Hospital Waste Management in Florida

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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>CICU</td>
<td>Cardiac Intensive Care Unit</td>
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<tr>
<td>SICU</td>
<td>Surgical Intensive Care Unit</td>
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<tr>
<td>NHCU</td>
<td>Nursing Home Care Unit</td>
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<td>ANOVA</td>
<td>Analysis of Variance</td>
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<td>Psyc</td>
<td>Psychiatry</td>
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<tr>
<td>MeWa</td>
<td>Medical wards</td>
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<tr>
<td>ExCa</td>
<td>Extended Care</td>
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<td>Dial</td>
<td>Dialysis</td>
</tr>
<tr>
<td>D</td>
<td>Dialysis</td>
</tr>
<tr>
<td>MI</td>
<td>Medical Intensive Care Unit (MICU)</td>
</tr>
<tr>
<td>LD</td>
<td>Labor and Delivery</td>
</tr>
<tr>
<td>R</td>
<td>Rehabilitation</td>
</tr>
<tr>
<td>A</td>
<td>Adolescents</td>
</tr>
<tr>
<td>BU</td>
<td>Burnt Unit</td>
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<tr>
<td>E</td>
<td>Emergency</td>
</tr>
<tr>
<td>PW</td>
<td>Patient Wards</td>
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<tr>
<td>U</td>
<td>Urgent Care Center (UCC)</td>
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<td>P</td>
<td>Pediatrics</td>
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<td>Maternity</td>
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<td>S</td>
<td>Surgery</td>
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<tr>
<td>misc.</td>
<td>Miscellaneous</td>
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**Symbols** * Multiplication

**Units of Measurement** FPS
ABSTRACT

Disposal of medical waste has emerged as a major problem in United States. The public is increasingly concerned over the improper disposal of medical waste, particularly the waste contaminated with communicable disease agents such as the AIDS and the hepatitis B viruses [William and David 1991; Lee, Huffman and Nalesink 1991; U.S.EPA 1991]. Given the general lack of federal standards and regulations and the large amount of biohazardous waste generated, it becomes extremely important to device efficient methods of waste handling and its disposal. The principal objective of this project is to characterize the medical waste by actual hand separation, and theoretical studies for clean incineration with the aim of complying with the State of Florida's emission standards. The present report highlights the test results of two years of study at two large hospitals in the State of Florida. Test results show a substantial proportion of plastic, paper and cotton in the waste stream. Plastic characterization has been carried out to differentiate between various types of plastic resins appearing in the waste stream. The waste characterization data obtained is statistically analyzed using the t-test. In addition, waste estimation studies have been carried out for the year 1992 by analyzing the procurement lists. The test results are compared with the actual amount of waste generated by one of the hospitals for the year 1992. One way analysis of variance test has been carried out to determine possible interrelationship between the waste originating from any two different departments of the Large Federal Hospital. The metallic constituents in the ash from the different parts of the incinerator of one of the hospitals have also been analyzed. Our two years of on-site research on medical waste gives a better insight into the characteristics of medical waste. Test results as well as theoretical studies show ample scope and increasing need for environmentally friendly disposal of medical waste.
Disposal of medical waste has emerged as a major problem in United States. The public is increasingly concerned over the improper disposal of medical waste, particularly the waste contaminated with communicable disease agents such as the AIDS and the hepatitis B viruses [William and David 1991; Lee, Huffman and Nalesnik 1991; U.S.EPA 1991]. Given the general lack of federal standards and regulations and the large amount of biohazardous waste generated, it becomes extremely important to device efficient methods of waste handling and its disposal. The principal objective of this project is to characterize the medical waste by actual hand separation, and theoretical studies for clean incineration with the aim of complying with the State of Florida's emission standards. Test results of the study at two large hospitals in the State of Florida show a substantial proportion of plastic and paper percentage in the waste stream. The metallic constituents in the ash from the different parts of the incinerator of one of the hospitals has been analyzed. The waste characterization data obtained is statistically analyzed using the t-test. Front end mass balance studies have been carried out to estimate the amount likely to end up in red bags. Plastic characterization has been carried out to differentiate between different types of plastic resins appearing in the waste stream.

This report presents the results obtained by the characterization of the biohazardous medical waste generated by a Large Federal Hospital (LFH) in the state of Florida. The amount of waste likely to be generated for different months of the year 1992 has been estimated based upon the front-end analysis. This estimate is compared with the actual waste generated for different months of the same year. The data collected is presented at the end of this report. For the purpose of characterization of medical waste, we have been going to the aforementioned hospital twice a week and have been working in conjunction with the Environmental Services Department of the hospital. Complete attention towards the LFH has yielded more number of data points, thus giving a better approximation to the amount and type of waste stream constituents for the same hospital.

Work at the Large Metropolitan Hospital (LMH) had to be discontinued owing to unusual circumstances developing between the LMH and the authorities. Full attention was given to the LFH. The new incinerator at the LFH is likely to be available for sampling in the month of June, 1994. This sets back the schedule for attaining the objectives of the project. This is because the installation of the incinerator is being delayed due to some reason. A research paper based on the characterization studies has been accepted by the Journal of Environmental Health for publication in the July/August 1994 issue.

