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Alternatives for the treatment and disposal of healthcare wastes in developing countries

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Abstract

Waste production in healthcare facilities in developing countries has brought about a variety of concerns due to the use of inappropriate methods of managing the wastes. Inappropriate treatment and final disposal of the wastes can lead to adverse impacts to public health, to occupational health and safety, and to the environment.

Unfortunately, most economically developing countries suffer a variety of constraints to adequately managing these wastes. Generally in developing countries, few individuals in the staff of the healthcare facility are familiar with the procedures required for a proper waste management program. Furthermore, the management of wastes usually is delegated to poorly educated laborers who perform most activities without proper guidance and insufficient protection.

This paper presents some of the most common treatment and disposal methods utilized in the management of infectious healthcare wastes in developing countries. The methods discussed include: autoclave; microwave; chemical disinfection; combustion (low-, medium-, and high-technology); and disposal on the ground (dump site, controlled landfill, pits, and sanitary landfill).

Each alternative for treatment and disposal is explained, including a description of the types of wastes that can and cannot be treated. Background information on the technologies also is included in order to provide information to those who may not be familiar with the details of each alternative. In addition, a brief presentation of some of the emissions from each of the treatment and disposal alternatives is presented.

1. Introduction

Wastes produced in healthcare facilities in developing countries have raised serious concerns because of the inappropriate treatment and final disposal practices accorded to them. Inappropriate treatment and final disposal of the wastes can result in negative impacts to public health and to the environment. In addition, pathological (infectious) and hazardous healthcare wastes, when inappropriately managed, may be the source of intra-hospital infections and may pose serious occupational health risks to those who care for the patients, as well as to those who participate in the management of the wastes within and outside the healthcare facility. The scavenger population, which works on the streets or at the final disposal facilities, is another relatively large population that is exposed to the risks posed by improperly treated healthcare wastes (HCW) in developing countries.

Every year, relatively large quantities of potentially infectious and hazardous wastes are generated in healthcare facilities throughout the world. However, in most economically developing countries, resources are inadequate to manage these wastes. Few staff of the healthcare facilities are acquainted with the methods required for proper waste management. Oftentimes, the management of wastes is delegated to poorly educated and untrained laborers, who perform most activities without proper guidance and insufficient protection.

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Healthcare workers are exposed to blood and other body fluids as part of their day-to-day activities at the healthcare facilities. As such, healthcare workers face the risk of infection due to blood or other liquid borne pathogens. There are several pathways for the transmission of disease to healthcare workers. Some of the most important pathways are: percutaneous injuries with contaminated sharps (e.g., through the skin), contamination through the fecal–oral route (e.g., salmonellosis, hepatitis A), and contamination through airborne transmission (e.g., tuberculosis, measles).

Percutaneous exposures account for 66–95% of all occupational exposures to blood borne pathogens (CCOHS, 2000; Puro et al., 2001; Romea et al., 1995). Injuries due to sticks from needles account for 62–91% of percutaneous exposures (NaSH, 1999; Puro et al., 2001; Romea et al., 1995).

An effective and efficient program for the management of healthcare wastes is a critical component of the facility's infection control program and consequently plays an important role in the quality of care, as well as in the occupational health of the entire staff of the facility.

Although proper management of healthcare wastes includes a number of activities and several members of the staff, this paper focuses on the treatment and final disposal of the wastes.

There is no single method of waste treatment or disposal that completely eliminates all risks to the public or to the environment. In general, depending upon the type of technology, the residues are transformed from one phase to another. For example, in incineration, the combustible components of the wastes are converted into gaseous byproducts (CO_2, H_2O, CO, and other gases, some of which are toxic) and non-combustible components remain as a solid byproduct, namely ash. With respect to risk reduction associated with microorganisms, the most important objective is to destroy them prior to release of the contaminated material into the environment. Pathogen destruction can be achieved through proper thermal, chemical, and irradiative treatment.

2. Treatment/disposal methods

Some of the more common treatment and disposal methods utilized in the management of infectious healthcare wastes in developing countries are:

- autoclaves and retorts;
- microwave disinfection systems;
- chemical disinfection;
- combustion (low-, medium-, and high-technology); and
- disposal on land (dump site, controlled landfill, pits, and sanitary landfill).

In addition, residues from immunization programs (primarily needles and syringes) generally are managed through the following options:

- burial in specific pits with a cover,
- encapsulation by means of immobilizing compounds (primarily cement and plastics),
- point-of-use needle destruction technologies, and
- mechanical destruction (compaction or size reduction).

Immunization programs generally incorporate the use of safety boxes or sharps containers for the temporary storage of used needles, syringes, and other sharps. These boxes or containers are composed of materials that are impermeable and resistant to punctures. Used syringes, needles, and other contaminated sharps are placed in these boxes. Once the boxes are approximately 75% full, they are secured and stored in a safe location until the boxes and their contents can be properly treated or disposed. Ideally, safety boxes should be filled only once and destroyed. Safety boxes generally range in size from 5 to 20 L.

2.1. Autoclaves and retorts

The utility of heat, in particular moist heat, in achieving disinfection has been known for decades. Healthcare facilities have been using steam for disinfecting reusable instruments for a very long time.

There are two basic types of units that utilize mainly steam for disinfecting healthcare wastes: autoclaves and retorts. The steam, required by these units, is generated by means of a boiler. The boiler can be one used for other services in the healthcare facility or it can be one specifically for the treatment of the wastes (a "dedicated boiler").

Before providing a description of autoclaves and retorts, a brief explanation of steam generation (and other parameters important in the field of steam production and heat transfer) is given so that the reader has a general appreciation of the entire process.

As liquids are heated, their temperature increases until the temperature reaches what is known as its boiling point. The temperature at which a liquid boils or, in this particular case, when water is turned into steam, is called the saturation temperature. The saturation temperature of liquids is impacted by pressure; as the pressure increases, the saturation temperature also increases. At standard atmospheric pressure (100 kPa or 14.7 psia), the saturation temperature of water is 100 °C. The steam that is produced at saturation temperature is known as saturated steam (these parameters at these conditions also are known as standard temperature and pressure, or STP). In practice, steam is produced in a piece of equipment called a boiler. Usually boilers are heated by means of conventional fuels such as gas, diesel, coal, or biomass. Some boilers have also been designed to use electricity and even waste oil for heating the water. The use of waste oil requires specialized burners, and the combustion process must be carefully monitored in order to avoid substantial air emissions. Furthermore, some countries may require special permits to use waste oil as fuel.

