Biomedical Waste: Impact on Environment and Its Management in Health Care Facilities

6

Gyanendra Kumar Sonkar, Sangeeta Singh, and Satyendra Kumar Sonkar

Abstract

Waste of any origin, if not properly disposed, possess a significant threat to the environment. Biomedical waste is a potential health hazard generated from institutions and laboratories providing health care facilities which includes all sorts of pathological, pharmacological, gentoxic, chemical, and radioactive wastes. About 20% of waste generated during patient care is hazardous and carries various health risks to hospital staff, patients, attendants, and the general population. Proper segregation and disposal of biomedical waste is the need of the hour as it will prevent contamination of groundwater sources that affect the health of humans and animals. Proper packaging and labelling of waste prevent the spread of infection through humans and animals. Biomedical waste is the source of water contamination and, if not rendered harmless before it is buried in land or disposed of in the water. Biomedical waste contaminates air if not segregated or incinerated properly, resulting in highly hazardous airborne particles of contagious diseases. The diagnostic laboratories using radioactive substances are potential pollutants of landfills and the atmosphere. The spread of air pollutants over huge areas of inhabited land has the potential to trigger several illnesses. Hence, there should be the management of biomedical waste at each level (i.e., places of its generation, collection, storage, transportation, treatment, and disposal). The stakeholders, including health care sector, state pollution control

G. K. Sonkar (✉)
Department of Biochemistry, King George's Medical University, Lucknow, Uttar Pradesh, India

S. Singh
Department of Biosciences, Integral University, Lucknow, Uttar Pradesh, India

S. K. Sonkar
Department of Medicine, King George's Medical University, Lucknow, Uttar Pradesh, India

© The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2023

B. K. Kashyap, M. K. Solanki (eds.), *Current Research Trends and Applications in Waste Management*, https://doi.org/10.1007/978-981-99-3106-4_6

board, and the municipal bodies, should work together to make the place safe for living with a neat and clean environment.

Keywords

Biomedical wastes · Hazardous · Infection · Disposable · Incineration · Autoclave · Hydroclaving

6.1 Introduction

Human body is in communion with five basic elements of nature. With the passage of time since evolution, there has been an increase in human population, leading to a decline in natural resources. No one is really worried about the future generation as no one fears the laws these days. With global industrialization, the biggest problem that came on the way was pollution. Many flora and fauna are on the verge of extinction, and even humans are not spared, and what prevails is medically affected. In November 1992, under the umbrella of UNESCO, various scientific personnel came together to address pollution.

6.1.1 Definition of Biomedical Waste

The medical documents related to waste management were first issued by World Health Organization (WHO) in 1996. As the medical sciences and its facilities have tremendously increased in the last few decades, it has led to a several-fold increase in biomedical waste (Sheth et al. 2006). The act of diagnosis, treatment, and immunization of human beings leads to generation of solid or liquid waste material. Wastes generated also add up to biomedical wastes. If these waste materials are not managed properly, they can be hazardous to health and the environment. All the hospital staffs are at risk to get various infections and injuries from these infectious materials. Diseases like hepatitis B, AIDS, etc., are on the increase, and these conditions have become critical public issues that need to be addressed. The technologies we are using for disinfecting these medical wastes are also adding toxic emissions polluting the environment. Hence to avoid these hazards, discriminate waste management system should be implemented in hospital infrastructure. Biomedical waste management (BWM) is a process that helps to ensure proper hospital hygiene and safety of health care workers and communities and the environment. BWM is concerned about planning and procurement, staff training and behaviour, proper use of tools, machines, and pharmaceuticals, proper methods applied for segregation, reduction in volume, treatment, and disposal of biomedical waste.

In India, the implementation of disposal of hospital wastes without segregation is still a problem. At many places, it is very common to find huge dumps of biomedical waste. The municipal workers or the rag pickers who are working at these sites in order to separate syringes, bottles, disposables, etc. for the sake of reselling them, incur the risk of getting infected by hepatitis B virus (HBV), hepatitis C virus (HCV), and human immunodeficiency virus (HIV) (Sulmer 1989).

According to Chartier et al. (2014), there are five principles that are widely used by several countries in their legislative and political systems.

1. The "polluter pays" principle is a policy implying to the basic rule that one should take responsibility of their own waste. It means that it's the companies and individuals responsible, legally and financially, for the safe and efficient disposal of waste generated by them.
2. The "precautionary" principle states that even when there is no clear evidence of harm and or risk from any human activity, still significant and protective measures must be taken accordingly to minimize environment damage from biomedical wastes.
3. The "duty of care" principle creates a connection between the individual handling and managing wastes, thus creating an ethical responsibility for the person. The most efficient way to keep this principle operating is to include working environments with people with proper education and knowledge in this area of business.
4. The "proximity" principle recommends that waste be treated and disposed of in the nearest possible location to its source. This way risks are minimized for the health category, and logistic costs for waste managing are diminished.
5. The "prior informed consent principle" the principle is mentioned in various international treaties, and it is designed to protect the environment and public health from several kinds of hazardous wastes.

6.1.2 Generation of Biomedical Waste

The biomedical wastes (Fig. 6.1) are usually generated from hospitals, various health clinics, laboratories and research facility centres, veterinarian clinics, offices, banned drugs, as well as during a disease outbreak (Hegde et al. 2007). Rapidly increased medical waste brings big challenges to their treatment and disposal. For example, recent COVID-19 outbreak, which has been characterized as a pandemic, causes the increase in generation of medical waste during the care of COVID-19 patients and the situation may be much more serious as the outbreak spreads. If medical waste is not properly managed, it will pose a great threat to the environment and humans due to its toxicity and infectious nature (Cai and Du 2020).

