AP42 Section 2.3

Background Chapter 2

Reference: 8

Title: The Smoldering Question of Hospital Waste.

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Pollution Engineering, 17:7, July 1985, p.35.

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The smoldering question of hospital wastes

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There is increasing concern today about the proper disposal of hospital wastes, which can contain many very hazardous and infectious materials. Landfilling these types of wastes is no longer considered environmentally acceptable; high temperature waste incineration is the preferred hospital waste disposal method.

Incineration of hospital wastes poses many problems. Most existing hospital incinerators are of older design and may not be fully capable of completely destroying all hazardous materials. Inefficient combustion of halogenated plastics and other organic halogen compounds such as bactericides and hazardous pharmaceuticals can generate toxic dioxin/dibenzofuran air emissions and hydrogen chloride/chlorine acid gas emissions. In many cases, these emissions are not properly controlled at the present time.

Modern controlled air incinerators, which only about 15 percent of American hospitals now utilize,[1] can effectively dispose of many types of complex wastes; with high combustion efficiencies assuring complete destruction of hazardous compounds and minimal trace emissions of toxic air contaminants. The use of efficient control technology such as alkaline scrubbing systems can effectively neutralize and remove acid gas and most toxic air contaminants, similar to the best available control technology (BACT) used in municipal waste incineration systems.[2]

General wastes—the plastics problem

Hospital wastes are highly variable in content; about 85 percent of the total hospital waste stream can be categorized as general refuse, which is non-hazardous. It is the presence of halogenated materials in the hospital refuse, however, that can generate toxic air contaminants during incomplete combustion that must now be investigated.

Hospital wastes usually contain about 20 percent plastics, with levels as high as 30 percent being reported.[3] **In comparison municipal solid waste (MSW) usually contains about 3-7 percent plastics.**[3,4] Hospital administrators and control agencies may now find that many incinerators, installed less than 10 years ago, are unable to cope with the increasingly varied composition of wastes. These problems are generally brought about by the presence of plastics and other disposables in the hospital wastes.[5]

The properties of hospital wastes can only be described statistically. Generally, MSW averages about 5000 Btu/lb heating value; hospital wastes by comparison can range from 7500-10,000 Btu/lb[3]. This higher value for hospital waste reflects the presence of a substantially larger amount of plastic products in refuse samples than those taken from the population at large.[3] The plastics can be a major generator of toxic air emissions, while their high heat value has major significance in the control and operation of the incinerator.

Most hospital wastes fall into the general waste category. However, there are many hazardous constituents in hospital wastes that deserve special attention in waste incineration. **Infectious wastes represent about 10 percent of the total waste stream**[1] and generally can be completely destroyed in a well designed and operated hospital incinerator. In fact, the destruction of these wastes onsite is one of the main reasons that hospitals have incinerators.

An improperly designed and/or operated hospital waste incinerator could lack the proper time/temperature factors to properly sterilize infectious wastes. Any one or a combination of the following factors could interfere with the necessary time or exposure for the sterilization of microorganisms: (1) Temperature gradients as a result of intermittent use, (2) linear velocities that exceed incinerator design, (3) charging beyond incinerator capacity, and (4) moisture content of refuse. Consequently, there is a potential for the incinerator ash to be contaminated with microorganisms as in the case of previous studies of municipal waste incinerators where complete waste incineration was not achieved.[3,2]

The proposed hospital incinerator ash sampling program for dioxins planned by U.S. EPA will not properly assess these toxic emission products.

Many waste laboratory solvents listed as hazardous under Resource Conservation and Recovery Act (RCRA) rules, such as those shown in Table 1, can be effectively reused as boiler or incinerator fuels if properly burned with an efficient combustor.[6]

Table 1.
Hazardous Laboratory Solvents Reusable for Heat Recovery

Acetone	Methyl alcohol
2-Butanol	Methyl cellosolve
Butyl alcohol	Pentane
Cyclohexane	Petroleum ether
Diethyl ether	2-propanol
Ethyl acetate	Sec-butyl alcohol
Ethyl alcohol	Tert-butyl alcohol
Heptane	Tetrahydrofuran
Hexane	Xylene

These compounds, while technically categorized as hazardous under RCRA regulations, do not usually

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generate hazardous combustion byproducts, since they are not halogenated.

All waste pharmaceuticals are hazardous and should be destroyed by incineration.[9] However, incineration does not destroy inorganic agents; emission from the combustion of these compounds may solubilize and be transferred into the food chain (mercury).[9]

Red bag mixed, highly variable hospital wastes can contain hazardous compounds exempt from RCRA requirements.