For safety reasons, boilers must be designed and built to withstand high temperatures and pressures. The design parameters must take under consideration a number of safety issues. The design parameters for boilers have been widely accepted around the world. To achieve optimum operation and maximum efficiency, the input water must be properly treated to reduce the buildup of salts and other compounds on the interior surfaces of the boiler; the buildup reduces the boiler's ability to transfer heat. Steam boilers are rated in horsepower, BTUs, or kW. A boiler must be properly selected such that its output (the amount and quality of the steam) will match the requirements of the particular application (in this case the autoclave or retort).

2.1.1. Autoclave

An autoclave essentially is a metal vessel (usually made out of steel). The vessel is hermetically sealed with a hinged door (with gaskets) and designed to resist high temperatures and pressures. Normally, a steam jacket surrounds the vessel. The steam jacket is incorporated into the design to reduce the amount of condensation on the inside wall of the vessel and thus reduce heat loss. A schematic diagram of an autoclave is shown in Fig. 1.

Disinfection in an autoclave is carried out in batches. That is, the unit is loaded, disinfection carried out, and then the contents are removed from the unit. The entire process from loading to unloading is called a cycle. During a typical operation of an autoclave, the material to be disinfected is loaded into the unit and air is evacuated. Air is removed from the interior of the vessel because of the air's insulating characteristics (i.e., if air is not removed, then heat transfer to the waste would be reduced and more fuel would be required). Air generally is removed from the autoclave by using a vacuum pump at the beginning of the cycle and prior to steam injection (these units are called high-vacuum) or by relying on the fact that air is more dense than steam such that as the steam is injected into the vessel, the air has the tendency to migrate to the bottom. The air at the bottom of the vessel is removed via a drain port. The high-vacuum method is the most effective and fastest of the two. Speed in this process is important, since it reduces the overall time required per cycle. Steam is injected into both the interior of the vessel, as well as into the steam jacket (Reinhardt and Gordon, 1991; US Congress, 1990).

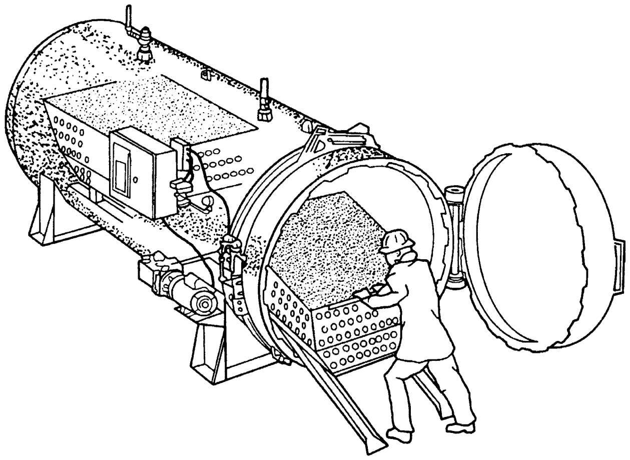

Fig. 1. Diagram of an autoclave.

2.1.2. Retort

This particular type of disinfection unit is similar in design to the autoclave. The major difference between the two is that the design of the retort does not incorporate a steam jacket. The absence of a steam jacket results in inefficiencies in heat transfer and, consequently, higher temperatures are required for a retort than are required for an autoclave. Retorts normally are utilized in large-scale operations (more than about 1000 kg per day) (Reinhardt and Gordon, 1991; US Congress, 1990).

2.1.3. Other considerations

In the overall waste management process in a healthcare facility, the waste to be treated typically is stored in plastic bags (placed inside rigid containers). The bags are collected in carts or in bins previously lined with special plastic sheeting to prevent the bags from adhering to the carts when heated. The bags should also be made of plastic that is resistant to the high temperatures inside the autoclave and at the same time be permeable to the steam in the direction toward the waste (i.e., allow the steam to penetrate the bag and go through into the waste).

If an autoclave is used, at the beginning of the cycle, steam is introduced into the outer jacket of the unit (this step is known as "pre-heating"). The loaded bins or carts are introduced into the autoclave and the door is sealed. At this point, air is evacuated from the unit either by vacuum or by introducing steam into the vessel. Steam is forced into the unit until the required temperature is achieved. Steam is added as necessary in order to maintain a prescribed temperature for a given period of time.

In some countries or states, it is necessary to record the time-temperature history for each load undergoing treatment. This generally is accomplished by means of a chart recorder. Upon reaching the necessary time–temperature requirements, vents in the unit are opened and the steam is released through a condenser (so that the water can be re-used). Once the waste has reached ambient temperatures or it is cool enough to be handled, the material is removed and taken to the disposal site or treated mechanically. Mechanical treatment generally involves size reduction, compaction, or both.

From time to time, either biological or chemical indicators are inserted in waste loads in order to evaluate the degree of disinfection. To test the effectiveness of the process, spores of *Bacillus stearothermophilus* are placed in the waste as it is introduced into the autoclave and removed after the process is finished. The spores are collected and incubated for about a week. The spores are available commercially in disks, strips, or in ampules (Reinhardt and Gordon, 1991).

2.1.4. Types of HCW that can be treated

Autoclaves and retorts generally are used to treat the following types of materials:

- sharps;
- cultures;
- items contaminated with blood;
- residues from surgery and from isolation wards;
- bandages, gauze, linen, gowns, and other similar materials (also known as “softs”); and
- non-chemical laboratory wastes.

In some special circumstances, it is technically possible to disinfect body parts. However, in the case of items with a large mass, care must be taken to achieve the necessary time–temperature relationships. In addition, any time that body parts are treated in an autoclave, cultural, ethical, legal, and other factors must be taken into consideration.

2.1.5. Types of HCW that should not be treated

Healthcare facilities produce a variety of chemical and hazardous substances that should not be treated in an autoclave. These types of wastes include: wastes from chemotherapy treatment, mercury, volatile and semi-volatile organic compounds, radioactive wastes, and other hazardous chemical wastes. In general, it is not advisable to treat large body parts, animal carcasses, or other large items that, because of their mass and other characteristics, make it difficult or time consuming for the entire material to reach the prescribed temperatures.