6.1.3 Categories of Biomedical Waste

Out of the total biomedical wastes produced each day, approximately 15–20% is hazardously injuring humans, animals, and the environment (WHO 2018). Mixing the non-hazardous waste with hazardous waste makes the whole of the waste very infective. WHO has categorized biomedical wastes into eight types, whereas the

Fig. 6.1 Biomedical wastes. (Source: Zafar 2020; https://stock.adobe.com/search?k="biomedical+waste")

Ministry of Environment and Forest in India (1998) has classified it into ten types (Kalpana et al. 2016) as follows:

Category 1	This includes human body parts, tissues, and other organs
Category 2	It includes several animal body parts, including tissues and bleeding parts of experimental animals used in research work or wastes generated from veterinary hospitals
Category 3	This includes wastes generated from Microbiology and Biotechnology laboratories, including research and industrial laboratories
Category 4	This constitutes waste that may cause punctures or cuts in body parts such as needles, syringes, scalpels, blades, glass, etc.
Category 5	All the medicines that have expired, contaminated, and discarded, including cytotoxic drugs, are included in this group
Category 6	This group comprises solid waste, i.e., those items contaminated with blood and body fluids
Category 7	This includes sharp, less solid wastes such as tabbing, catheters, and intravenous sets used for medical purpose
Category 8	This category includes liquid waste generated from laboratory and washing, cleaning, housekeeping, and disinfecting activities
Category 9	It includes ash generated from incineration of any bio-medical waste
Category 10	This group includes chemical and biological wastes.

6.2 Biomedical Waste Management Strategies

The management of biomedical waste is described as a multifaceted process that typically involves effective legislation, training, minimization, proper handling, segregation, storage, transportation, treatment, and safe disposal (Rao et al. 2004; WHO 2007).

6.2.1 Biomedical Waste Segregation and Storage

Segregation of biomedical waste is an important component of any waste management scheme (Fig. 6.2). It is an extensive challenge for the government and the health sector (Riyaz et al. 2010). It is still in its infancy all over the world (Arvind and Girish 2010). Proper management ensures that infectious waste is handled in accordance with established and acceptable procedures from the time of generation through treatment of the waste and its ultimate disposal (Sawalem et al. 2009). Proper container or color-coded bags must be used for each category of waste generated (Table 6.1) which will avoid environmental contamination and human health infection and help in segregating biomedical pollutants from non-pollutants. This practice reduces the total treatment cost, the impact of waste in the community, and the risk of infecting workers. Waste should be segregated into different

Fig. 6.2 Biomedical waste segregation and storage. (Source: BMWM Cell, KGMU, Lucknow)

Table 6.1 Color-coding for biomedical waste segregation (Source: Biomedical Waste Management Rules, CPCB 2016)

S. No.	Category	Items	Container/ disposable bags color
1.	Non-Plastic infectious waste	Body parts of humans and animals and other items used in day to day procedures such as cotton dressings, plaster casts and other materials contaminated with blood	Yellow
2.	Plastic Infectious waste	Glucose bottles, hub removed syringe, catheters, intravenous sets, gloves, etc. which are disposable in nature	Red
3.	Sharp waste	Needles, scalpels, blade, etc.	Red (puncture proof)
4.	Glass Waste	Bottle, ampoules, slides, tubes, etc. made from glass	White
5.	Liquid waste	Wastes generated from washing, cleaning and disinfecting activities	Blue
6.	General waste	Papers, wrappers, Fruits and vegetables peel and leftover food and edibles, etc.	Black

categories at the site of generation (Park 1997; Rao et al. 2004). Segregation of biomedical wastes at source is a key, and it will help hospital authorities to save money on waste disposal (Vorapong 2009).

After segregation, biomedical wastes should have safe and secured storage. All the containers mentioned above should be spill-proof and strong enough to hold the designed volume and weight of wastes without getting damage and preferably having a cover lid that can be operated by a foot (Mastorakis et al. 2011). The biomedical wastes should not be stored beyond 48 h onsite, and hence they should be collected on a regular basis every day. It should be further seen that this storage area should not be accessible to unauthorized people such as patients or visitors (WHO 2005a, b). Large hospitals and institutions having different departments, laboratories and operating theatres (OTs), wards, etc., should have a centralized collection/ storage room where the wastes can be collected before sending it to treatment or disposal site.

6.2.2 Biomedical Waste Handling and Transportation

Such wastes should be handled very carefully while it is being collected, stored, or during transportation. Time of collection should be well documented in duty charts and a copy of the same should be given to concerned waste collectors and supervisors. The waste bags should always be closed during transportation, with no leakage and no dragging of bags on the floor (Chandra 1999). The person collecting the waste should come in minimum contact to avoid infection. It should be done in the utmost safe manner while being transported outside the hospital

Fig. 6.3 Proper collection and handling of biomedical wastes. (Source: BMWM Cell, KGMU, Lucknow)

premises to the site of disposal. The vehicle used for transportation within and outside the hospital premises should be covered and have proper door closure and avoid leakage. The reusable containers used during such transport should not have sharp edges or corners to easily be washed and disinfected (Fig. 6.3) (Pruss et al. 1999; Chandorkar and Nagoba 2004).