Results obtained by waste characterization at both hospitals indicate variation in the composition of waste generated by different departments. Since the waste composition from various departments are different, the kind of emissions generated can be expected to be different. Knowing the kind of emissions generated by waste from a particular department will help in better control over the emissions. As an example, for smaller hospitals not having a scrubber, a waste mixture generated by combining wastes from different departments with waste paper, etc. can be burnt to keep HCl emissions below acceptable level.
HOSPITAL WASTE MANAGEMENT IN FLORIDA

1. INTRODUCTION

Disposal of medical waste has emerged as a major problem in the United States. The public is increasingly concerned over the improper disposal of medical waste, particularly the waste contaminated with communicable disease agents such as the AIDS and the hepatitis B viruses [William and David 1991; Lee, Huffman and Nalesink 1991; U.S.EPA 1991]. Approximately 465,000 tons of biohazardous waste is generated by United States each year by 377,000 health care facilities. Hospitals, which comprise only 2% of the total number of generators, produce the greatest quantity (approx. 77%) of the biohazardous waste among the different types of institutions [Green 1992]. Given the general lack of federal standards and regulations and the large amount of biohazardous waste generated, it becomes extremely important to device efficient methods of waste handling and its disposal. Autoclaving, shredding and chemical disinfection and incineration are the three principal technologies for the treatment and disposal of medical waste. Incineration process is widely used for medical waste disposal as it disposes of most waste types and forms, is suitable for large volumes, causes large weight and volume reductions, sterilizes and detoxifies, and heat can be recovered. According to U.S.EPA 1991, a key factor in specifying an incineration system for a particular application is the clear identification of the ranges of waste properties and waste characteristics. Use of averages could lead to inadequate incinerator capacity and could jeopardize performance. Also characterization of waste is important to effectively control the potentially toxic pollutants such as acid gases, heavy metals, and dioxins.

This report presents the results from a two year study of characterization of the biohazardous medical waste generated by a Large Metropolitan Hospital and a Large Federal Hospital in Florida. The data collected is presented at the end of this report. For the purpose of characterization of medical waste, we have been going to the aforementioned hospitals twice a week and have been working in conjunction with the Environmental Services Department of the hospitals.

2. MOTIVATION AND OBJECTIVES

The amount of waste generated by hospitals and other health care facilities has increased with wide acceptance of single use items. The State of Florida prohibits the disposal of infectious waste in landfills without prior treatment. The most common method of treatment is incineration. Studies have shown that hydrogen chloride and heavy metals are emitted from medical waste incinerators causing air pollution. In order to reduce air pollution, identification of all sources of pollutants in the waste stream is important [U.S. EPA 1989, 1990, 1991]. So, quantifying and characterizing the waste stream becomes a very important initial task in pursuing the goal of managing the medical waste. The principal objective of this project is to characterize the medical waste by actual hand separation and as well as to predict the amount of waste generation from a large hospital. Preliminary studies have been done to investigate into the type of emissions produced if waste from different departments of a hospital are burnt separately. The concept is to meet the emission standards without any costly add-on's to the incinerator through the control of the waste feed into the incinerator and the operating conditions of the incinerator. Thus characterization of medical wastes from hospitals becomes an integral part of this concept so that management of such wastes can be improved. Other objectives include education of hospital workers in the state and source reduction of waste.
3. MEDICAL WASTE MANAGEMENT IN THE LMH AND THE LFH

3.1 LARGE METROPOLITAN HOSPITAL

The LMH has more than 500 beds and has an occupancy of over 90%. American Hospital Association, 1991, classifies this facility as a General Medical and Surgical Facility. This facility includes trauma, maternity and pediatrics care units.

3.1.1 Waste Management

The LMH is a large hospital and has many departments. The disposal of medical waste (biohazardous as well as non-biohazardous) is the responsibility of the Environmental Services Department of the hospital. The waste originates from different departments located on different wings or towers of the hospital.

Each tower has several floors and on each floor there are separate trash rooms for the collection of medical waste. Generally only one department is present on a particular floor. Some departments may extend to many floors. The trash rooms are located near the service elevator on all the floors. Each floor has a house keeper who collects the waste and dumps it into the nearest trash room. The trash rooms have one or two large trolleys kept inside which receive all the trash. An employee of the Environmental Services Department periodically comes and transfers the waste to the back of the hospital. He takes the trolley containing medical waste from trash room and replaces it with an empty trolley which he brings with him. If that employee is working for different floors, which is true for most of the employees, he may transfer the waste into the empty trolley he brings with him from the trolley kept inside the trash room. The biohazardous medical waste is identified by the red plastic bags containing waste and all other plastic bags are considered non-biohazardous. The trolley(s) containing waste are then transported manually by the employee via an elevator to the ground floor. The trolley(s) are then moved through the hospital corridors to location 1 (Figure 1). On reaching location 1, the employee transfers the waste from his trolley(s) to the trolleys kept at location 1. The trolleys kept at location 1 are used to transport waste to the incinerator. The employee is now ready for another cycle of waste collection. Medical waste is collected on all seven days of a week. Medical waste from some of the departments goes to location 2 which is different from location 1. Trolleys kept at location 2 contain all the medical waste. Waste from location 2 is directly transferred to the incinerator. A day is divided into three shifts namely, morning shift (6.30 am to 3.00 pm), noon shift (3.00 pm to 11.30 pm) and night shift (11.00 pm to 6.00 am). According to the hospital staff, most of the trash is collected in the morning shift.

3.1.2 Incinerator

The incinerator at the Large Metropolitan Hospital is located in a separate building. It is operated by the staff of the Environmental Services Department of the LMH. The incinerator operates twenty-four hours a day and is only shut down during routine cleaning operation or when it breaks down. The medical waste is transported to the incinerator in trolleys towed by a small truck. The truck leaves the trolleys with waste at the incinerator and brings back empty trolleys from the incinerator to the location 1. The red bags in the trolleys containing medical waste are directly fed to the incinerator by tilting the trolleys onto the catchment of the incinerator. The incinerator ram then pushes the bags into the incinerator where they are burnt. The incinerator has two chambers one on top of the other. The lower chamber is maintained at 1600 degrees Fahrenheit and the upper chamber where the flue gases are burnt is maintained at 1900 degrees Fahrenheit. The thermal energy generated by burning the waste is used to heat the water which is supplied to the hospital. The heat exchange
between the hot flue gases and water takes place in a three pass boiler. The gases produced by burning the waste are then passed through a wet scrubber and then are released to the atmosphere through the chimney stack.