2.1.6. Solid residues from the process

Waste materials that are treated in an autoclave do not change considerably from their original state. Waste that is treated in an autoclave would look essentially the same as it did prior to the treatment. In fact, due to the addition of water and depending upon the type of unit, the mass of the waste may increase. Consequently, in order to meet local regulations, some manufacturers incorporate into their systems some type of mechanical processing and, most commonly, size reduction, compaction, or both. Size reduction essentially changes the appearance of the waste and increases the bulk density of the mixture, thereby reducing the volume that the mass would occupy by 60–80%.

2.1.7. Liquid and gaseous emissions from the process

In addition to the treated solid matter, a typical autoclave would release liquid and gaseous discharges. Both of these discharges must be properly managed prior to release into the environment.

2.2. Microwave disinfection systems

Microwaves are very short waves in the electromagnetic spectrum and are within the range of the radio frequency band. Microwaves have wavelengths in the centimeter range and fall below the range for infrared (IR) waves and above the ultra-high frequency (UHF) waves used for television.

Microwaves typically are generated by means of magnetrons; however, they can also be generated by klystrons, or traveling wave oscillators. All of these units essentially convert electrical energy into microwave energy. The microwaves are then guided into a metallic channel known as the “wave guide”. The guide focuses the microwaves into a particular location. Microwaves cycle very quickly between positive and negative, and at a very high frequency (around 2.4 billion times per second). The high frequency makes the molecules in the receiving body (liquid or solid) vibrate very rapidly as they attempt to align to the changing electromagnetic field. The very high level of vibration results in friction. The friction generates substantial amounts of heat (Reinhardt and Gordon, 1991; US Congress, 1990).

It has been demonstrated that disinfection in microwave units is not a result of exposure of material to the microwaves. The steam produced from the moisture in the waste by the microwave energy brings about the destruction of the pathogenic organisms in the waste. Consequently, microwave systems in the healthcare waste sector typically require the addition of water (or steam) into the waste during the treatment process.

2.2.1. Typical microwave disinfection system

Microwave disinfection systems typically consist of three major types of equipment: (1) material handling equipment, (2) the disinfection equipment itself, and (3) environmental control equipment.

The disinfection area or enclosure includes a hermetically enclosed chamber, where the materials to be treated are placed and into which the microwaves are focused. Microwave systems are designed and built in a variety of sizes, ranging from a few kg per hour to more than 400 kg per hour. The units can be operated as a batch process or in a semi-continuous mode.

Large-scale systems can have from 1 to 6 microwave generators (magnetrons). Generally, each magnetron has a power output on the order of 1.2 kW.

A flow diagram showing a typical large-scale system is presented in Fig. 2. As shown in the figure, the waste to be treated is placed in carts and transported to the treatment facility. The carts are lifted by a hydraulic mechanism, a gate that seals the hopper opens, and the waste is discharged into the hopper. As the waste is introduced into the hopper, steam is injected into the hopper and air is extracted from the unit. All extracted air is passed through a high efficiency particulate air (HEPA) filter. The waste in the hopper is forced into a shredder. The shredded waste is transported via a rotating screw, exposed to steam, and then heated to between 95 and 100 °C by means of microwaves. The treated waste may be passed through a secondary shredder to achieve a higher degree of particle size reduction than with only one shredder. Secondary size reduction is particularly important in the event that sharps are part of the waste stream.

2.3. Chemical disinfection

Chemical disinfectants have been utilized in the healthcare sector for many years. Disinfectants have been used in a variety of applications, from preparing a particular area in the body prior to an injection to cleaning surfaces in the working areas. Chemical disinfection has also been applied to the treatment of healthcare wastes. In this section, various options of chemical disinfection of healthcare waste are discussed.

Chemical disinfection relies on the particular properties of the chemical agent to inactivate pathological organisms. The effectiveness of a certain chemical agent depends upon temperature, pH, and on the possible presence of other compounds, which can have a negative impact on the effectiveness of the chemical agent. Any or all of these factors play a role in the ability of the chemical agent to act on the cells of the particular microorganism. Furthermore, it has been determined that some microorganisms are more resistant to chemical treatment than others. The most resistant microorganisms to chemical treatment include bacterial spores and hydrophilic viruses. On the other hand, some of the least resistant to chemical treatment include fungal spores and vegetative bacteria.

Antimicrobial agents act at the cellular and at the molecular levels. At the cellular level, these agents can damage the cell wall or the membrane of the cell. On the other hand, at the molecular level, antimicrobial agents can alter protein and DNA synthesis or cause inhibition through enzymatic reactions.

Chemical methods of microbial control include antiseptics and disinfectants, which are non-specific for the cells that they affect. Antiseptics are used on animate objects, while disinfectants are used on inanimate objects.

Sterilization can be achieved by using several chemical compounds in the gaseous form. These compounds, such as formaldehyde and ethylene oxide, are extremely toxic.