6.2.3 Treatment and Disposal of Biomedical Waste

In developing countries, the unsanitary disposal of waste has put millions of lives at risk because people often visit dumping sites scavenging for goods. Biomedical wastes are disposed of on the bare ground, discarded into water bodies, or thrown away casually, which raises health issues in the surrounding habitat. As in some countries like Pakistan, biomedical wastes are simply thrown out on the ground, mixed with ordinary waste, or buried without any appropriate measure (Mustafa and Anjum 2009). In India, the effective waste disposal system still lacks in many small hospitals and nursing homes except in a few large hospitals (Dwivedi et al. 2009). Even the Government and municipal hospitals are no better than the private nursing homes regarding their waste disposal. A large volume of infectious wastes is disposed of in burial pits located at hospital sites and in municipal landfills, both practices pose significant risks to humans, including direct contact and contamination of surface water or groundwater (Rolando et al. 1997). Hence, before the actual disposal of biomedical waste, it should be disinfected, made environmentally non-toxic, and aesthetically acceptable. New processes and technologies are being introduced and marketed (Verma 2010; Diaz and Savage 2003; Mindrescu 2010). However, the final choice of treatment technology should be made carefully based on various factors, many of which depend on local conditions.

Broadly five methods viz. (a) chemical, (b) biological, (c) mechanical, (d) thermal, and (e) irradiation are being used in several places to treat biomedical wastes.

6.2.3.1 Chemical Processes

It is used for treating liquid wastes consisting of microorganisms, amount of contamination present, and biology of the microorganism (Patan and Mathur 2015). The wastes are first shredded, grinded and then mixed with chlorine dioxide, sodium hypochlorite, peracetic acid, lime solution, calcium oxide powder, and other inorganic chemicals. Anatomical wastes of humans and animals are treated with hot alkali in a stainless steel tank to disinfect them (Chartier et al. 2014).

6.2.3.2 Biological Processes

Using the naturally occurring aerobic and anaerobic processes, the organic substances are degraded, transformed, and stabilized into non-toxic end products (Verma et al. 2018). These fundamental processes are the basis for management strategies focusing on the biological treatment of organic waste materials. Biological degradation of waste materials is ambivalent and can lead to harmful effects if microbial activities occur under uncontrolled conditions in imbalanced systems (Bohm et al. 2011). Three changes occur during aerobic self-purification: coagulation of colloidal solids passing through the primary sedimentation stage; oxidation of carbon, nitrogen, and phosphorus; and nitrification. The basic requirements of any aerobic system for successful treatment of organic matter are a community of acclimatized microorganisms, adequate substrate (food), and a suitable environment (Scholz 2016). The organic wastes containing pathogens are destroyed using certain kinds of enzymes in the system. Digesting of such organic wastes with the help of worms (vermiculture) and composting. Deep burial is used successfully to decompose household kitchen wastes and hospital wastes such as placenta and other pathological wastes (Mathur et al. 2006). However, due care must be taken at such burial sites to restrict only authorized personnel and adequate precautions must be taken to prevent pollution and contamination of ground and surface water sources (Pruss et al. 1999) Furthermore, infectious and hazardous residues must be encapsulated with immobilizing agents prior to burial.

6.2.3.3 Mechanical Processes

This is done to reduce the bulk volume by more than 60%. It includes several processes such as granulating, pulverizing, shredding, grinding, mixing, agitating, and crushing of the biomedical wastes. This helps to facilitate further processes of treatment or disposal. Hence compaction and shredding are essentially the two important mechanical methods. These two are not used for untreated wastes because it generates aerosol and spilling of microorganisms which can be health hazard such as tuberculosis (Acharya and Meeta 2000). Shredder's basic work is to shred sterilized/autoclaved biomedical wastes before they are disposed. It is mainly used in combination with an autoclave. This makes the wastes almost unrecognizable (Rasheed et al. 2005) and makes transportation easy. The problem with shredder is that its blade has to be regularly replaced due to its wear and tear process with preventive and breakdown maintenance every 6 months. Nowadays, electrically operated shredders are readily available. Mashing or shredding of solid biomedical waste can generate dust. If this dust becomes airborne, it can be a workplace hazard and a threat to the environment, hence, closed rooms and hood with ambient pressure are used for keeping mechanical equipment. The next equipment used is needle cutters and destroyers which can be either mechanical or electrical. Studies show that more than 20% of those, who administer injections, suffer "needle stick injuries". These are used at those locations where needles are used for blood collection or the immunization process and nursing stations and clinics. As per WHO report, 8–-10 million Hepatitis-B, 2.3–4.7 million Hepatitis-C, and 80,000–160,000 HIV are estimated to occur from the reuse of syringe and needles without sterilization. The hospital staffs have plenty of chances of accidental needle stick injuries during administration of injections, drawing blood, and disposing used needles. Needles should be destroyed immediately after use since stick injury may occur at any stage after use (International Health Care Worker Safety Center 1998). These instruments help in avoiding the reuse of disposable syringes. There is an advantage of using electrical syringe cutters over mechanical ones as it can both cut and burn the needle and completely destroy it.