3.2 LARGE FEDERAL HOSPITAL

The LFH has more than 500 beds and has a occupancy of over 75%. American Hospital Association classifies this facility as a General Medical and Surgical Facility. This facility does not have trauma, maternity or pediatrics care units. This facility has a nursing home type care unit.

3.2.1 Waste Management

In the LF Hospital, the management of medical waste is the responsibility of the Environmental Management office. The wastes which are generated by different departments and wards are collected separately as non-biohazardous and biohazardous wastes by the housekeepers. There are two collections daily from monday through friday. There are no collections on saturday and sunday. The first collection is done in the morning at 7 am, the second is done at 2:30 in the afternoon. The housekeepers collect the wastes and bring them down to the back platform of the hospital, where they put the non-biohazardous and biohazardous carts into different trailers. Each trailer can hold 103 biohazardous carts at a time. Typically, two trailers are used every three days. (Note: because the incinerator in the LFH did not work, they have to put the waste carts into trailers to be transported to another place to burn). The flow of the medical waste in LMH is similar to LFH, except that all the waste is collected at a single location from where it is transferred to the trailers.

3.2.2 Purchase and Distribution

In the LF Hospital, the Supplies Process and Distribution Department(SPD) is responsible for buying the materials ordered by different departments of the hospital. Each item has a unique number for identification. All the supplies are stored in a storage room, where they are kept on shelves. Some of the supplies are also stored in the Emergency room which were also surveyed under the present study. The SPD keeps a running database of all the items purchased and their usage.

4. METHODOLOGY AND PROCEDURE

4.1 FRONT END MASS BALANCE STUDIES(LFH)

These studies involve survey of the material bought by the hospital's supply department. The procedure included the weighing of the packaging and the contents of the different items. The total weight of packaging and the amount of supplies (excluding ingested material) gives an idea about the worst case scenario, when all the medical supplies including the packaging end up in the red bags.

An overwhelmingly number of products are used by the LF Hospital. To characterize them and to predict their monthly usage following strategy has been carried out:

1. The SPD department of the LFH manages a computer database of medical supplies needed for the Hospital. From this running computer database a list of products with their name, identification number and monthly usage is printed out.

2. Then with the help of experienced personnel of the SPD Department of the LF hospital, those items on the list which are most likely to end up in red bags and contribute appreciably towards the red bag waste are highlighted. The rest are ignored for the present case. For example, sutures may end up in red bags, but their weight is so small that they can be neglected.
3. The above eliminating process still leaves a great number of products which are then grouped according to packaging type and item category.

4. Then a sample item is picked up and the package is opened. While the package is characterized as paper or plastic, the product is characterized as composed of plastic, paper, cotton, and metal.

5. This weighing was carried out for all the items that are most likely to end up as red bag waste. These weights and the monthly usage for the year 1992 have been obtained from hospital records. The monthly usage multiplied by the weights of the different material gives the monthly usage weight of the materials. Adding the monthly usage weight for all the materials gives an estimate of waste likely to end up as red bag waste as shown in Table 1 and Table 2(a).

4.2 BACK END WASTE CHARACTERIZATION

Medical waste produced by the hospital can be divided into two groups:
(a) Biohazardous
(b) Non-biohazardous
The biohazardous waste produced is characterized as to how much paper, plastic, cotton, metal, glass and other miscellaneous items are present as percentage by weight in a sample taken from waste produced by a particular department. In the second phase of the project the plastic found in the waste has been further characterized into the following seven categories:

1. Polyethylene Terephthalate (Industrial Code "1")
2. High Density Polyethylene (Industrial Code "2")
3. Poly Vinyl Chloride (Industrial Code "3")
4. Low Density Polyethylene (Industrial Code "4")
5. Polypropylene (Industrial Code "5")
6. Polystyrene (Industrial Code "6")
7. Others (Industrial Code "7")

The plastic characterization has been done as a part of total waste characterization. By characterizing the red bags at the LFH and LMH, we obtained the different components of the medical wastes as follows:

[1] Plastics include: gloves, containers, tubes, bowls, bags, etc.
[2] Cotton includes: diapers, bandages, cotton balls, clothes, etc.
[3] Paper includes: towel papers, newspapers, office papers, etc.
[4] Metals include: aluminum cans, metal cans, etc.
[5] Glass includes: bottles, etc.

4.2.1 Large Metropolitan Hospital

The Large Metropolitan Hospital is divided into individual departments for the present work. For the characterization of the waste a particular department or a group of departments are chosen during a scheduled week and waste characterization is done for those departments only. The different departments of the hospital are as follows:
* Emergency
* Laboratories
* Maternity
* Labor and Delivery
* Pediatrics
* Adolescents
* Urgent Care Center
* Dialysis
* Rehabilitation
* Psychiatry
* Surgery
* Patient Wards
* Infants
* M.I.C.U.
* Burnt Unit
* Trauma Center