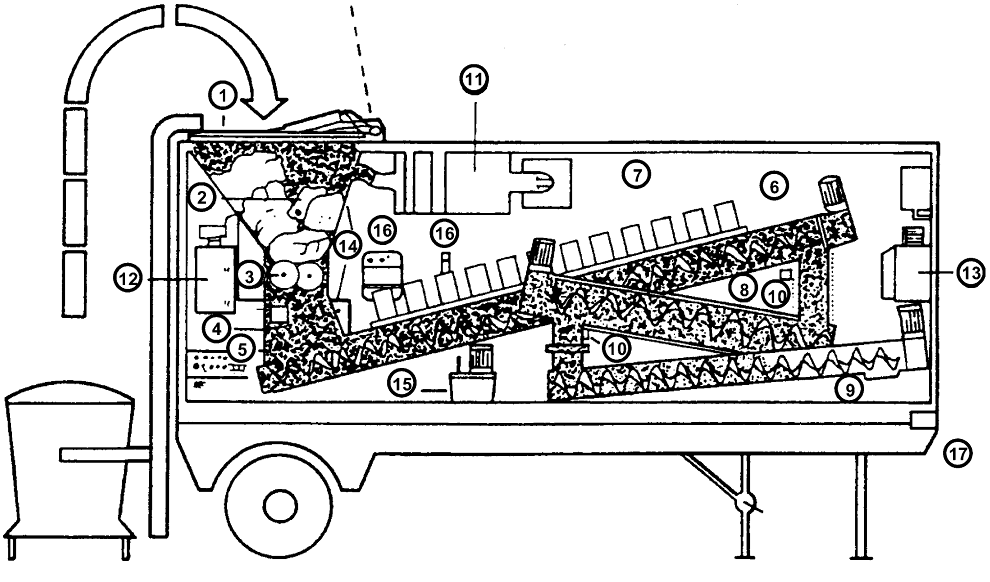

Fig. 2. Diagram of a mobile microwave unit. Process scheme of a mobile microwave-disinfection unit: 1. Feeding hopper, 2. Feeding crank, 3. Shredder, 4. Connecting hopper with inspection window, 5. Level sensors, 7. Microwave generators, 8. Temperature holding section, 9. Discharge conveyor auger, 10. Temperature sensors, 11. Filter system, 2-state, 12. Water tank with pump and spraying connection, 13. Steam generator, 14. Steam connection, 15. Hydraulic aggregate, 16. Room heater, 17. Container.

A variety of chemicals can be used to achieve chemical disinfection; some of these chemicals include: alcohols, acids, alkalis, phenols, halogens, heavy metal compounds, detergents (including quaternary ammonium compounds), anti-metabolites, and peroxides. Ideally, a disinfectant should have the following characteristics:

- capable of destroying all microorganisms as well as viruses;
- possess a high degree of stability;
- not be toxic to humans or to animals;
- be soluble in water;
- be tasteless and odorless; and
- be relatively inexpensive.

Acids and bases are effective disinfecting compounds because they release hydrogen (acids) and hydroxyl ions (bases). Enzymes are very sensitive to pH and are inactivated by very acid or very basic compounds.

Some of the types of disinfectants and antiseptics are described in the following paragraphs (Meyer, 1997).

Alcohols are compounds that usually are used as skin antiseptics. Alcohols are surfactants and also coagulate proteins. Ethanol, isopropanol, and benzyl alcohol are effective at concentrations of 50–70%. Alcohols are not effective in destroying, fungi, spores, or most viruses.

Phenol (carbolic acid) and its derivatives (cresol, orthophenylphenol, and others) are used for sterilizing surfaces. Phenols act mostly by coagulation and by damaging plasma membranes. They tend to remain on surfaces. The effectiveness of phenols is similar to that of alcohols. The strengths of new disinfectants are expressed by comparison to phenol. This is known as the phenol coefficient.

Halogens, especially iodine and chlorine, are widely used as antiseptics and disinfectants. Iodine and chlorine are lethal to a large variety of fungi, bacteria, and viruses through the inactivation of proteins. Tincture of iodine (a solution of 1–2% iodine in alcohol) is widely used for wounds. The iodine reacts with hydroxyl groups and inactivates proteins. Chlorine gas reacts with water to form hydrochloric acid (HCl) and hydrogen peroxide. Both of these compounds destroy microbial cells. They have been commonly used to disinfect public water supplies and sewage, and they have been widely used in the dairy industry. Common household bleach consists of 5.25% sodium hypochlorite.

Aldehydes such as formaldehyde (8%) and glutaraldehyde (2%) are alkylating agents that react with amines, some groups of proteins (such as sulfhydryl and carboxyl), and small organic molecules to inactivate them. Aldehydes essentially destroy all forms of microbial life, but their application is limited due to their noxious vapors.

Heavy metals precipitate proteins and therefore are effective as antimicrobial agents. Silver nitrate is used in the eyes of newborn babies, copper sulfate has been used in swimming pools, and some mercury compounds are used in the clothing and flower industries. Merbromin (mercurochrome) has been used extensively as an antiseptic. Heavy metal compounds are primarily bactericidal.

Detergents include soaps and synthetic detergents. Soaps are potassium or sodium salts of high fatty acid content. Detergents are mainly surfactants and are used to wash away debris from surfaces. Synthetic detergents are manufactured such that they have some soap properties. Essentially, there are three types of detergents:

1 anionic detergents (e.g., sodium lauryl sulfate);
2 cationic detergents (e.g., alkybenzyl sulfonates) and quaternary ammonium compounds (such as zeepryn and zephiran) are effective against bacteria and fungi; and
3 non-ionic detergents.

Gases, due to their ability to penetrate in a closed system, are excellent disinfectants and are effective against all forms of microbial life. Some of the gases that are most commonly used are ethylene oxide, propylene oxide, and β-propiolactone. Sulfur dioxide is commonly used as a food preservative.

Hydrogen peroxide (H_2O_2) is a mild antiseptic. Hydrogen peroxide is commonly used on wounds to destroy anaerobic bacteria.

2.3.1. Other considerations

Some of the most common chemical disinfectants used in the treatment of healthcare waste used to be chlorine-based. Of these, sodium hypochlorite (commonly known as bleach) was formerly one of the more common solutions used for disinfection. However, due to chlorine's negative health effects and since it has been demonstrated that chlorine is a precursor to the formation of dioxins in combustion, non-chlorine-based disinfectants are now being used. Some of these alternatives include: aldehydes (such as formaldehyde and glutaraldehyde), calcium oxide, ozone, and others. Calcium oxide (lime) generally is applied to healthcare wastes and other organic residues at disposal sites in developing countries. Lime added in sufficient quantities raises the pH to 11 or higher. A high (i.e., alkaline) pH creates an environment that inhibits the survival of microorganisms. In such an environment, the residues will not generate unpleasant odors or break down as long the pH is maintained at the requisite high level. Quickly covering the waste/lime mixtures with soil at the disposal sites helps preserve the advantages of the highly alkaline environment. When lime is added to the waste, adequate personal protection should be given to the workers applying the lime. Also, liquid discharges from the area must be carefully monitored and managed.

Some of the more important requirements to achieving efficient and productive chemical treatment of healthcare wastes are: (1) sufficiently high concentration of the chemical agent, (2) sufficient time in which the wastes are in contact with the chemical agent (retention time), and (3) waste with small particle sizes.