6.2.3.4 Thermal Processes

This method is regarded as the most revolutionary and universal method. This uses a high temperature, which leads to the destruction of microorganisms. Broadly two methods are known—(1) low heat systems (LHS) and (2) high heat systems (HHS). LHS operates at a temperature range of 93–177 °C and uses steam, hot water, or electromagnetic radiation to decontaminate the wastes. The two best known are Autoclave and Microwave. HHS usually requires very high temperatures to decontaminate the wastes. The best examples are incinerators, hydroclaving, and thermal plasma.

Autoclaving

It is simply also known as steam sterilization. It is used to sterilize or disinfect biomedical wastes before being disposed-off. There are two types of autoclaves in use (i.e., gravity type system or pre-vacuum-based system). The latter obtains the optimum result because it allows deeper sterilization of the contents, as it completely removes the air within, and allows high-temperature steam to penetrate and sterilize areas that would typically be occupied by ambient air, that is hard-to-reach (Baccini and Brunner 1991; Pruss et al. 1999). Gravity ones are used for non-porous items (i.e., those with hard surfaces). The third type of system is also in use, called the

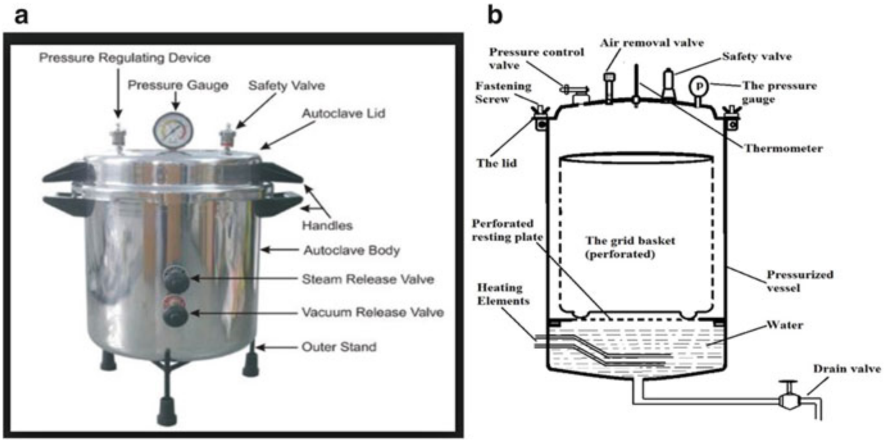

Fig. 6.4 (**a**) Vertical autoclave (source: Pharmawiki). (**b**) Working of autoclave. (Source: https://www.microsporemaster.com)

retort type system, which operates at a much higher temperature and pressure than others (Sah 2007).

For carrying out the process of autoclaving, the wastes are kept inside a strong chamber and steam is introduced into it for a specified temperature, pressure, and time (Fig. 6.4a, b). This method applies to most biomedical wastes, especially microbiological ones; however, it is not suitable for pathological, cytotoxic, or other toxic chemical wastes (Shukla et al. 2013; Hegde et al. 2007). Steam sterilization should be carried out after separating infectious wastes from non-infectious hazards. Waste that contains antineoplastic drugs, toxic chemicals, or chemicals that would be volatilized by steam should not be steam-sterilized (Chandra 1999). These methods require simple maintenance procedures which are low cost and a popular technology in waste treatment. There is 30% reduction in waste volume if mechanical shredders are also used along with it. These can later be used compacted and used for land filling. Care should be taken not to treat anatomical or pathological wastes, or wastes containing low levels of radioactive substances or laboratory chemicals and organic solvents as operational malfunction may result in ineffective treatment.

Microwave

It is used for disinfecting biomedical wastes using electromagnetic radiations (frequency between 300 and 300,000 MHz) in the presence of steam (Pruthvish et al. 1998). This is a relatively advanced and latest technology in the field of BMW. The wastes to be decontaminated are first shredded and mixed with steam in order to promote uniform heating and disinfecting. It is then subjected to microwave heating at 94 °C for a specified time. It is best suited for microbiology wastes, human blood, body fluids, and sharp wastes. However, it is not suitable for human and animal anatomical wastes and cytotoxins. After this, the wastes are allowed for disposal in other ways. The advantage of this method is that it can reduce the bulk volume of the

Fig. 6.5 Incinerator. (Source: https://www.Eco-business.com)

waste tremendously at very minimum costs, with no emission of harmful gases, and no chemicals required (Sah 2007; Dumitrescu et al. 2007; Heberlein and Murphy 2008; Aravindan and Vsumathi 2015). It is fully computerized to handle. The use of this technology has started in the USA and European countries but is still not carried out in India.

Incineration

This process uses a high-temperature dry oxidation process (Fig. 6.5). It helps in converting biomedical wastes into ash and gases. It consists of two chambers, outer and inner chambers with operating temperatures of 800–1000 °C and 850–1100 °C, respectively. There are two drawbacks of this system; the first one is that it can emit huge quantities of ash and several air pollutants such as particulate matter, metals, acid gases, oxides of nitrogen, carbon monoxide, etc. and secondly, it requires huge investment, operation, and maintenance costs together with costly emission control equipment (Nemathaga et al. 2008; Yang et al. 2009). However, such methods are being opposed by NGOs and common people in India and abroad. The setting of such facilities requires clearances as they involve risk of life due to occupational hazards and potential fire accidents. It is an old technology and was widely used in the past for all sorts of waste. However, biomedical waste, which is typically heterogeneous, is not acceptable for incineration if the combustible fraction is below 60%. Nowadays, incinerators are better equipped with pollution control equipment that requires no pre-treatment of biomedical wastes. Since most of the biomedical waste can be incinerated, the waste does not always require sorting or separation prior to treatment. It can reduce the volume of the waste by 80% or more and solid mass by up to 85%, sterilize the waste, and reduce the need to pre-processing the waste before treatment (Goddu et al. 2007; Sorrels et al. 2017). The resulting incinerated waste can be disposed of in traditional methods, such as land filling. Modern incinerators can provide another benefit by creating heat to power boilers in the facility. It is recommended for human anatomical waste, animal waste, cytotoxic drugs, discarded medicines, and soiled waste (like dressings, plaster casts, cotton swabs, etc.) (Dumitrescu et al. 2007; McCormack et al. 1989).