On arrival to the backyard or location 1 of the hospital, an employee or employees working for scheduled department are identified with the help of the supervisor. Then for the separation of medical waste large cardboard sheets, which are freely available, are laid on the floor. The purpose of this is to keep the floor clean. Small trash bins 4 to 6 in number are arranged around the cardboard sheet near the weighing scale. The person(s) characterizing the waste dress up by putting on a light overall gown, gloves and face mask to protect nose and mouth. As soon as the predetermined employee arrives with a trolley containing waste, the unwanted trash(cardboard boxes and white bags) are separated out. Then the red bags are pulled out manually and put on the scale. The empty trolley is taken by the employee back to the floor in which he is working, for the next round of trash. This way the employees work is not hindered or slowed down. This total trash is a single sample representing a particular department. A sample may weigh 10 lb to 250 lb and may contain 0 to 25 red bags. An average red bag weighs about 10 lbs. If a sample weighs less than 50 pounds then the whole sample is characterized; otherwise in case of a large sample, red bags are selected randomly. On an average 45 to 50 pounds of waste are characterized from a particular department. The red bags are opened and waste is dumped on the cardboard sheet one by one. Simultaneously paper, plastic, etc. are separated out and put into small trash bins arranged along the cardboard sheet until all red bags are exhausted. The bins arranged alongside also have red bags wrapped inside them. After the sample is separated, the red bags from the bins are taken out. These red bags now contain exclusively either plastic, paper, metal, cotton, glass or miscellaneous items. The red bags are then weighed individually. This gives us the amount of each individual item present in the sample. The percentage composition by mass can also be found out using the total weight. So the process of waste characterization involves removal of biohazardous waste from red bags and putting them into different red bags after separation of different items manually. Any additional trash coming from the same department at some other time on the same day is also taken into account by measuring the total weight of red bags present. This gives us an estimate of total trash produced in a day by a particular department. After characterization, the red bags are dumped into different trollys which include trash from other departments also. These trollys are periodically towed by a truck to the incinerator where the waste is burnt. Ash samples from different locations of the incinerator are also collected. The flow chart of the whole process is depicted in Figure 1. For the characterization of the trash going to location 2, the trash is transported to location 1 as there is no weighing scale and proper space for waste characterization at location 2.

4.2.2 Large Federal Hospital

The Large Federal Hospital has been divided into the following departments for the purpose of waste characterization. For the characterization of the waste a particular department or a group of departments are chosen during a scheduled week and waste characterization is done for those departments only. The different departments of hospital are as follows:
* Nursing home care
* Surgical intensive care
* Psychiatry
* Surgery
* M.I.C.U (Medical intensive care)
* C.I.C.U (Cardiac intensive care)
* Medical ward
* Dialysis
* Extended care
* Ambulatory
* Spinal cord injury center
* Chemotherapy clinic
* Emergency
* Mental hygiene
* Day treatment
* Laboratory outpatient

Waste characterization at the LF Hospital has been done in the same way as that of the Large Metropolitan Hospital. The only difference being that in the LFH, the medical waste is collected only twice a day and no waste is collected on weekends. Also waste is transported by trailers outside the hospital for incineration. Although there are many departments and wards in the hospital, some of them have very little biohazardous wastes or even no red bags. For example, in the Emergency department the arriving patients are stabilized and diagnosed and admitted to the appropriate ward. As a result there is very little red bag waste from the Emergency ward in the LF Hospital. The departments which account for over 90 percent of the total biohazardous wastes produced in the LF hospital as per the experienced personnel of LFH are:
* Nursing home care
* Surgical intensive care
* Psychiatry
* Surgery
* M.I.C.U
* C.I.C.U
* Medical ward
* Dialysis
* Extended care

Waste characterization in the LFH is done for the above departments only.

4.3 PLASTIC CHARACTERIZATION AT THE LMH AND LFH

Plastics found in the waste is further characterized into seven sub-groups based on resin type. The plastic characterization is done as described below.

After characterizing trash from a particular department into paper, plastic, metal, cotton etc., the individual group is weighed and noted down. Then all the separated groups, except plastic, are disposed off. Then the plastic characterization is carried out in the same way by arranging bins along side the plastic waste and picking up plastic items belonging to a particular category and dumping them into a particular bin. Plastics are separated into seven different groups as explained before. The characterization of plastic requires a prior knowledge of type of plastic resin. Also quite a few of the plastic products appearing in the red bags have resin name on them. Some of the very conspicuous plastic products are: Thermocole(#6) and PVC(#3) and hard plastic products(Usually #2). In case of doubt information from the front end was obtained about the product type or the manufacturer was called. Plastics have been characterized according to following seven standard categories:

#1 or Polyethylene Terephthalate: White or colorless bottles (seldom seen).
#2 or High Density Polyethylene: chemical bottles, hard plastic stuff etc.
#3 or Polyvinyl Chloride: Tubing, gloves and plastic bags.
#4 or Low Density Polyethylene: Thin plastic covers.
#5 or Polypropylene: Jam and small juice containers, hard yellow pots.
#6 or Polystyrene: Thermocole coffee cups and thin brittle plastic package bottoms.
#7 or Others: Seldom Seen.

4.4 INCINERATOR STUDIES (LMH)

4.4.1 Ash Sampling

Ash sampling involves regular collection of ash samples from the bottom of the incinerator (bottom ash) and collection of ash samples from I, II, III pass and scrubber of the boiler whenever the boiler is shut down for repairs. Bottom ash samples from the incinerator were collected approximately once a week and the ash samples collected over a period of time were sent to Florida Institute of Technology for analysis of its metallic constituents.

4.4.2 The stack sampling

The stack sampling involves an analysis of particulate and gaseous material emanating from the chimney of the incinerator. Standard Methods, Method-26 for Hydrochloric acid gas and Method-5 for particulate material was followed. Since stack sampling ports are situated at the top of the 40-Feet chimney, a rope and pulley assembly and a roller arrangement have been designed and fabricated at the University of Miami, College of Engineering Machine shop to hoist the instruments and to hang them above the sampling ports. Initial test runs have been carried out successfully to check the functioning of purchased as well as fabricated equipment. The procedure used is explained below.

On arrival to the incinerator a person climbs up to the chimney top and the other person standing at the bottom ties the equipment to a rope which goes around a pulley installed by us at the platform near the chimney top. The equipment is hoisted up piece by piece by the person standing below. After everything is pulled up, the equipment is assembled and the sampling port is opened and the probe of the sampling train is inserted into the stack. The samples will be collected according to the standard method. After sampling the equipment is disassembled and hoisted down with the help of the same rope and pulley assembly. The sample is then brought back for analysis.

A trial run was made using the above procedure at the LMH incinerator. After the run access to the incinerator was not available, owing which no further sampling was done. The LFH incinerator was being replaced during the time of present study. It should be available after June 1994.

