1. INTRODUCTION

1.1. Biomedical Waste Generation and Characteristics

Wastes produced from hospital and laboratories, physician and dental clinics, research laboratories, surgery centers, nursing homes, veterinary practices, funeral homes, and personal home health care come in the category of biomedical waste. These biomedical wastes are capable of spreading infectious diseases in man or animal and are considered as an extreme hazard. It can be the source of diseases like acquired immune deficiency syndrome (AIDS), hepatitis, tuberculosis, and other communicable diseases. Due to the fact that higher risk to community is associated with these wastes, environmental scientists, media persons and social activists have paid considerable attention. However, still the biomedical waste is poorly defined and there is inconsistency in the terminology used to define infectious waste. The terms infectious, pathological, biomedical, biohazardous, toxic, and medically hazardous have all been used to describe infectious waste. Regulatory agencies, hospitals, and research laboratories have differing perspectives and objectives that influence their views. Bhadram (2002) studied that biomedical waste has been a growing concern ever since the Environmental Protection Act, 1986 (Government of India), redefined it as hazardous waste. The disposal of hospital waste can be very hazardous particularly when it is mixed with municipal solid waste.

The situation of increasing usage of highly developed medical devices; drugs and disposable products, it is a major task for hospital epidemiologists to maintain high standards of hygiene while reducing environmental pollution, reducing consumption of limited natural resources, and minimizing costs. The reduction of hospital waste, the control of polluting and toxic emissions, the avoidance of unnecessary disinfection procedures and disposables, and the implementation of energy and water saving technologies are practicable measures in hospital ecology. To realize a sustainable development within hospitals, it is necessary that the need to maintain a balance between effective infection control and a good ecological environment is recognized and supported by health-care workers and the hospital management (Daschner and Dettenkofer, 1997).
The potential microbiological risks associated with health care waste are still unfamiliar to health workers, and the assessment requires expert advice. Public health is compromised due to lack of accountability in the handling of some hospital and veterinary wastes; specifically body fluid contaminated equipment and containers as well as microbiological materials. The most important to protect public health is a manifest system of cradle-to-grave accountability for an infectious portion of a hospital’s waste. The waste produced in the course of health-care activities carries a higher potential for infection and injury than any other type of waste. Inadequate and inappropriate handling of health-care waste may have serious public health consequences and a significant impact on the environment (Pruss et al., 1999). For proper handling of waste generated, it is equally important to predict the amount of waste generation beforehand. Unfortunately, there is virtually no any mathematical model or correlation available that can predict waste generation rate throughout the year. In the present work an attempt has been made to develop a model to correlate seasonal variation in generation rate of a particular category (yellow bag). Before developing the model a detailed survey of existing norms and trends were also studied.

Categorization and segregation of biomedical waste are very important, as severity of the risk associated in handling them is different for each type of wastes. Personnel involved in the treatment of medical waste are exposed to infectious agents through several routes including skin penetration, skin contact, or by the aerogenic route. Medical waste contains variety of human pathogens including bacteria, fungi, viruses, and parasitic organisms as well as microbial toxins. Needle sticks, cuts, falls, strains, sprains, burns, electrical, mechanical, and chemical injuries are additional potential consequences of medical waste treatment. Additional hazards include radioactive, hazardous, and cytotoxic waste exposures (Cole et al., 1993).

The risk is further aggravated due to improper handling and disposal of waste. El-Hamouz (2002) reported that medical waste generated in West Bank hospitals and medical centers is collected in plastic bags and then dumped together with other domestic waste without any separation. This malpractice usually leads to air pollution and the danger of spreading viruses and bacteria widely.
Results of a survey made in Taiwan (Chou et al., 1999) indicated that most animal hospitals did not classify infectious and non-infectious wastes properly. Animal hospitals in Taiwan generally do not have their own effluent outlets, and more than 80% of the wastewater does not meet the applicable standards. One quarter of the wastewater samples can be classified as highly toxic. More fecal coliforms were found in animal hospital wastewater than in general medical waste. The risk of dissemination of waterborne diseases cannot be excluded. Although the total pollution due to animal hospital waste is minute, the toxic and pathogenic characteristics of the waste can be harmful to the environment and to the public health.