Hydroclaving

The instrument has a vessel, cylindrical in shape, double-walled, and mounted horizontally. It has a top-loading door and an unloading door at the bottom. There is a powerful motor with fragmenting/mixing arms inside it that slowly rotates the vessel. Steam is allowed to pass through the outer jacket with continuous tumbling. The optimum temperature required is 132 °C with a steam pressure of 36 psi for 20 min. During the whole process of treatment, the biomedical waste never comes in direct contact with steam. The entire process involving start-up to dehydration takes about 50 min. This helps hydroclave retain some steam back to the boiler (Sah 2007; Wallis 2010).

Moreover, it removes water from the waste and reduces the volume and weight significantly (85% and 60%, respectively) (Dumitrescu et al. 2007). However, one of the disadvantages of the hydroclave over the autoclave is that it takes more steam to heat up initially. It has to transfer the heat from the outer jacket into the vessel chamber through conduction. This initial high-energy requirement then diminishes for the continuing cycles (Fig. 6.6).

Fig. 6.6 A Hydroclave. (Source: https://www.healthmanagement.org)

Thermal Plasma

The technology has gained much importance these days because of generation of valuable co-products. It has attracted interest as a source of energy and spawned process developments (Heberlein and Murphy 2008). Traditional thermal technology for medical waste processing may cause indispensable secondary pollution such as dioxin, furan, heavy metals, and infectious materials that may remain in the solid residual. Thermal plasma technologies offer advantages of effectively treating medical waste due to its high temperature and energy density, lower pollutant emissions, rapid start-up and shut-down, and smaller size of the installation. These benefits play roles in treating medical waste on-site or off-site, especially when somewhere encounters an abnormally sharp increase in medical waste (Cai and Du 2020). This technique is already in commercial use for various industrial processes. Potential benefits are a more efficient use of energy, lower capital costs, and the substitution of exhaustible fossil fuels. This technology is also expected to have environmental benefits since the total gas flow rate is much smaller compared with conventional heating systems (Fig. 6.7) (Chang 2009).

6.2.3.5 Irradiation Processes

one of the most advanced ways of degradation of pollutants from wastewater by the use of powerful gamma rays and beta rays (Lajayer et al. 2020) as well as less energetic Ultraviolet rays (UV) (Lee et al. 2015). The advantages of this technology are that it does not require chemical additives and no lethal by-products are produced (Chu et al. 2010).

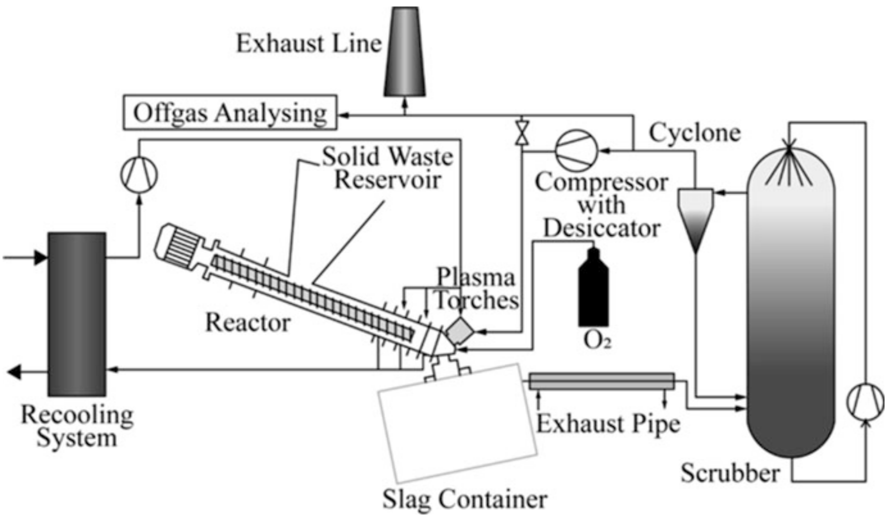

Fig. 6.7 Thermal plasma treatment of biomedical waste. (Source: https://www.springer.com)

6.3 Risks to Environment and Health

Disposal of waste has been known to be in civilization since 5000 BC. Since that time, the sewage system has been used to effectively dispose of waste in town planning. With urbanization and industrial development, the general public and social activists were not much aware of biomedical waste hazards and were not concerned about how the biomedical waste had to be disposed.

As per the WHO report, global life expectancy is increasing, but also there has been a steep increase in deaths due to increase in infectious disease. A study in the 1990s reported that infectious diseases such as tuberculosis, whooping cough, diarrhoea, pneumonia, etc. claimed more than 50,000 lives each day due to improper management of biomedical waste (Chitnis et al. 2002; Marinkovic et al. 2005).