5. DATA ANALYSIS

5.1 STUDENT t-TEST

The waste generated by various departments of the LMH and LFH has been sampled and analyzed separately to determine the percentage of different trash constituents, namely paper, plastic, cotton etc. The data so generated is statistically analyzed using student-t test as the number of samples for each department are less than 30[Richmond, S. B.]. Various statistical parameters for the percentage of trash constituents are calculated. Since the actual standard deviation and mean of percentage of trash constituents for different departments are unknown, hence use of student-t test is recommended. The ash generated by the incinerator in LMH is sampled to determine the various metallic constituents of the ash.
Standard deviation of percentage, mean percentage, standard error and median for student-t test also known as "small sample test" [Richmond 1964] in the present case for a particular constituent of trash and for a particular department is calculated using the equations given below:

**Number of Samples** \( N \)

**Number of Degrees of Freedom** \( N - 1 \)

\( X_1, X_N \) Individual Percentage of Samples

**Mean** \( \bar{X} \) \( \frac{X}{N} \)

**Standard Deviation** \( S \) \( \sqrt{\frac{(X - \bar{X})^2}{N - 1}} \)

**Std. Err.** \( S_x \) \( \frac{S}{\sqrt{N}} \)

**Median** Middle Value

Since we do not know the true means and standard deviations of various constituents of trash, and to determine how much the sample means and standard deviations represent their true values, the value of 't' of student-t test is selected from the standard student t-distribution table. The criterion for the selection of t value from standard table depends upon the level of significance and degrees of freedom.

In the present case the level of significance for all samples is taken to be 0.05. A level of significance 0.05 implies a 95% confidence interval. For the corresponding level of significance and degrees of freedom, the value of t is picked. Then the confidence limits for the mean are calculated as below:

**Confidence Limit** \( \bar{X} \pm t \ S_x \)
This directly follows from the basic formula for the calculation of t value if the true mean is known. i.e.

\[
t = \frac{(\bar{X})}{\left(\frac{S}{\sqrt{N}}\right)}
\]

5.1.1 Front End Mass Balance (LFH)

Table 1 gives the total weight of items purchased for the year 1992, which are most likely to end up in red bags. It also shows the percentage of packaging and products inside the package which are most likely to end up in the red bags. The table shows that the percentage of paper as package material is considerably higher than the percentage of plastic as package material. On the other hand, the percentage of plastic as product material is the highest followed by percentage of cotton products. The percentage of paper as product material is the least. For example, in the data obtained from the Engineering Services Department of LFH the total red bag waste for the September 1992 month is 104,000 lbs. The total weight of supplies most likely to end up in red bags is 104,659 lbs. This figure is obtained by adding all the entries in the row entitled weight(lb) for the month of September 1992 in Table 1. The weight without the packages can also be calculated from Table 1.

From Table 1, the ratio of the actual weight from the back end incinerated to the total weight from the front end estimated, can be calculated. This ratio is calculated for the individual waste constituents as well as for the total waste also. Table 2(b) gives this ratio for the different components of the waste. For example for the month of April 1992, the ratio of back end incinerated to the front end estimated is 23195.13/20205 = 1.147. Which means the actual amount of paper ending up at the back end for the month of April 1992 is 1.147 times as estimated from the front end.

Table 2(c) gives the ratio of percentages of front end estimation and back end incineration of various waste constituents for the year 1992. Table 2(a) gives the ratio of actual weight of waste from back end incinerated to the front end estimated for each month of the year 1992. This ratio could not be calculated for the month of May and June due to non-availability of the data for these months.

A very conspicuous fact during the characterization of medical waste has been the absence of any body parts. The reason for this is, that the LMH operating regulations require that the body parts such as umbilical chords and placenta be stored separately in a refrigerator kept at East Tower 4 (ET-4), and not be disposed off as part of other biohazardous waste. After the refrigerator is filled to capacity the body parts are then disposed off into the incinerator along with the other waste present at that time at ET-4. In the LFH, the body parts are disposed off once a week from the laboratories located in the research building.

For the LMH, similar tables could not be completed because the work had to be discontinued owing to unusual circumstances developing between the LMH and the authorities.

5.1.2 Back End Waste Characterization

Table 3(LFH) and Table 4(LMH) present the average percentage of different components from the different departments of the hospitals. It also presents the number of samples, sample standard deviation, standard error, median value and confidence limits for different categories and different
departments in the LFH and LMH Hospital. The statistical parameters are calculated for constituents of red bag wastes from different departments. They also include the limit within the true value of mean percentage will lie for different constituents of trash generated by different departments. Some of the confidence limits show negative values in Table 4. This implies that the present amount of data points for that trash constituent of a particular department are insufficient to represent the true mean. There is however no such problem with the data from the LFH.

In the present case the true mean and standard deviations are unknown. The use of confidence limit implies that we are 95% confident, that the true value of mean will lie between the average sample mean plus or minus t times standard error. For example in the case of SICU department of the Large Federal Hospital there are 21 data points. Considering plastic for this department, the average percentage is 46.63 and the standard error is 3.01. Then for a 0.05 level of significance and 20 degrees of freedom (N - 1) the value of t is 2.086. Hence we can say that the true mean percentage of plastic for SICU department of the Large Federal Hospital will lie between 46.63 -3.01*2.086 and 46.63 + 3.01*2.086; in other words, between 52.90 and 40.36. Similarly for NHCU of the Large Federal Hospital we can say for that the true average percentage of paper will lie between 13.36 and 7.48. The degrees of freedom in this case is 21 and value of t is 2.080 for 95% confidence interval.