If segregated properly, the amount of potentially dangerous waste is quite low. Biomedical waste (infectious waste/regulated medical waste) is estimated to be 15 percent or less of overall waste stream. However, as shown in Table 1.1, its composition and characteristics varies considerably.

**Table 1.1.** Typical Composition and Characteristics of Infectious Waste.

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Composition:</strong></td>
<td></td>
</tr>
<tr>
<td>Celluloid Material</td>
<td>50-70%</td>
</tr>
<tr>
<td>(paper &amp; Cloth)</td>
<td></td>
</tr>
<tr>
<td>Plastics</td>
<td>20-60%</td>
</tr>
<tr>
<td>Glassware</td>
<td>10-20%</td>
</tr>
<tr>
<td>Fluids</td>
<td>1-10%</td>
</tr>
<tr>
<td><strong>Typical Characteristics:</strong></td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>8.5-17% by weight</td>
</tr>
<tr>
<td>Incombustibles</td>
<td>8% by weight</td>
</tr>
<tr>
<td>Heating Value</td>
<td>7,500 BTU/lb</td>
</tr>
</tbody>
</table>


Each country has its own set of regulations defining and setting standards for the handling, treatment and disposal of regulated medical wastes. Further each health care institution may refine those definitions and standards depending on the nature of the facility, types of procedures, patients, and other site-specific conditions. Compounding the problem of classification is a confusing mix of medical waste categories based on type (e.g., microbiologic, pathologic, etc.), based on origin (e.g., isolation waste, surgery waste, laboratory waste, dialysis waste, etc.), and based on physical characteristics (e.g., soft
wastes, hard metals, glass, plastics, liquid, etc.). Many regulatory definitions of regulated medical waste are based on ten broad categories defined in a 1986 USEPA guide on infectious waste.

1.2. Waste Management Plan

Biomedical waste management strategies include planning and organization; characterization of waste and losses; development of waste minimization options; technical, regulatory, and economic feasibility; implementation; monitoring and optimization; continued and ongoing evaluation of reaching a zero generation status. Implementing effective biomedical waste management programmes require multisectoral cooperation and interaction at all levels. Establishment of a national policy and a legal framework, training of personnel, and raising public awareness are essential elements of successful health care waste management. Management of health care waste should thus be put into a systematic, multifaceted framework, and should become an integral feature of health care services. Each hospital is required to develop a waste management plan that provides for a thorough segregation and treatment of waste. The main aims of biomedical waste management are:

- minimizing risk for personnel, general public and environment
- minimizing the amounts of waste being generated
- segregation and separation of wastes
- designation of deposit areas in the wards
- establishment of safe routes for the transportation of the waste
- establishment of a safe and proper area for the temporary storage
- proper waste treatment and disposal

Correct identification and quantification of biomedical waste is of paramount importance in order to have a cost effective waste disposal system. Above all, segregation is the key to effective biomedical waste management. It ensures that correct disposal routes are taken. Segregation should be carried out under the supervision of the waste producer and as close as possible to the point of generation. Segregation must therefore take place at source, that is, in the ward, at the bedside, in the theatre, in the laboratory, in the delivery room, etc.,
and must be carried out by the person generating the waste, for example the nurse, the doctor or the specialist, in order to secure the waste immediately and to avoid dangerous secondary sorting.

According to the “polluter pays” principle, each health care establishment are financially liable for safe management of any waste it generates. The costs of separate collection, appropriate packaging, and on-site handling are internal to the establishment and paid as labour and supplies costs; the costs of off-site transport, treatment, and final disposal are external and paid to the contractors who provide the service. The costs of construction, operation, and maintenance of systems for managing biomedical waste can represent a significant part of the overall budget of a hospital or health care establishment. Funds may come from the private sector or from one or more levels of government. For government owned health care establishments, the government may use general revenues to pay the cost of the waste management system.

Over the past few years privatization has been increasingly adopted in a number of countries (including India) as an alternative method of financing various types of public works, including health care waste management. Under such an arrangement a private entity finances, designs, builds, owns, and operates the treatment facilities and sells its collection and disposal services to government and private health care establishments. It may be a desirable option, particularly for treatment methods other than incineration. The following are probably among the main reasons for considering privatization:

- inability of hospitals to raise the needed capital
- expected greater efficiency in the private sector because of fewer constraints than in the public sector (e.g., greater flexibility in purchasing and personnel policies, allowing for more rapid adaptation to changing needs)
- transfer of responsibility for proper operation and maintenance to an organization with more resources for minimizing risk.