With the introduction of hospitals across the cities, there was a problem in handling and disposal of waste generated during their care in hospitals. These were managed by untrained sweepers and some sanitary inspectors who did not have proper training in BMW (Park 1997). The improper management of biomedical wastes becomes a health hazard and spreads diseases in the population. They also add to environmental pollution and degradation. Hence, urgent protocols are needed to improve BMW, thereby eliminating occupational health hazards and protecting the environment.

Hospitals are involved in treating diseases, but it is also responsible for generating a large amount of biomedical waste. It has been known from several studies that patients acquire hospital-borne infections where the management of biomedical waste is poor. Though new drugs and technology for the management of diseases in the health care system are available, waste generation and their disposal have been neglected. Therefore, it is essential to take precautions in the design and organization of a hospital to minimize the risk of infection (Thomas and Timmreck. 2001).

A special attribute of biomedical waste is that even though it forms only a small part of the total solid waste, it can pollute and infect the whole solid waste if not taken care of properly. Once that happens, all the waste must be considered infected and treated as infectious waste. Improper handling, treatment, and disposal of biomedical wastes lead to pollution of air, water, and land (Sharma and Chauhan 2008). Indoors and outdoors environments can easily be affected by air pollution. The three types of air pollutions generated by biomedical waste are biological, chemical and radioactive. Indoor pollution can be due to pathogens in the form of spores that may remain suspended in the air for a long time.

On the other hand, open burning and incinerators add to the chemical pollution, which should be strictly avoided (Mandal and Dutta 2009). The dumping of biomedical waste can also pollute water bodies due to biological, chemicals, or radioactive substances in it. There is a serious threat to ground and surface water due to leakage of waterborne pathogens in the biomedical waste. Apart from harmful living organisms (pathogens), harmful chemicals, and heavy metals such as cadmium, lead, mercury, etc., present in the biomedical waste gets into the food chain after getting absorbed by plants. Salts of nitrates and phosphates that leach out into the landfills are also pollutants causing harm to crops, animals, and human beings (Mehta 1998).

Water pollution can alter the pH, BOD, DO, COD, etc. Toxins such as dioxins which are harmful to human and animal health have been present in water bodies near incinerator plants (Saini and Dadhwal 1995; Ravikant et al. 2002). Disposal of biomedical wastes inland gives rise to land pollution. Even liquid effluent after treatment is spread on land leading to land pollution. The dumping of biomedical waste in open land is the greatest cause of its pollution (Sharma and Mathur 1989).

In urban areas, improper practices such as dumping biomedical wastes in dustbins and open land and water bodies lead to diseases. Emission of harmful gases from incinerators and open burning can be carcinogenic and lead to respiratory problems (Manohar et al. 1998; Da silva et al. 2005). Every day huge amounts of plastic wastes are thrown in the open, which choke animals upon eating them. Wastes containing sharp items can cause harm to humans and animals (Code and Christen 1999).

6.4 Biomedical Waste Management Strategies

Management of biomedical wastes is a challenge for any city in a developing country due to a lack of funds and national regulations. In urban India, waste generation rates will reportedly reach 250 million tons annually by 2030, an increase of 130% from 2001 (Singh 2020). Hence each country has to frame their national legislation for the betterment of health care. It establishes legal controls and permits the national agency responsible for the disposal of biomedical waste, usually the Ministry of Health, to apply pressure for their implementation. The public, private, and informal sectors are the ones who are responsible for the waste management of any municipality. The central governments form the core of the public sector that consigns legal responsibilities of waste management to municipalities and local governments. Asian countries reportedly spend a significant $25 billion each year on waste management, including BMW (Hoornweg and Thomas 1999), although this has not significantly improved waste management. These results in ineffective management practices including, lack of training, non-segregation, unsafe storage, lack of treatment, open dumping, and crude burning. So, the effective management of biomedical wastes requires sound legislation, training, safe handling, segregation, storage, transportation, treatment, and disposal practices (Mbongwe et al. 2008).

Apart from public sectors, private sectors have started to participate in the management of biomedical and general wastes in many developing countries (Post 1999). The advantage of having this sector is that it creates competition which ultimately brings down the management costs. This sector has less political interference and hence more effective in running the system smoothly (Zhu et al. 2008).

The third sector (i.e., the informal sector) is also a strong pillar in many developing countries. They contribute significantly to waste management and resource efficiency by collecting, sorting, trading, and sometimes even processing waste materials. Moreover, the informal sector activities are highly adaptable, flexible, and able to respond quickly to demand-driven forces. In India, the informal waste sector is socially stratified in a pyramid with scrap collectors (waste pickers and itinerant waste buyers) at the bottom and re-processors at the top. Policies with the legal provision are necessary to assist in the effective management of biomedical waste (Phillips 1999).

Proper management of biomedical wastes starts at the source (i.e., segregation). This will help the medical/health care authorities to save money on the cost of disposal. Moreover, it will help to reduce the amount of infectious biomedical wastes from general wastes at the source. This saves more than 50% of costs, thereby minimizing health risks and costs of environmental hazards.

WHO (2005a, b) states that policies and plans should be implemented to ensure comprehensive waste management from production to disposal. It is required that hospitals and other areas that generate clinical waste comply with good practices and legislation regarding its disposal.

Still, there is no documentation of BMW policy, which leads to delay in final disposal.