Small- and large-scale systems have been designed and used for chemical treatment of healthcare wastes. A diagram showing a typical installation is presented in Fig. 3. These systems typically incorporate some type of size reduction equipment to shred the wastes before chemical treatment. The chemical that has been used in the past for disinfection is a solution of chlorine. Subsequently, the treated solids are separated from the liquids. The addition of a liquid into the system means that eventually the liquid has to be managed prior to discharge into the environment. In the past, the liquid has been discharged into the sewerage system. In some locations, a special permit must be obtained for this type of discharge. In other situations, it may be necessary to treat the liquid prior to discharge into the sewer (because of the concentrations of metals, organic contaminants, dissolved solids, and others). Aerosols and particulate matter that may be released from the process are managed by means of air pollution control devices, which include: enclosures, ducting, HEPA filters, and blowers providing negative pressure.

2.3.2. Types of HCW that can be treated

Chemical disinfectants generally are used to treat the following types of materials:

- sharps;
- cultures and stocks;
- items contaminated with blood, liquid human and animal wastes;
- residues from surgery and from isolation wards;
- bandages, gauze, linen, gowns, and other similar materials; and
- non-chemical laboratory wastes.

2.3.3. Types of HCW that should not be treated

Healthcare facilities produce a variety of chemical and hazardous substances that should not be treated with chemical compounds. These types of wastes include:

- wastes from chemotherapy treatment;
- mercury;
- volatile and semi-volatile organic compounds;
- radioactive wastes; and
- other hazardous chemical wastes.

In general, it is not advisable to treat large body parts, animal carcasses, or other large items that, because of their mass and other characteristics, make it difficult or costly for the entire material to be properly treated.

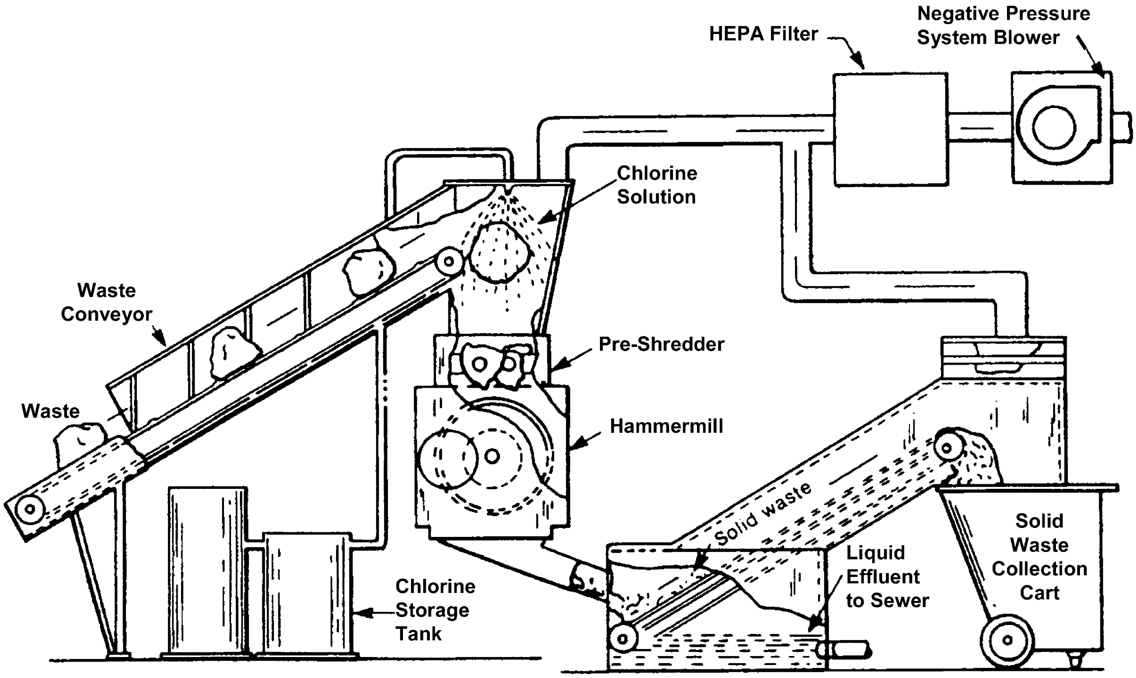

Fig. 3. Diagram of commercial chemical treatment unit.

In several healthcare facilities in developing countries, it is common practice to use a recycled container from within the hospital that is partially filled with a chemical disinfectant (usually a solution of sodium hypochlorite) to store used needles prior to disposal. This practice presents a risk to the medical staff and other personnel in the facility just by the mere fact that the containers must be filled. This compound and others of similar characteristics are, at the very least, strong irritants to the skin and to the respiratory system. Furthermore, it has also been observed that at the time of collection, the containers with disinfectant and sharps are simply capped and taken to the storage facility prior to treatment or final disposal. Thus, the liquid remains in the container. The presence of sodium hypochlorite can cause occupational health problems and, in the event that the wastes are treated in an incinerator, contribute to the formation of dioxins and furans.

The treatment facility can also pose occupational hazards because chemical processes generally require some type of size reduction of the treated waste. Thus, there is the possibility of pathogen release through the formation of aerosols.

2.4. Combustion

Infectious healthcare waste may be treated by combusting it in a variety of methods. The "vessels" used for the combustion process range from simple open pits in the ground, to metal drums, to sophisticated units that incorporate specialized equipment to control emissions from the process.

Any method used for the combustion of solid wastes generally produces three types of discharges: gaseous, liquid, and solid. The exception would be the use of combustion in the open air, in which case water may not be used to quench the hot ashes.

In a conventional, modern solid waste-fired incinerator equipped with air pollution control equipment, concentrations of heavy metals and dioxins would be present in the fine solid removed from the stack gas (fly ash). In some countries, the fly ash collected from incinerators treating municipal solid waste is considered a hazardous waste.

In this discussion, the combustion technologies are divided into three general types: low, medium, and high technologies (Brunner, 1996).