A disadvantage of privatization is the potential loss of overall control by the responsible public agency. The feasibility of cooperation between local health care establishments needs be explored as another means of minimizing costs.
1.3. Systems and Standards for Treatment

Several types of treatment and disposal processes have been applied to biomedical waste. However, incineration has been identified as the best option for the disposal of infectious hospital waste in many areas. Treatment of regulated medical waste by US hospitals is most commonly accomplished by incineration (range = 64%-93% by type of waste). About one-third of US hospitals steam sterilize their microbiological waste, and about one-fourth pour liquid blood down a drain connected to a sanitary sewer. Nonregulated medical waste is discarded via a sanitary landfill. Presumably the reason for excluding medical waste from landfills has been concern that pathogenic microorganisms might persist in and move through landfilled solid waste, become part of the leachate produced, enter the surrounding environment (i.e., ground and nearby surface waters), and result in human exposure and disease through ingestion of leachate contaminated waters (Rutala and Mayhall, 1992).

Hospital waste incineration has been the main method for disposing of a wide range of materials, including combustible materials such as polyvinyl chloride plastics, papers and discarded items of equipment that constitute biomedical waste, because it can significantly reduce the volume of waste material and can also destroy organic matter (Lee et al., 2003a,b).

The main disadvantage of medical waste incineration is the emission of pollutants to the atmosphere, some of them extremely toxic. Pollutants are usually emitted either in condensed (particulate matter) or in gaseous phases. Many organic and metallic compounds have known effects on human health and environment (Alvim-Ferraz et al., 2000, Alvim-Ferraz and Afonso, 2003a,b). UNEP (2005), explained standard method to safely and reliably destroy viruses, bacteria, and pathogens the infectious hospital waste, often treated by incineration or pyrolysis. Further, due to its origin and its composition, medical waste can contain toxic chemicals, e.g., heavy metals or precursors, which may form dioxins and furans. However, it has also been shown that incineration of medical waste in small and poorly controlled incinerators was a major source of PCDD/PCDF. According to Chen et al. (2003) the inventories of potential emissions of polycyclic aromatic hydrocarbons (PAHs) performed in a lot of countries in the recent past have shown that combustion is a major contributor to the environmental concentrations of these
toxic pollutants. Up to now, the emissions of PAHs have become one of the most controversial issues related with different incinerators.

Steam autoclave treatment has been used for sterilizing medical instruments in hospitals and the treatment of waste in laboratories for many years, thus the validation of autoclaving for sterilizing medical equipment is well documented. Medical waste may contain many of the same pathogens as those associated with used medical equipment and supplies, however, medical waste may contain a much higher concentration of organisms in a more complex matrix. These differences make it necessary to have a unique test method specifically for the assessment of steam autoclaving as an effective medical waste treatment technology. The factors that affect the efficacy of steam autoclave treatment of medical waste are those affecting the internal waste load temperature, steam penetration of the waste, and the duration of treatment. Steam autoclaves operate most effectively when the temperature measured at the center of the waste load approaches 121 °C and there is adequate steam penetration of the waste load under pressure. Steam autoclave treatment does not normally include a destruction step in the treatment cycle. The solid wastes remain recognizable after treatment, although they may be adequately treated to inactivate all types of microorganisms, including bacterial spores (Cole et al., 1993).

1.4. Processing and Disposal of Treated waste

The main goal of incinerators is to develop a sustainable waste management by reducing volume of nonavoidable and nonrecyclable medical waste to be disposed, and to decrease its post depositional reactivity due to its organic matter inventory. Priority pollutants are trace metals enriched in medical waste products. Since combustion will not destroy inorganic compounds present in healthcare waste, such as metals, it is possible that such compounds may end up in bottom ash at harmful concentrations. While some general information is available from recently published work, the behaviour of the metals in the bottom ash of medical waste incinerators is yet to be understood. Although the bottom ash can be utilized for recovery from the conventional incinerators based on the grate system, a major portion of these residues are still landfilled (Racho and Jindal, 2004).
In Japan, reported Shimaoka and Hanashima (1996), landfilling or ocean dumping of fly ash is prohibited. To avoid the possibility of causing damage to environment and human health, fly ash must be subjected to intermediate treatment to be stabilized and made insoluble and non-unhygienic. Four methods can be used for the fly ash intermediate treatment; (1) cement solidification, (2) treatment by chemicals, (3) acid and other solvents and (4) melting and solidification.