Cytotoxic agents used in chemotherapy and anti-neoplastic agents may not be effectively destroyed unless hospital waste incinerators can achieve at least 1000 C (1800 F) or greater temperatures. For example, the Memorial Sloan Kettering Cancer Center in New York requires that all chemotherapy wastes be incinerated. Experts at the Center believe that a temperature of 1800-2000 F is necessary to ensure complete degradation of these organic compounds. Since this Institute did not have an incinerator capable of attaining these temperatures, they retained an outside firm to remove chemotherapy waste and ensure proper incineration.[10] Improper incineration of these carcinogenic hazardous pharmaceuticals may result in the release of the original hazardous contaminant, plus secondary toxic contaminants as well.

A paradox is that "red bag" mixed, highly variable hospital wastes can contain hazardous compounds that are currently exempt from RCRA regulations. In any other industry, many of these wastes would be RCRA regulated.

Low level radioactive wastes can also be disposed in hospital incinerators. The Nuclear Regulatory Commission (NRC) considers that incineration is an excellent means of disposing of radioactive hospital waste.[1] Atmospheric dilution appears to be widely used for direct application to most liquid and gaseous radioactive hospital wastes, subject to regulatory constraints.[1] The biomedical waste deregulated by the NRC includes scintillation vials and research animal carcasses with less than 0.05 microcuries of tritium or carbon-14 per gram.[11] Hazardous waste sites have been reluctant to accept this deregulated material and incineration by the hospital has been seen as an important alternative to shallow land burial.[11]

Emissions

Polyvinyl chloride (PVC) and other halogenated polymers and copolymers make up a significant fraction of plastics in hospital wastes; which are generally composed of disposable instruments, syringes, petri dishes, plasticized paperware, cutlery, plastic containers, packaging, bedpans, urine bags, respiratory devices, dialysis equipment, etc.[6]

Halogenated organics when burned completely will usually generate hydrochloric acid (HCl) and/or chlorine (Cl_2) acid gases depending on combustion conditions. If there is an adequate source of hydrogen in the fuel or in the waste, and combustion is at or near stoichiometric conditions, about 65 percent of the refuse chlorine will be converted to HCl[2]. On the other hand, there are cases of refuse combustion with too much excess air, which can lower combustion temperatures by dilution with cool gas. This inhibits HCl formation because the additional oxygen forces the reverse reaction toward greater chlorine concentration. Thus excess air should be limited.[12]

A dual chamber design, excess air hospital waste incinerator rated at a capacity of about 100 lb/hr Type O-2 waste, was tested for chlorine/chloride emissions. The waste had a plastic content of about 30 percent by weight.[5] These tests indicated that HCl emissions averaged only 5 mg/m³ while chlorine Cl_2 emissions averaged 100 mg/m³ and posed a potential health risk.[5]

Previous studies of HCl acid gas emissions from hospital refuse incinerators in Germany reported that hospital refuse incinerators emitted chlorine containing waste gases that caused serious vegetation damage at two nearby farms.[13] Dust samples from 18 German hospital incinerators varied up to 12.9 percent chlorides. In other instances,[13] single measurements yielded emissions of up to 1382 mg HCl/m³. Current German air pollution control regulations limit HCl emissions from MSW incinerators to 100 mg/m³ (63 ppm).

A 1980 test of a California pathological waste incinerator burning 1300 lb/hr of hospital wastes, indicated an average HCl emission of 1120 ppm for 3 test runs.[10] A 1983 stack test of a Canadian hospital incinerator gave the following results listed in Table 2.[14,14A] (This test consisted of 7 runs; 2 for HCl, 7 for SP, etc.; 4 for dioxins/furans; and 1 for PCB/PAH.)

Table 2
Summary of Environment Canada Royal Jubilee Hospital Incinerator Test Results[14A]

HCl 983-1520 ppm @ 50% excess air	(2 runs)
TSP 195 mg/nm³ average @ 50% excess air	(7)
Dioxins, PCDD 69 ng/m³ average	(4)
Furans, PCDF's 156 ng/m³ average	(4)
Total PAH 4 ug/m³ average	(1)
Total PCB's 2.17 ug/m³*	(1)

*Some PCB's may have escaped collection;[14A] and real emissions may be significantly higher.

