleaning equipment is used. The Figure indicates the effectiveness of the various types of APCE. Arsenic is predicted to be relatively volatile, compared to other metals. Significant amounts of arsenic are therefore expected to vaporize in an incinerator (EPA, 4/91).

CONCLUSION

Some metals and metal species found in waste materials are volatile and will vaporize at the conditions found in incinerators. The vapors are carried away from the waste by the exhaust gas and they recondense as the gas cools. The vapors condense both homogeneously to form new particles and heterogeneously on the surfaces of existing fly ash particles. To control metal emissions, metals which are of a highly volatile nature are of main concern in terms of installing the proper APCE. Because there are many APCE sizes and types, it is very important to fully understand metal emissions characteristics, combustion control and operating possibilities, and expected APCE performance so that metal emissions can be minimized.

REFERENCES

(EPA, 4/91), "State-of-the-Art Assessment of Medical Waste Thermal Treatment," A Draft Report to EPA's Risk Reduction Engineering Laboratory, April 1991.

(Hickman, 1987), "Cadmium and Lead in Bio-Medical Waste Incinerators," Master of Science Thesis, University of California, Davis, 1987.

TABLE 1. UNIT RISK (UR) VALUES FOR FOUR CARCINOGENIC METALS	
Metals species	Unit risk
Arsenic (As)	0.0043
Beryllium (Be)	0.0025
Cadmium (Cd)	0.0017
Chromium (Cr^{+6})	0.012
UR: incremental lifetime cancer risk from exposure to 1 µg/cubic meter	

TABLE 2. REFERENCE AIR CONCENTRATIONS (RACs) FOR SIX TOXIC METALS	
Metals species	RAC ($\mu g/m^3$)
Antimony (Sb)	0.025
Barium (Ba)	50.00
Lead (Pb)	0.09
Mercury (Hg)	1.70
Silver (Ag)	5.00
Thallium (Tl)	500.00

TABLE 3. TYPICAL APCE CONTROL EFFICIENCIES			
	Control Efficiency(%)		
APCE	Particulate	Fume	Vapor
Venturi scrubber 20" pressure drop	90	85	60
Venturi scrubber 60" pressure drop	98	97	90
Fabric filter	95	90	50
Spray drier/ fabric filter	99	95	90

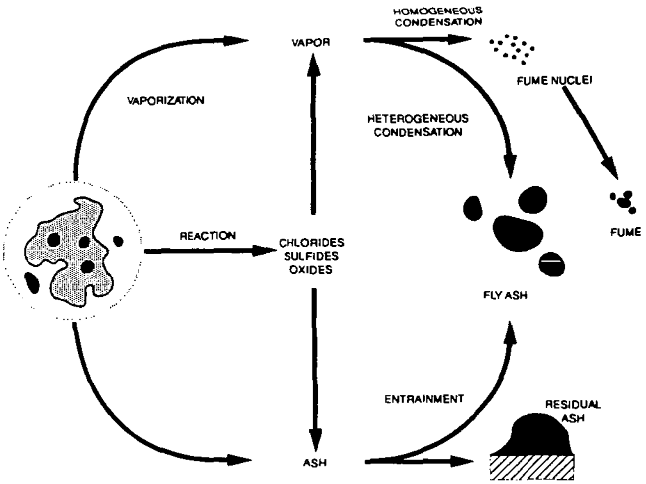

FIGURE 1. METAL TRANSFORMATION DURING INCINERATION (EPA, 4/91)

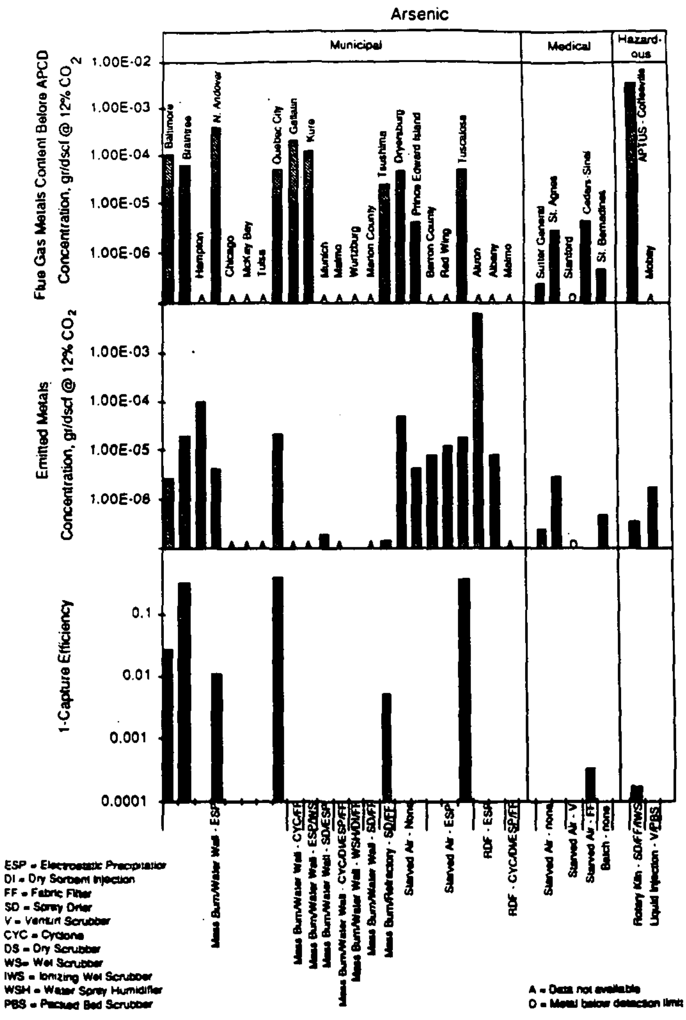

FIGURE 2. ARSENIC EMISSIONS (EPA, 4/91)