2.4.1. Low-technology combustion

In many developing countries, some fractions of healthcare wastes, and in particular used injection equipment, are commonly burned in the open air or in simple (and oftentimes improvised) units such as pits, burners (made out of brick or cement), and in drums. The units obviously are relatively inexpensive, are easy to build, and require little or no maintenance. Because of the relatively uncontrolled conditions under which the combustion takes place, the process reaches only what is considered to be low temperatures (about 400 °C or below). Combustion at these temperatures does not completely burn all of the wastes, particularly if the wastes contain a relatively high moisture content. Some syringes and needles may remain relatively unchanged at the completion of the combustion process. Furthermore, the uncontrolled process may not destroy all of the pathogens. This type of combustion does not control any type of emissions (particulate matter, heavy metals, and others) and, in fact, may lead to the production of relatively high concentrations of toxic organic compounds. Whole vaccine vials and similar glass containers have the tendency to explode and thus pose an additional risk to the person tending to the combustion process.

A photograph of a makeshift combustion device used for treating healthcare wastes in the rural area of an Asian country is presented in Fig. 4.

2.4.2. Medium- and high-technology combustion

Medium-technology combustion is defined as that which in some manner attempts to control the combustion process and, therefore, provides slightly better air pollutant control than that achieved by the low-technology options. There are some relatively simple and not excessively expensive units available in the marketplace that fit into this category. In essence, the units generally have a small capacity, are operated in batches, and do not include any type of air pollution control equipment.

High-technology combustion is defined as the combustion of healthcare waste under controlled conditions, using equipment that operates at temperatures on the order of 900–1000 °C, and that includes air pollution control equipment as well as other components to manage the emissions from the unit. These units generally include a second chamber (known as secondary chamber) in which the off (byproduct) gases from the first chamber are treated at high temperatures by means of an

Fig. 4. Photograph of simple incinerator used for the combustion of healthcare wastes in a developing country.

ancillary burner. High-technology combustion essentially provides the necessary conditions (temperature, time, and turbulence) to achieve complete combustion and to keep the concentration of undesirable compounds to a minimum. These types of incinerators operating in developing countries do not usually have post-combustion air pollution control systems.

The auxiliary fuel for these types of incinerators is diesel or gas. The incinerator may be operated in batch or continuous modes. A diagram of a high-technology controlled air incinerator is shown in Fig. 5.

2.4.3. Types of risks associated with combustion

The direct combustion (incineration) of HCW generates particulate matter and chemical compounds that can potentially affect human health and safety and have a negative impact on the environment. These materials can be emitted in gaseous, liquid, or solid form, and the impacts to humans can be direct (through inhalation of the emissions) or indirect (by ingesting items upon which particulate matter may have settled).

2.5. Land disposal

In general, land disposal of municipal solid wastes can be divided into three methods: open dumps, controlled landfills, and sanitary landfills. The method used to dispose of treated or untreated healthcare wastes in developing countries depends upon the type of disposal facility available. Facilities vary from open dumps, to controlled landfills, to sanitary landfills. Due to the prevalence of land disposal of HCW in developing countries, it is important to discuss the more common, special techniques available for disposal of solid wastes, HCW, or both (Diaz et al., 2003).

2.5.1. Open dumps

At the present time, the most common method of land disposal of solid wastes in developing countries is the open dump. Because of the uncontrolled nature of disposal, this method obviously is the least costly option, but at the same time, it is the one that causes the most negative impacts to the public and to the environment. Consequently, open dumping should be discontinued as soon as possible and in particular should not be used for the disposition of untreated healthcare wastes because of the potential risks to the public and to the environment. Open dumps, at the very least, should be upgraded as soon as possible to controlled landfills and eventually to sanitary landfills.

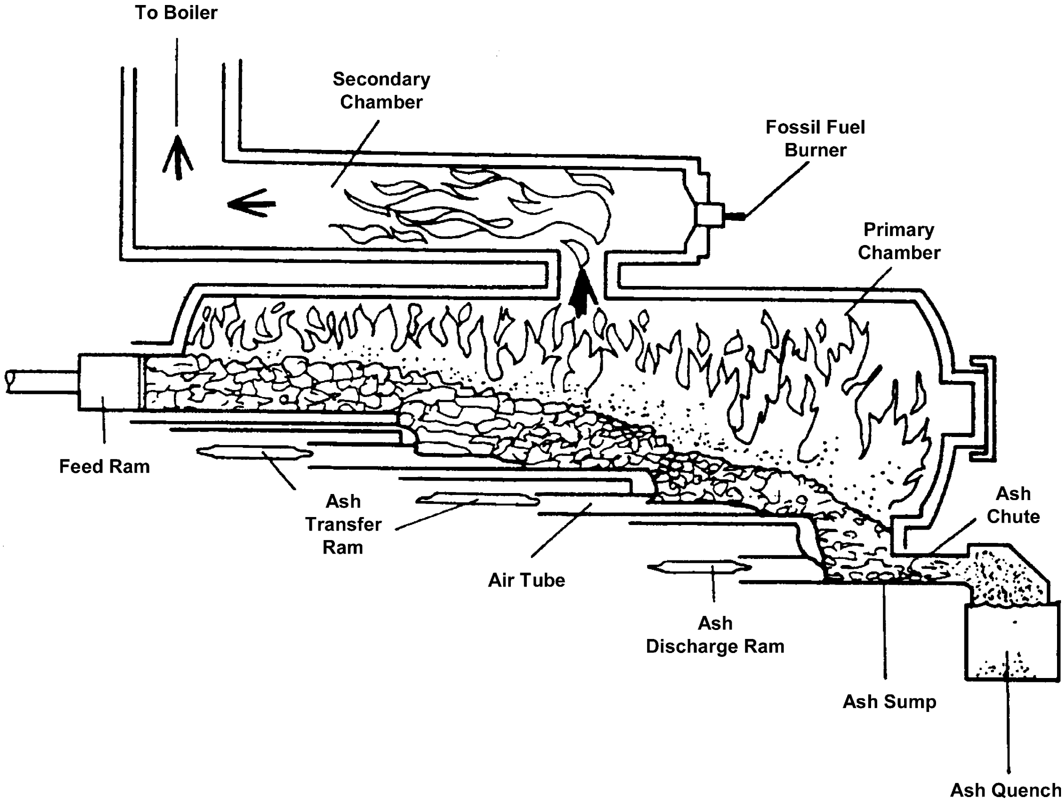

Fig. 5. Diagram of a controlled air incinerator.