The hospital incinerator tested, burned about 800 kg/hr of mixed hospital waste and was a modern controlled-air, two-chamber type, capable of high combustion efficiencies. The high levels of acid gas HCl emissions are again indicative of the high halogenated plastic content of hospital wastes.

Hydrochloric acid (HCl) emissions can corrode metals, irritate the eyes, nose and throat and can contribute to acid rain problems.[2] Chlorine is a toxic air contaminant. Thus, acid gas emissions of HCl and Cl_2 emissions may be a public health problem when emitted from hospital incinerators. Perhaps the most advanced BACT system for hospital waste incineration is the proposed energy-from-waste plant for Victoria Hospital, London, Ontario, Canada which will utilize state-of-the-art dry scrubbing technology.[31]

According to a Canadian report from an expert advisory committee,[15] the largest source of dioxin-type substances emitted into the environment is from improper-

ly operated incinerators. Some forms of dioxins and similar compounds are environmentally persistent and are transmitted by flue gas and particulates emitted from improperly designed and/or controlled solid waste incinerators. The incomplete combustion of certain hospital wastes containing halogenated organics could produce high levels of dioxins and similar toxics.

This report does not attempt to deal with the toxicity of dioxins; however the Canadian report notes that "the high toxicity of many dioxins clearly represents a significant health hazard to those Canadians with exceptionally high exposure and the number of individuals at risk will increase if dioxins continue to be put in the environment."

The concentrations and types of the toxic substances formed during the incineration process are extremely variable, and appear to be dependent on forever-changing conditions during the incineration process. Limited emission tests for the dioxins and other halogenated organics are not fully representative.

The mechanisms for formation of PCDDs and PCDFs[16,18,22] include:

1. Combustion and pyrolysis of chemically related compounds such as chlorobenzenes, PVC, chlorophenols, and chlorinated pharmaceuticals, and
2. Thermal recombination of nonchlorinated organic precursors and inorganic forms of chlorine in the waste.

Chlorinated precursors such as chlorinated phenols are often found in hospital refuse.[15] In addition, refuse containing polyvinyl chloride (PVC), lignin, chlorinated pharmaceuticals, chlorinated salts and additional aromatic organic compounds (benzene-ring type) may react with oxygen and/or chlorine during the waste incineration process to form the chlorinated dioxin-type precursor compounds. Chlorinated benzenes, which are also dioxin precursors, can be formed during the combustion of hospital waste, as in the case of MSW refuse combustion.[27]

Organic compounds decompose with exposure to sufficiently high temperatures. The thermal stability of an organic compound is dependent on its composition and structure. **Duvall and Rubey[24] suggest that highly chlorinated organic compounds will be effectively destroyed at temperatures near 800 C (1470 F). Other studies[25] suggest that higher temperature near 1000 C may be required for complete destruction.**

Dioxins (PCDDs) and furans (PCDFs) exhibit relatively low vapor pressure and can be present in the emissions in both particulate and vapor phases. Since they have a high affinity for certain soils and combustion particulate matter, they may be controllable with a suitable dust collector.[26] In addition, they appear to be generally stable and unreactive, although they do tend to undergo dechlorination in the presence of ultraviolet light.

Some hospital waste incinerators operate at temperatures considerably below the 800 C level required for complete dioxin destruction and may be expected to emit dioxins in both particulate and vapor phases. It has been suggested that a dust collector operated at low enough temperature would condense and collect dioxin in both the vapor and particulate phase.[26]

A review of the Canadian hospital incinerator test data shown in Table 2 indicates that dioxin/furan, and PCB emissions are significantly present in hospital incinerator emissions, and can be expected to be highly variable, depending on the composition of waste streams incinerator combustion efficiency. This data suggests that high combustion efficiency operation can minimize dioxin/furan emissions as in the case of MSW incineration.[2]

It is unknown whether the PCB's found in the emissions were due to the content of the waste, and/or from complex combustion/pyrolysis/recombination reactions; however it is known that PCBs have been found in significant quantities in municipal refuse,[27] and may be also present in hospital wastes.

Flyash and bottom ash samples were also analyzed in these Canadian tests: there was very little dioxins or furans found in the bottom ash samples, while much higher levels were found in the flyash,[14A] this confirms that dioxins and furans concentrate on fine particles. The Canadian report on dioxins, noted that the particles escaping with the flue gases will have about 10 times the concentration of adsorbed dioxins present than on precipitated flyash; and that more dioxins escape in vapors in flue gases than on emitted flyash particles. The proposed hospital incinerator ash sampling program for dioxins, planned by U.S. EPA will not properly assess these toxic emission problems; both vapor and particulate phase dioxins should be sampled in hospital incinerator flue gas emissions.