1.5. Common Treatment Facility – Case Study

In exercise of the powers conferred by sections 6, 8 and 25 of the Environment (Protection) Act, 1986; Ministry of Environment and Forests, Government of India has notified “Biomedical Waste (Management and Handling) Rules, 1998” which came into force on July 27, 1998 (MoEF, 1998). These rules apply to all persons who generate, collect, receive, store, transport, treat, dispose, or handle biomedical waste in any form. It shall be the duty of every occupier of an institution generating biomedical waste which includes a hospital, nursing home, clinic, dispensary, veterinary institution, animal house, pathological laboratory, blood bank by whatever name called to take all steps to ensure that such waste is handled without any adverse effect to human health and the environment. The amendments of Principal Rules have further been notified on March 06, 2000; June 02, 2000 and September 17, 2003. Thus the rules emphasized the treatment and disposal of biomedical waste in compliance with standards prescribed therein. Under normal circumstances biomedical waste generated is not allowed to be mixed with other waste and stored beyond a period of 48 hours. If for any reason it becomes necessary to store the waste beyond such period, the authorized person must take permission of the prescribed authority and take measures to ensure that the waste does not adversely affect human health and the environment.

Every occupier of an institution is required to set up in accordance with the time schedule prescribed in the rules, requisite biomedical waste treatment facilities like incinerator, autoclave, microwave system for the treatment of waste, or ensure requisite treatment of waste at a common waste treatment facility or any other waste treatment facility. All types of health care institutions were required to set up treatment facility by December 31, 2002.
Selection of appropriate waste treatment technology is most crucial in laying down a system of proper waste disposal in a health care institution. One of the options which is most common in India for the treatment of health care waste is the incinerator. There is growing interest in alternative technologies for treatment of biomedical waste due to concerns of air pollution from biomedical waste incineration. Therefore, some of the advanced technologies alternative to incineration such as microwave, hydroclave, pyrolysis, ozonation, alkaline hydrolysis etc., is being critically examined for economical and safe handling. Common treatment facilities are necessary because it is not feasible for smaller health care establishments to set up a complete treatment and disposal system due to lack of space, trained manpower, minimum scale of operation and scale of economy. The main reasons for improper management of the biomedical waste are financial and technological constraints and difficulty in monitoring of scattered health care facilities. The central treatment facilities would be providing advantage of economies of scale, state-of-art technologies, air control devices and ease of monitoring the functioning of waste management facilities.

In compliance to Biomedical Waste (Management and Handling) Rules, Municipal Corporation Shimla established a centralized treatment facility for incineration of infectious hospital waste during the month of August 2002. Incineration is commonly used method to be quite safe means of neutralization of infected wastes from hospitals provided that it is carried out under appropriate thermal conditions so that it does not lead to contamination of the environment by toxic chemical compounds, which are produced in reactions of secondary synthesis which takes place during high temperature processes.

There are around 100 clinics and health care facilities in the limits of Municipal Corporation, Shimla. In the present study only five major health care facilities viz., Indira Gandhi Medical College & Hospital (IGMCH), Kamala Nehru Hospital (KNH), Deen Dayal Upadhyay Hospital (DDUH), Indus Hospital (IH), and Shimla Sanatorium (SS) are considered. Biomedical waste generation data at major health care facilities of Shimla town, under present study, have been collected for two consecutive years (2003 & 2004).
Thereafter preliminary trends for amount of infectious waste collected in colour coded bags from IGMCH, KNH, DDUH, IH, and SS were analyzed. Finally, results of the mathematical model developed for the prediction of seasonal variation in the waste generation rate is integrated to compare the waste (yellow bags) incinerated at the common treatment facility available in Shimla town.