2.5.2. Controlled landfills

A controlled landfill is a land disposal facility that:

- is sited according to basic hydrogeological conditions;
- restricts access to the area by means of a fence or a similar structure;
- controls scavenging;
- keeps waste discharges to a small working area;
- makes use of a soil cover on a regular basis;
- controls surface water and drainage;
- maintains basic records;
- manages the landfill gas; and
- applies a final cover and vegetation once filled.

2.5.3. Sanitary landfills

A sanitary landfill is an engineered waste disposal facility that, among other aspects, includes in its design:

- siting in accordance with hydrological, geological, social, and other factors;
- a bottom liner composed of a natural or synthetic layer of a low permeability material;
- measures to ensure that leachate and landfill gas are collected and properly managed;
- groundwater monitoring wells;
- use of daily, intermediate, and final covers; and
- a comprehensive closure and post-closure plan.

2.6. Burial in special pits

Burial of HCW in special pits is particularly applicable to relatively small healthcare facilities located in isolated (rural) areas where the geological and hydrological conditions are suitable and the area is sparsely populated. Suitability depends upon the amount of waste generated, the type of soil in the area, the distance to groundwater, and the distance to the nearest receptor. The pit should be about 2–3 m deep and approximately 2 m wide. If possible, the entire pit should be lined with a 30-cm layer of compacted clay or any other suitable low permeability material. If sufficient quantities of the impermeable material are not readily available, then only the bottom of the pit should be lined such that percolation of any liquids into the soil underneath is reduced to a minimum. The top portion of the pit should be slightly elevated and properly sloped to keep surface waters from entering the pit. Ideally, the pit should be covered with a simple, but sturdy removable cover. The pit should be built by persons knowledgeable in construction so that it is built efficiently and, most importantly, to prevent the sides from collapsing. The entire disposal area should be properly fenced off in order to keep unauthorized personnel or animals from entering into the area.

This type of pit may be used by small healthcare facilities, but may not be suitable for large-scale immuniza-

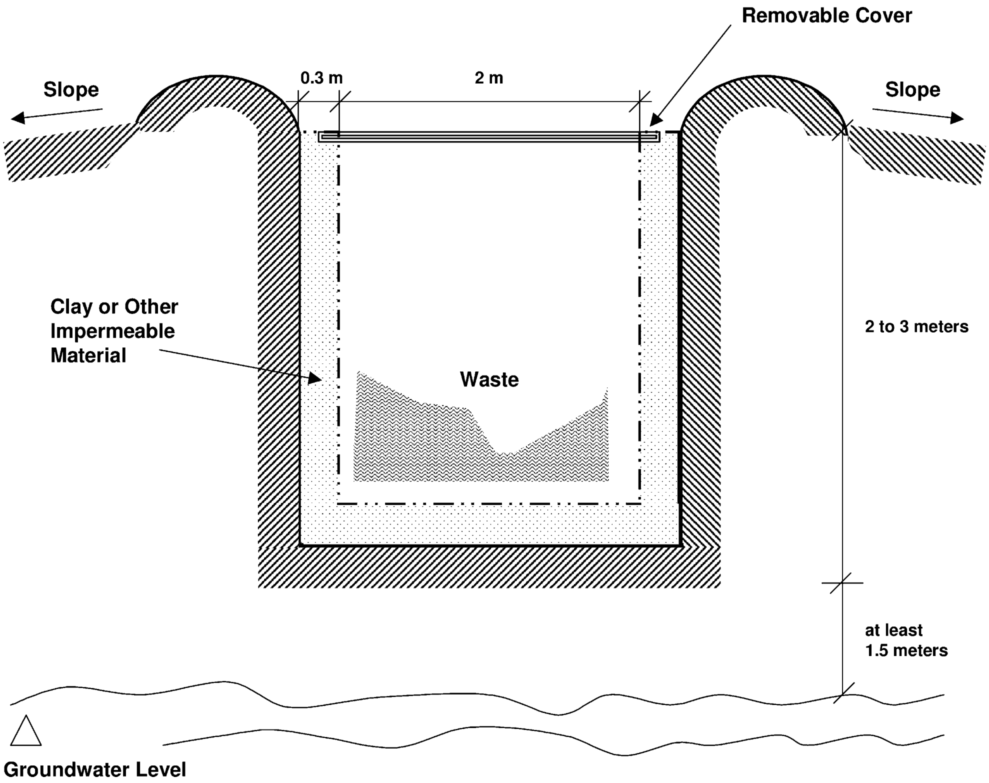

Fig. 6. Schematic diagram of a pit.

tion programs due to the large number of used needles and syringes that would be generated.

Once the pit is full, the top opening should be sealed with soil or with cement and the area clearly identified. A diagram of a pit is presented in Fig. 6.

If sufficient funds are available, the pit should preferably be constructed entirely out of cement, much like a septic tank, including a solid cover, as shown in Fig. 6. The pit or vault can be built with a hinged, lockable cover for additional security.

2.7. Encapsulation

Encapsulation is a procedure that has been widely used in the field of hazardous waste management, and it is a procedure that can be used for the treatment of sharps and more specifically hypodermic needles. In the process, the sharps are placed in containers. The containers can be made out of cardboard, plastic, or metal. The size of the containers varies from a fraction of a liter to about 100 L. When the containers are almost full, a material known to immobilize the sharps is added. The most common materials that are used to immobilize the sharps are cement, plastic foams, resins, and clay. Once the immobilizing material is dry or has hardened, the container should be properly sealed and disposed. Disposal can take place in a municipal disposal site or through on-site burial.

Cement encapsulation can also be utilized to dispose of sharps generated by large immunization programs, either using large containers as described in the previous section or by building a sufficiently large pit to accommodate the wastes (see Section 2.6). In this particular case, it is important to calculate the size of the pit or trench that will be required to hold the "volume" of needles and syringes produced. Ideally, the pit or trench should be built as described in the previous section and lined with an impermeable layer. The wastes should be carefully placed in the pit. If a flexible membrane is used to line the pit, then the sharps should be contained in boxes or similar containers to avoid punctures of the liner. Once all of the sharps are in the pit, the cement mixture is added. For optimum results, the mixture should be prepared as follows:

- 1 part cement;
- 1 part lime;
- 4 parts sand; and
- 1/2 part water.