To further confirm the presence of dioxins and dibenzofurans in hospital incinerator emissions, and the previous Canadian test data, three hospital incinerator stack test filter samples were obtained from another state environmental agency. These EPA method 5 filters were extracted and analyzed by GC/MS for dioxins and dibenzofurans by Midwest Research Laboratories in Kansas City, MO.[29]

A description of the incinerators tested[28] and the dioxin/furan emissions found (in the sampled particulate phase only) is given in Table 3. These incinerators are fairly modern controlled-air types capable of relatively high combustion efficiencies. The dioxin/furan levels shown in the Table are probably less than half of the total actual emissions, since it is known that general-

Table 3
Results of Emissions from three U.S. hospitals

	Waste Feed	Secondary Chamber Temp.	PCDD ng/m³	PCDF ng/m³
Incinerator #1 w/scrubber	400 lb/hr infectious waste	1750 F	11.8	18.9
Incinerator #2 w/waste heat boiler	730 lb/hr general hospital waste	1950 F	28.2	52.1
Incinerator #3 w/waste heat boiler	1150 lb/hr general hospital waste	1700 F	4.8	4.8

ly more than 50 percent of dioxins and furans are in the vapor phase, which was not analyzed in these particulate screening tests.

These particulate filter sample screening analyses only confirm the Canadian data, that dioxins and furans are routinely present in hospital incinerator emissions. The more prevalent older type excess air hospital incinerators having lower combustion efficiencies can be expected to emit much higher levels of these toxic air contaminants.

Typical hospital incinerators have relatively low stack heights of 20-60 ft and low exhaust gas temperatures of 150-470 F. Such emissions cannot be expected to be diluted to a high degree and are generally in the order of 2000 fold dilution. Such toxic emissions from improperly controlled incinerators could possibly pose significant health hazards to nearby receptors. For example, Incinerator #2 having the highest PCDD emissions could have a total PCDD emission of about 70 ng/m³. Using conservative, worst case modeling, these emissions from a newer, efficient, controlled air incinerator would not exceed the Ontario Ministry of Health 30×10^{-12} g/m³ PCDD ambient guideline. Older, less efficient hospital incinerators would probably exceed such a health-related dioxin guideline by much larger margins: for dioxin emissions an order of magnitude or more greater than this level, which are believed to occur from older designed and improperly operated incinerators.

It appears that state's program of upgrading hospital incinerators to the more efficient, controlled air type, has minimized toxic, dioxin emissions; other agencies may want to consider similar programs.

The full magnitude of this toxic emission problem can not be accurately assessed, without more complete vapor and particulate phase dioxin/furan test data. The authors recommend that U.S. EPA give this problem a suitable priority in its Dioxin Test Program.

Incinerator Design & Operation

The design of an effective incinerator depends primarily upon:

1. Physical form of the waste (liquid, solid, sludge, etc.).
2. Total thermal input — including heat from the waste (i.e. Btu/hr).
3. Special performance requirements (such as 99.99% destruction for hazardous compounds).

Incinerator configuration will depend upon Items 1 & 3 combined with the combustibility of waste solids. Dry combustibles (paper & plastics) can be burned on a grate with cold air blown up through it. If the solids are wet, this combustion air must be hot. If the solids are not combustible, there is no advantage to blowing air through the wastes. These differences mean that it is difficult to design an incinerator which burns all types of waste well. It also indicates that changing the purpose of an existing incinerator for instance, from destroying pathological waste to general purpose disposal, may be impractical.

Note that the thermal input is more critical than the amount of waste to be incinerated. The heat input to an incinerator for wet pathological waste is provided by the fuel used to fire it; while the heat input to a refuse incinerator may come almost entirely from the waste. In either case, it is the rate of heat release which primarily determines the size of the unit rather than the rate of waste feed. In addition, the rate at which waste can be fed is determined by the amount of heat which it releases or absorbs and not on a simple pounds per hour basis. The fuel feed rate must also be controlled in order to provide whatever heat is not supplied by the waste in order to maintain temperature.

The need to control both waste and fuel flow rates to maintain target operating conditions is one reason for operating problems on any incinerator, especially a hospital incinerator. When the combustibility of the waste stream changes, the waste feed rate and fuel flow rates should be adjusted accordingly. Hospital wastes include substantial amounts of plastics with high heating value as well as wet or pathological wastes with negligible heating value. This results in a larger variation in waste heating value on a hospital incinerator than for other types of incinerators with a commensurate requirement for more sophisticated control of the incinerator.