6.5 Handling of Biomedical Wastes During COVID-19 Pandemic

COVID-19 pandemic brought unprecedented challenges to all sectors including health care sector. This created panic in health sector and everyone was affected by it. Death toll started to increase with each passing day which roused a sense of fear even in health care professionals. This pandemic resulted in huge generation of BMW which presented a threat to the existing BMW infrastructure worldwide. Hence safe disposal of COVID-19 biomedical waste was a challenge (Dehal et al. 2022).

Increase in use of medical technologies in health care system to prevent spread of COVID-19 has generated tremendous amount of biomedical wastes raising fear among biomedical wastes handlers leading to occupational stress (Ma et al. 2020). Use of personal protective equipment (PPEs), boots, face shields gloves, goggles, along with sanitizers, masks, syringes, testing kits, etc. have added to the existing biomedical waste composition (Das et al. 2021; Praveena and Aris 2021). In spite of all these hazards, the knowledge about segregation and management helped reduce COVID-19 wastes.

Looking at the sensitivity of the situation and specific need of the local civic bodies, it was very urgent to evolve our own approach towards COVID-19 waste management. In India, the CPCB is responsible for the implementation of BMW (2016) rules. CPCB (2016) issued guidelines to treat BMW management as "essential services" and ensured the uninterrupted movement of vehicles and people involved in COVID-19 BMW management. There was adequate supply of yellow, red, white, and blue bags and containers to all the hospitals and as well as at the quarantine facilities so that proper segregation ad collection of biomedical wastes can be done.

Our Medical University is one of the oldest and biggest in the country providing tertiary care to admitted patients. During the pandemic times, the majority of hospital wards were converted into COVID facilities which few were still catering to non-COVID cases as well. This helped to segregate COVID and non-COVID wastes. Collection and transportation of COVID-19 wastes were carried out by dedicated staffs in PPE. These biomedical wastes were continuously handed over to the authorized agency for further processing.

Handling of solid and liquid COVID biomedical wastes should be done as per the guidelines recommended. That is, using color-coded bins for onsite segregation, carrier trolleys for handling of BMW generated at COVID-19 areas, regular cleaning of trolleys with 1–2% sodium hypochlorite solution, maintaining a separate record of COVID-19 related activities, liquid wastes should be treated chemically, personal protective equipment should be given to all persons involved in COVID-19 BMW handling, and should follow basic hygiene and infection-control measures with regular health screening (Arya and Mandavkar 2020; WHO 2020; Chand et al. 2021).

6.6 Conclusion and Recommendations

The health care sector must understand the importance and seriousness of BMW and comply with the rules and regulations of their waste management policy. The responsibility lies at the first step of segregating biomedical wastes at the source of generation, collecting them in prescribed colour-coded bags, followed by safe transportation, applicable treatment, and proper disposal of biomedical wastes. Apart from this, training programs should be conducted in their set up for all and especially for tho who are responsible for such management. These things have to be implemented effectively accountability should be fixed for each and every person involved in management of biomedical waste. This will help to protect not only our health but also our environment.

The following recommendations are to be noted:

- In coordination with the Ministry of Environment and other concerned ministries and local administration, any country’s health ministry should specify the responsibilities towards managing biomedical waste within and outside the health care establishments.
- There is need for sustained cooperation among all key actors (government, hospitals, and waste managers) in implementing a safe and reliable medical waste management strategy, not only in legislation and policy formation but also particularly in its monitoring and enforcement. This can be achieved through the cooperation between the Ministry of Health, Environmental Quality Authority, Ministry of Local Government, and Non-Governmental Organizations working in related fields.
- It should be the responsibility of each health care facility (HCF) to ensure a safe and hygienic system of medical waste handling, segregation, collection, storage, transportation, treatment, and disposal, with minimal risk to handlers, public health, and the environment.

- All staff and waste handlers in each hospital should be well trained at the beginning of their work at hospitals and regularly updated with pre-employment and in-house specialized training, which provides them with a knowledge base about the process of waste management and associated health risks.
- Economically and environmentally sustainable technological options for waste treatment, which can be well operated and maintained, should be considered for medical waste management.
- There should be a hazardous waste landfill specially designed for the final disposal of treated hazardous healthcare waste. Its specifications are well known in the international literature, and we should benefit from that.
- There should be proper documentation on the quantity of medical waste generated per day/week/month/year to serve as a guide for effective and efficient planning.
- Waste should be segregated using management tools like colour-coding and proper labelling of waste containers. There should be appropriate and modernized methods of disposing of and treating medical waste.
- Infectious waste should be treated and disposed of separately from non-infectious waste.
- A waste management department headed by a waste management Officer should be in place to ensure effective supervision of the waste workers.
- There should be regular training programs for all categories of health workers concerning waste management.
- Waste management policy/legislation should be in place to regulate how waste would be managed.
- A waste management manual or guide document should be provided to guide waste handlers on how best to handle medical waste such as infectious and non-infectious.