From the bar chart[Figure 2(a,b)], we can see the percentage of different categories for each department is different, for example, for the department of dialysis, LF Hospital, the percentage of the plastics is the highest; for the department of the NHCU, the percentage of the cotton is the highest. This large percentage is due to the nature of care provided. This department essentially provides a nursing home type care and most of the cotton comes from diapers used by the patients. But one fact is apparent, no matter in which department, the plastic, paper, and cotton products together always account for most of the total wastes. During this period of characterization, as a whole, plastic, paper and cotton products make up over 90 percent. Thus, we can say that most of the biohazardous waste in the LF Hospital are plastic, paper and cotton products. At the Large Metropolitan Hospital the cotton percentage is much smaller than the LF Hospital, but plastic and paper still remain the main constituents of the trash.

The waste at the LFH is collected once in the morning and once in the evening only. This is done Monday through Friday. The waste is not collected on Saturday and Sunday. This allows us to weigh the total waste from each department on the days sampling was done at the LFH. Using the average weight of the wastes, it is possible to calculate the average percentage of the red bag waste produced by each department. This is shown in Table 5(a). As can be seen from the table, the NHCU department produces the largest amount as can be expected. The Dialysis ward produces the smallest amount.

Based upon the comparison data from each department and the weight, we can calculate the percentage of the different components in the total red bag waste. These results are shown in Table 5(b). The largest fraction is that of cotton, followed closely by that of plastic. The third largest component is paper. These three components together account for over 90% of the total red bag waste generated.

Taking the total weight of each component to be 100%, it is possible to calculate the percentage contribution of the component from each department. These results are shown in Table 5(c). Dialysis and MICU are the largest generators of plastics. CICU, Surgery and Medical Wards are the largest generator of paper, while the NHCU is the largest generator of cotton.

For the LMH, similar tables could not be completed because the work had to be discontinued owing to unusual circumstances developing between the LMH and the authorities.
5.1.3 Plastic Characterization

Table 6 gives the t-test results of plastic characterization for the departments of the LFH. A marked feature about the results is the absence of #1 and #7 plastics. The percentages of #2 and #3 plastics are the highest for most of the departments.

Table 7 gives the t-test results of plastic characterization for three departments of LMH. Again #1 and #7 plastics are absent. The percentages of #2 and #3 plastics are the highest. For other departments of the LMH, tables could not be generated because the work had to be discontinued owing to unusual circumstances developing between the LMH and the authorities. Figure 3(a) and Figure 3(b) are the stacked bar representation of percentage composition of various plastic components for different departments of LMH and LFH. For example the MICU department of LMH shows more than 60% of PVC in the total plastic content. The department is shown as MI in Figure 3(a). Plastic #2, #3 and #4 account for more than 50% of total plastic present in the waste.

5.1.4 Ash Samples

A look at the initial test results of the metallic constituents (Table 8(a,b)) of the ash samples show a high percentage of iron and lead. The III-pass of the boiler shows a high concentration of Cadmium. The test result show a substantial amount of Chromium and Nickel too. Test results for the amount of mercury present in the waste are also shown in Table 8(a,b). The scrubber has the highest amount of mercury present and the incinerator ram has the second highest amount of mercury present. All amounts are listed in g/g.

The difference between the bottom ash and the ram is that the ram ash falls into a cooling pit and is then collected as bottom ash. The number of samples is too small to statistically confirm if the difference in the amount of mercury is really true.

5.2 ANALYSIS OF VARIANCE TEST(ONE WAY)

The analysis of variance test is used to find the homogeneity of a set of sample means by analysis of the variability or variance among them. The basic contribution of the analysis of variation is a technique for testing whether a set of two or more sample means can be taken to be random samples from the same population. The basic idea is that the population variance may be estimated from the sample in several ways, the comparison among these estimates can tell us a great deal about the population.

Using the terminology that is used for the student's t test, the variance for the sample data points is calculated in following three different ways [Richmond, S. B.]:

1) The variation between groups

\[ \sum_{i} n_{i} (\bar{X}_{i} - \bar{X})^{2} \]

This is the weighted variation of the group means about the grand mean. Each group mean is compared with the grand mean, the difference is squared and weighted by the number of observations in the group, and these weighted squares are summed for the k groups. X double bar is the grand mean of all samples. ni is the number of observations in the ith group and i is the group designation.
(2) The variation within groups

\[(X_{ij} - \bar{x})^2\]

This is the variation of all the individual observations about their respective group means. Each observation is compared with its own group mean, the difference is squared, and the squares are summed for the group, and then combined for all k groups. In the above equation j is the serial number designated for individual observation within groups.

(3) The total variation

\[(X_{ij} - \bar{X})^2\]

This is the variation of all the individual observations about the grand mean.

Each of these sum of squares measures the degree of variation among the elements in the population. When each is divided by the appropriate number of degrees of freedom, the resulting variance is an unbiased estimate of the population variance; and, if the hypothesis of no difference between the population mean is true, they are all estimates of the same variance and should not differ more than might be expected on the basis of chance. If, however, the variance among groups is significantly greater than the variance within groups, the hypothesis of the homogeneity of the group means will be rejected. For the variance between group means, the degrees of freedom is taken to be k-1 and for the variance within the groups the degrees of freedom is T-k and total variance the degrees of freedom are taken to be T-1. T is the total number of observations for all samples and k is the number of samples each sample having more than one data points. Then the ratio of variance between groups and variance within groups is calculated. This ratio corresponds to F value. This value is compared with the standard value given in standard F table for a given level of significance. In the present case the level of significance is taken to be 0.05. For example for 95% confidence limit the value of F(2,11) is 3.98, where 2 is the degrees of freedom for variance between groups and 11 is the degrees of freedom for variance within groups.