Organic emissions from an incinerator result from insufficient exposure of incinerated wastes to temperature and/or oxygen. A general criteria for 99.99 percent destruction is to heat the waste (or its combustion products) to about 2000 F for two seconds or more. Emissions can result from a lack of sufficient control, as when insufficient supplemental fuel is added to maintain temperature, or when insufficient air flow causes incomplete combustion. It can also result from nonuniform conditions, as when a fraction of the waste finds a cooler path through the incinerator — a short circuit. The two second residence time is not a fundamental necessity, but it helps to ensure against these short circuits. Measurable oxygen in the combustion zone is not a fundamental necessity either, but it substantially reduces the temperature needed to destroy most organic emissions.

Incinerators have evolved from simple devices which destroyed most of what was put in them to the present day versions which destroy essentially 100 percent of the organic waste. Hospital incinerators originally were used to disinfect and destroy pathological wastes, (which can be achieved at relatively low temperature) but now are also used to destroy general wastes (which can require very high temperature for destruction).

The evolution toward very high destruction efficiency requirements in addition to the appearance of halogenated organics in the wastes has led to the multiple chamber incinerator. In a double or triple chamber incinerator most of the incineration occurs in the first chamber while the second guarantees complete destruction. Solids are burned or heated to destruction in the first chamber and the off gases are heated (if necessary) in the second chamber to 2000 F by supplementary firing. The second chamber is large enough that it takes an average of 2 seconds for the combustion gases to pass through it. This incinerator concept is effective because

the second chamber can be used to compensate for uncontrollable variations in the burning rate of solids in the first chamber. Unless the properties of the solid wastes fed to a single chamber incinerator are extremely consistent, it is almost impossible to control the combustion well enough to assure continuous complete destruction of potential organic emissions.

Operation & Control

Good control of an incinerator is not (yet) simple. Since the sophistication of controls is independent of incinerator size, the cost of building and operating a small incinerator is harder to justify than for a large incinerator. Continuous skilled operator supervision is essential because of the variety of problems associated with handling and burning solid wastes. Good instrumentation and automatic controls are also necessary.

Adequate incinerator control requires that flue gas oxygen be maintained at a set level. Although this can be accomplished in an approximate fashion with an appropriate supplemental fuel control, it is best done by directly measuring the oxygen and trimming the flow controls for air and supplemental fuel. High oxygen levels reflect too much air which cools the fire resulting in insufficient temperature to destroy certain toxic organic compounds. Incinerator test data indicate a clear correlation between high oxygen levels and emission of organic compounds. Low oxygen levels reflect insufficient air to completely oxidize (burn) all the wastes (or fuel), which will certainly increase emissions or carbon monoxide (CO) and probably various organic species.

It appears that there is an empirical correlation between high combustion efficiency (low CO levels) and high destructability of halogenated organics, such as dioxins and furans. It is prudent therefore to provide continuous CO exhaust gas monitoring to ensure proper high efficiency incineration of hospital wastes.[2]

The combustion rate of a varying solid waste feed in an incinerator is impossible to predict, so that controlling the air flow to match the rate at which oxygen is consumed is difficult. However, failure to adequately control air flow means either incomplete combustion or low temperatures. On many incinerator designs, air distribution and feed controls must be modulated in addition to the overall air flow rate. Adequate control of these systems is possible, but it is not simple.

Summary and Conclusions

Traditionally the hazards of hospital wastes have been viewed in terms of the dangers posed (primarily) to the staff and patients by their proximity to various drugs, chemicals and infectious waste. These potential hazards remain, but in addition, it is now recognized that the gases emitted from the incinerator may pose hazards to the downwind environment (which may include the hospital itself). Specific emission data for hospital incinerators is generally lacking, but comparable data from municipal and industrial incinerators indicate the potential for both acid gas and toxic emissions. This concern is reinforced by the dated incinerator designs and operating practices reported for a number of hospitals. Current limited test data definitely confirms the presence of toxic dioxin/furans in hospital incinerator emissions, which can be minimized by high combustion efficiency design and operation, and/or the use of appropriate BACT air pollution control technology.[2]

Current local, state, and federal air pollution control regulations applicable to hospital waste incinerators are dated and generally only require the control of smoke and particulates. A greater emphasis should be placed on properly evaluating and controlling both conventional and toxic emissions from hospital incinerators. **PE**

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