A sufficient quantity of this mixture should be added to enclose the entire mass of waste in the pit. After the mixture has set or hardened, the pit should be covered with soil, properly contoured to reduce the amount of water infiltration, and identified to denote the type of

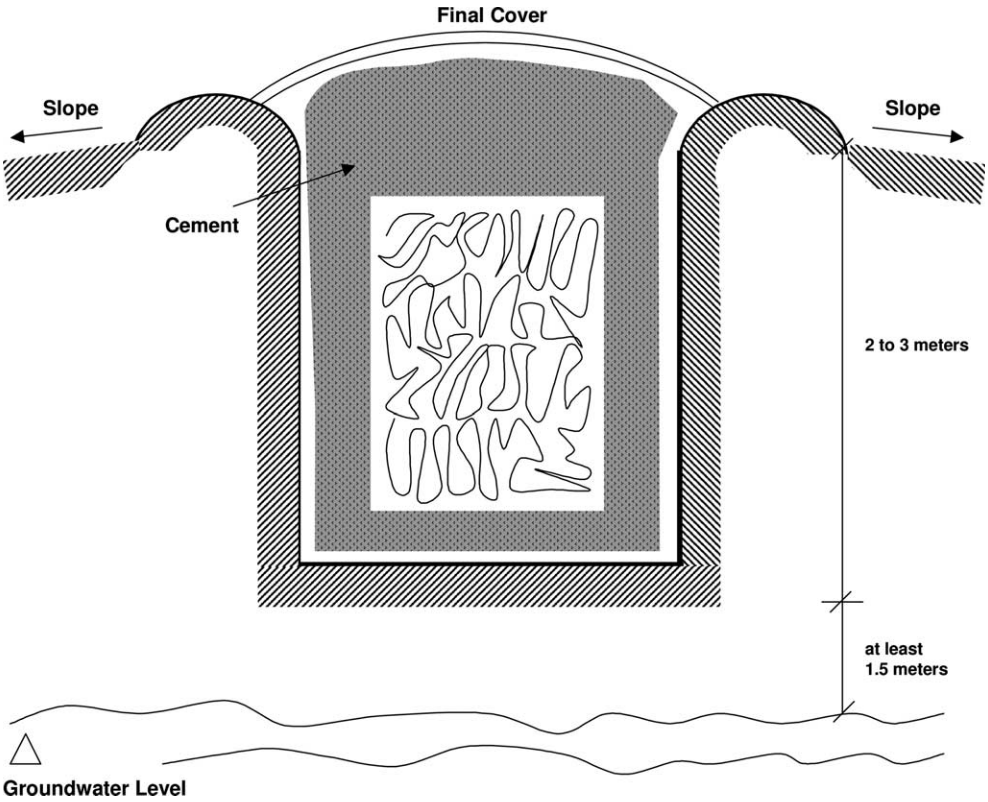

Fig. 7. Schematic diagram of cement encapsulation in a special pit.

waste buried on the site. A schematic diagram of the process is presented in Fig. 7.

This process is relatively inexpensive and uses a simple technology. In addition, encapsulation keeps personnel in the waste management system and scavengers at the disposal sites from accessing the materials and from being injured. No data have been found on the survival of microorganisms under encapsulation conditions.

3. Conclusions

Based on an analysis of HCW management in developing countries and on the experience of the authors, it is apparent that:

- Most developing countries are becoming more and more aware that healthcare wastes require special treatment.
- Every year, relatively large quantities of potentially infectious and hazardous wastes are generated in healthcare facilities throughout the world. Unfortunately, most economically developing countries are constrained by a number of factors from adequately managing these wastes.
- At the present time, the major fraction of healthcare wastes collected in developing countries either is disposed on the land or is incinerated.
- There is a slow but concerted effort to discontinue the reliance on incineration for the treatment of HCW. It is expected that the incineration of HCW in developing countries will be phased out within the next ten years.
- A review of available information points out the need to reach consensus on a worldwide basis on the definitions used to describe the various types of wastes generated in healthcare facilities. One reason for resolving this shortcoming is that comparative analyses, as well as the exchange of information, are severely compromised by ill-defined and ambiguous terms. Without well-defined terms, major difficulties and misunderstandings are bound to occur when discussing and analyzing HCW characteristics.
- The most common method of land disposal of solid wastes used in developing countries is the open dump. This method of waste disposal poses severe negative public and environmental health effects, in particular with healthcare wastes, and must be discontinued.
- Currently available alternative technologies for the treatment of HCW require that suitable land disposal facilities be available.

References

Brunner, C.R., 1996. Medical Waste Disposal. Incinerator Consultants Inc., Reston, VA.

CCOHS, Canadian Center for Occupational Health and Safety, Needlestick injuries, October 2000 (accessed at http://www.ccohs.ca/oshanswers/diseases/needlestick_injuries.html, September 2003).

Diaz, L.F., Savage, G.M., Eggerth, L.L., Golueke, C.G., 2003. Solid Waste Management for Economically Developing Countries, second ed. CalRecovery Inc., Concord, CA, January.

Meyer, J.E., 1997. Tutorials in Microbiology, Chemical Control of Microorganisms: Sterilization and Disinfection (accessed at http://instructors.sbcc.edu/meyer/bms127/lab/lab6chemical/).

NaSH, The National Surveillance System for Hospital Care Workers. Summary Report for data collected from June 1995 through July 1999 (accessed at http://www.cdc.gov/ncidod/hip/nash/report99.PDF, September 2003).

Puro, V., De Carli, G., Petrosillo, N., Ippolito, G., 2001. Risk of exposure to bloodborne infection for Italian healthcare workers, by job category and work area, Studio Italiano Rischio Occupazionale da HIV Group, Infect. Control Hosp. Epidemiol. 22 (4), 206–210.

Reinhardt, P.A., Gordon, J.G., 1991. Infectious and Medical Waste Management. Lewis Publishers Inc., Michigan, USA.

Romea, S., Alkiza, M.E., Ramon, J.M., Oromi, J., 1995. Risk of occupational transmission of HIV infection among healthcare workers, study in a Spanish hospital. Eur. J. Epidemiol. 11, 225–229.

US Congress. Office of Technology Assessment. Finding the Rx for Managing Medical Wastes, OTA-O-459. Government Printing Office, Washington, DC, September 1990.