### 5.2.1 Back End Waste Characterization (LFH)

Table 9(a-f) presents the ANOVA (Analysis of Variance) test results for the LFH hospital. Comparisons have been made to check whether waste composition of one department is significantly different from the other departments of the hospitals or not. An appearance of 'Y' or 'YES' in the tables means that waste from two departments is indeed significantly different in a statistical sense and appearance of 'N' or 'NO' means that waste from two departments is not significantly different in a statistical sense, or in other words 'N' means that waste samples from the two departments come from same parent population. From the tables the following information about different components of the medical waste can be inferred.

**Plastics:** The percentage of plastics in the red bag waste from different departments are significantly different from each other in most of the cases (greater than 95% confidence limits). The comparisons are shown in Table 9(a).

**Glass:** The percentage of glass in the red bags from the CICU is significantly different from most other departments. There is no significant difference between the glass composition from the other eight departments. The results are shown in Table 9(b).
Paper: The percentage of paper in the red bag waste from the Surgery department, the NHCU and the CICU are significantly different from all other departments. They are also significantly different from each other. The results are shown in Table 9(c).

Metals: The percentage of metals from most departments are not significantly different from all other departments except that of Medical wards. The results are shown in Table 9(d).

Cotton: The percentage of cotton in the red bag waste from the different departments are significantly different from each other in most cases. The results are shown in Table 9(e).

Others: The percentage of miscellaneous waste from all the departments is not significantly different from most other departments. The results are shown in Table 9(f).

Since the difference in plastics are significant in most cases, it might provide us with an opportunity to reduce emissions by regulating the amount of plastics fed into the incinerator.

6. THEORETICAL ESTIMATIONS

For the analysis of medical waste incineration theoretical estimations have been carried out for mass balance, heat balance and flue gas generation. Theoretical results show extra amount of air is required to keep the combustion chamber temperature below the operating temperature limit of 1800 F. The calculations also show generation of HCl above the levels set by the law. In all the calculations it has been assumed that only paper, cotton and plastic burn and contribute to flue gas. Details of calculations being very long and tedious are not included in this report. The following describes in brief the various estimations for medical waste incineration of the LFH:

6.1 INCINERATION AT STOICHIOMETRIC CONDITIONS

For theoretical estimations of medical waste incineration, it is important to know the chemical combustion formula for various components of the waste. It is assumed that only paper, cotton and plastics take part in combustion. One main reason for this assumption is, because paper, cotton and plastic are the major components of medical waste generated by the LFH. The other three components, namely metal, glass and miscellaneous items account for less than 10% of the total medical waste generated at the LFH, hence they are neglected for the purpose of calculations.

The major component of paper and cotton is cellulose. Plastic #2 and #4 are composed of polyethylene. Plastic #3 is Poly Vinyl Chloride. Plastic #5 is composed of Polypropylene. As indicated by waste characterization, plastic #1, #6 and #7 are rarely found in the waste at the LFH. The stoichiometric combustion equations for above mentioned components are as listed below:

Paper/Cotton:

\[
\begin{align*}
\text{Paper/Cotton:} \\
\text{C}_6\text{H}_{10}\text{O}_5 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 5\text{H}_2\text{O} + (6*3.76)\text{N}_2
\end{align*}
\]

\[
\begin{align*}
\text{162.16} & \quad 32.0 & \quad 28.02 & \quad 44.01 & \quad 18.02 & \quad 28.02 \\
\text{162.16} & \quad 192 & \quad 632.1 & \quad 264.06 & \quad 90.10 & \quad 632.1 \\
\text{1.00} & \quad 1.18 & \quad 3.90 & \quad 1.63 & \quad 0.56 & \quad 3.90
\end{align*}
\]

Plastics:

#2,#4:
First line in all the above equations is the molecular weight of a single molecule of the reactants and the products. The second line is the chemical formula for the combustion reaction. The third line is the molecular weight of actual amount of molecules of reactants and products. The fourth or the last line is the amount of air needed to burn each pound of reactant.

For example, paper or cotton are mostly composed of cellulose. The chemical formula for cellulose is $\text{C}_6\text{H}_{10}\text{O}_5$ as shown in line 2. Therefor the molecular weight of cellulose is 162.12 as shown in the first line. Similarly the first line shows the molecular weight for $\text{O}_2$, $\text{N}_2$, $\text{CO}_2$, $\text{H}_2\text{O}$, and $\text{N}_2$. The third line gives the molecular weight of total number of molecules present for each component in the combustion reaction. The third line for combustion equation for paper or cotton show 192 for $\text{O}_2$, which is number of participating oxygen molecules times the molecular weight of oxygen, or $6\times32=192$. This line also shows that for each molecule of oxygen there are 3.76 molecules of $\text{N}_2$ present in the combustion air by weight. The fourth line gives the amount of oxygen needed to completely burn 1lb of cellulose.

In real life air is used for combustion purposes. Since oxygen and nitrogen are the main components of air, only they are listed in all the above combustion equations. For example, to burn 1lb of cellulose, the major component of paper and cotton, 1.18lbs of oxygen and 3.90lbs of nitrogen is needed. In other words, for complete combustion of 1lb of cellulose approximately 5lbs of air($1.18\text{lbs oxygen} + 3.90\text{lbs nitrogen}$) is needed. Clearly nitrogen does not take part in the combustion process.

Table 10 shows various assumed characteristics for combustion of medical waste. It shows the moisture content and the higher heating value(HHV) for various components. It also shows stoichiometric requirements, that is the amount of air needed per pound of waste burnt, for various components of medical waste. For example, to burn 1lb of polyethylene, approximately 15lbs of air is needed, and to burn 1lb of paper or cotton, 5lbs of air is needed. The moisture content and HHV are used for the calculation of heat and mass balance.

### 6.2 FLUE GAS COMPOSITION

Another important aspect of the selective burning is emissions. Since the waste composition
from various departments are different, the kind of emissions generated can be expected to be different. Stack sampling involving Method-5, also known as Isokinetic sampling or Particulate sampling and Method-26 for HCl emissions would be undertaken on-site. Knowing the kind of emissions generated by waste from a particular department will help in better control over the emissions. As an example, for smaller hospitals not having a scrubber, a waste mixture generated by combining wastes from different departments, or from red bag wastes diluted by waste paper, can be burnt to keep emissions below acceptable level.

Based upon the available data, calculations have been carried out to estimate the flue gas composition of waste from different departments are burnt separately. Table 11 shows the different gaseous components generated in lb/hr as well as in percentage of the total amount of flue gas. The table is generated by assuming a wet feed of 500lb/hr. By wet feed it is meant that the waste from a particular department is assumed to have a moisture content. This moisture content is calculated by using Table 3 and Table 10. From Table 11 we can see that the percentage of various components of flue gases for different departments are similar. The reason for this is that increase in a particular component results in the increase in total flue gas resulting in a small difference in ratio. From the table, it can be seen that the Dialysis department produces the maximum amount of CO$_2$. The NHCU department produces the least amount of CO$_2$. Similarly the Dialysis department produces maximum amount of HCl. The Dialysis department also produces the maximum amount of water in combustion gases.

Table 12 shows the calculated results for allowable emission limits based upon the State of Florida's allowable limits for particulate emission. The table also shows the theoretically calculated amount of particulate emission in lbs/hr from burning waste from various departments of the hospital. These calculations are based upon mass and heat balance calculations. Since the actual emissions are considerably higher than the allowable emissions, an efficient scrubber is required. This table also lists the scrubber efficiency needed if wastes from different departments are burnt separately.

7. RECOMMENDATIONS

Cleanliness kept at both the hospitals as well as great cooperation of the employees of the Environmental Services Department is highly appreciated. A discussion is given below on some of the observations that have been made.

Figure 2(a) and Figure 2(b) show that the plastics percentage is the highest in the waste stream. Within the plastics, polyvinyl chloride, the main source of hydrochloric acid gas upon incineration, is present in an appreciable amount [Figure 3(a) and Figure 3(b)]. A great deal of pollution could be potentially avoided by replacing the material or recycling the PVC. In addition, the paper comprises the second highest percentage in the waste stream. From the characterization of the waste stream, it has been found that the paper is mostly newspapers plus office and toilet papers. Recycling of newspaper, instead of burning could reduce the lead pollution, as lead is present in the printing ink used for printing newspapers.

In the LMH, the following procedure is used. The red bags containing biohazardous waste as well as the white bags containing non-biohazardous waste are burnt randomly in the order they arrive at the incinerator. In other words, universal precaution has to be taken for all wastes. A simple segregation of waste just before incineration of the waste could improve the incinerator thermal efficiency. Using semi-transparent red bags could aid in the visual appraisal of their contents, so that by just looking at the red bags, a person can segregate the waste appropriately. Most of the time, the red bags have liquid in the form of water, chemicals or blood, inside them. Drying the waste before incineration could greatly improve the thermal efficiency of the incinerator.
The following is a list of suggestions which could enhance the operating efficiency of the hospitals with regards waste management:

1. Many times red bags contain newspapers and other types of printed matter in large proportions which cannot be considered as bio-hazardous.
2. Some of the floors which do not have any type of patient wards or have only administrative offices also produce red bags.
3. Many times wasted food, cold drink cans and bottles are disposed off in red bags. These are shown as miscellaneous items in the data.

The reasons for (1), (2) and (3) could be
(a) vicinity &
(b) availability of red bags.

Stopping of the above three practices will reduce the red bag waste.

4. Some of the red bags contain white bags inside them. This may happen because the employee collecting trash from trash rooms generally carry empty red bags with him. So for manageability he may put smaller white bags into a larger red bag.
5. Red bags containing biohazardous waste as well as white bags are dumped into the same trolley kept inside the trash room in the LMH.
6. As a universal precaution all types of wastes that are generated in the LMH are burnt. Separation of white bags from red bags can be more economical. This can be easily seen in case the hospital incinerator is down, and the red bags and white bags have to be hauled off by a commercial medical waste management company. Burning red bags costs more than burning white bags.
7. Among the biohazardous wastes, plastic products make up the highest portion: if they are put into different red bags according to the resins and then recycled, the wastes and pollution would be reduced. Waste treatments such as microwaving, autoclaving and electron beam impingement for disinfecting waste are important before recycling is carried out.
8. Because the medical waste include many categories of products, if they are burnt selectively, it can reduce pollution and also save energy.
9. In the red bags, there are some unused medical goods such as plastic tubes and some office paper. If this is avoided, medical waste will be reduced and money will be saved for the hospital.
10. Education of the staff and patients of the hospitals with regards the above findings will lead to improved waste management and savings.

The state of Florida regulations stipulate that the HCl acid (HCl) emissions shall not exceed 4.0 pounds per hour for stationary sources. From Table 12, it can be seen that the waste from each department generates HCl much above the stipulated levels on combustion. The solution to this problem is the use of a high efficiency scrubber. For small and medium size hospitals that do not have scrubbers on their incinerators, HCl can be diluted by mixing the waste with waste paper, etc. Other options are recycling and separating the PVC at the point of discard. In addition, PVC can be replaced by something else that does not produce harmful substances on combustion. The replacement of PVC in the manufacture of gloves would be a very significant improvement since the PVC in the gloves is a major source of HCl in all departments.
8. REFERENCES


GLOSSARY

Summation

N    Number of Samples
X    Individual Value of Variable
X    Sample Mean
S_x  Standard Error
S    Standard Deviation
    True Mean
t    Standard Statistical Parameter
k    Number of Groups
T    Total Number of Observations in All Groups Combined
i    Group Designation
j    Serial Number Designation for Individual Observations Within Groups
n_i  Number of Observations in the ith Group
X_{ij} An Observation. The jth Observation in the ith group
X    Grand Sample Mean of All T of the Observations
X_i  Arithmetic Mean of ith group
To

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