References

Acharya DB, Meeta S (2000) Hospital waste management. Minerva Press, New Delhi. 15, 47

Aravindan A, Vsumathi AM (2015) Case study exploration of biomedical waste in multispeciality hospital in Madurai. Int J Appl Env Sci 10:347–363

Arvind VA, Girish BD (2010) A study on hospital waste management at a rural hospital. J Ind Soc Hosp Waste Manag 9(1):22–32

Arya A, Mandavkar G (2020) Impact of bio-medical waste management on corona virus in India: a critical analysis. Int J Law Manag Human 3(733–744):2

Baccini P, Brunner P (1991) The metabolism of the anthroposphere. Springer, Berlin

Bohm K, Tintner J, Smidt E (2011) Modelled on nature – biological processes in waste management. In: Kumar S (ed) Integrated waste management, vol I. https://doi.org/10.5772/17140

Cai X, Du C (2020) Thermal plasma treatment of medical waste. Plasma Chem Plasma Process 41:1. https://doi.org/10.1007/s11090-020-10119-6

Chand S, Shastry CS, Hiremath S, Joel JJ et al (2021) Updates on biomedical waste management during COVID-19: the Indian scenario. Clin Epidemiol Glob Health 11:100715

Chandorkar AG, Nagoba BS (2004) Hospital waste management, 2nd edn. Paras Medical Publisher, Hyderabad. 7, 63-65, 106

Chandra H (1999) Hospital waste - an environmental hazard and its management. International Society of Environmental Botanists. Arch Environ News Newsl ISEB India 5(3):1

Chang JS (2009) Thermal plasma solid waste and water treatments: a critical review. Int J Plasma Environ Sci Technol 3:67–84

Chartier Y, Emmanuel J, Pieper U et al (2014) Safe management of wastes from healthcare activities, 2nd edn. WHO, Geneva. vi + 116 pp

Chitnis V, Chitnis S, Patil S, Chitnis DS (2002) Is inefficient in decontaminating blood containing hypodermic needles. Indian J Med Microbiol 20:215–218

Chu L, Wang J, Wang B (2010) Effects of aeration on gamma irradiation of sewage sludge. Radiat Phys Chem 79(8):912–914

Code A, Christen J (1999) How are we managing our healthcare wastes? SKAT, St. Gallen

CPCB (2016) Biomedical waste management rules. CPCB, New Delhi

Da Silva CE, Hoppe AE, Ravanello MM, Mello N (2005) Medical wastes management in the south of Brazil. Waste Manag 25:600–605

Das AK, Islam MN, Billah MM, Sarker A (2021) COVID-19 pandemic and healthcare solid waste management strategy — a mini-review. Sci Total Environ 778:146220. https://doi.org/10.1016/j.scitotenv.2021.146220

Dehal A, Vaidya AN, Kumar AR (2022) Biomedical waste generation and management during COVID-19 pandemic in India: challenges and possible management strategies. Environ Sci Pollut Res Int 29:14830–14845

Diaz LF, Savage GM (2003) Risks and costs associated with management of infectious wastes. WHO/WPRO, Manila

Dumitrescu A, Vacarel M, Qaramah A (2007) Waste management resulting from active medical devices. J Environ Prot Ecol:116–119

Dwivedi AK, Pandey S, Shashi (2009) Fate of hospital waste in India. Biol Med 1(3):25–32. http://www.biolmedonline.com

Goddu VK, Duvvuri K, Bakki VK (2007) A critical analysis of healthcare waste management in developed and developing countries: case studies from India and England. Proceedings of the International Conference on Sustainable Solid Waste Management. Centre for Environmental Studies, Department of Civil Engineering, Anna University, Chennai, pp 134–141

Heberlein J, Murphy AB (2008) Thermal plasma waste treatment. J Phys D Appl Phys 41:053001

Hegde V, Kulkarni RD, Ajantha GS (2007) Biomedical waste management. J Oral Maxillofac Pathol 11:5–9

Hoornweg D, Thomas L (1999) What a waste: solid waste management in Asia. Urban Development Sector Unit, World Bank, Washington, DC

International Health Care Worker Safety Center (1998) Estimated annual number of U.-S. occupational percutaneous injuries and mucocutaneous exposures to blood or potentially infective biological substances. Adv Exposure Prevent 4:3

Kalpana VN, Prabhu DS, Vinodhini S, Devirajeswari S (2016) Biomedical waste and its management. J Chem Pharm Res 8:670–676

Lajayer BA, Najafi N, Moghiseh E, Mosaferi M, Hadian J (2020) Effects of gamma irradiation on physicochemical and biological characteristics of wastewater effluent and sludge. Int J Environ Sci Technol 17(2):1021–1034

Lee OM, Kim HY, Park W, Kim TH, Yu S (2015) A comparative study of disinfection efficiency and regrowth control of microorganism in secondary wastewater effluent using UV, ozone, and ionizing irradiation process. J Hazard Mater 295:201–208

Ma Y, Lin X, Wu A et al (2020) Suggested guidelines for emergency treatment of medical waste during COVID-19: Chinese experience. Waste Dispos Sustain Energy 2:81–84

Mandal SK, Dutta J (2009) Integrated bio-medical waste management plan for Patna City. Inst Town Plann India J 6:01–25

Manohar D, Reddy PR, Kotaih B (1998) Characterization of solid waste of a super speciality hospital – a case study. Ind J Environ Health 40:319–326

Marinkovic N, Vitale K, Afric I, Janev HN (2005) Hazardous medical waste management as a public health issue. Arh Hig Rada Toksikol 56:21–32

Mastorakis NE, Bulucea CA, Oprea TA, Bulucea CA, Dondon P (2011) Holistic approach of biomedical waste management system with regard to health and environmental risks. Dev Energy Environ Econ 5(3):287–295

Mathur UB, Verma LK, Srivastava JN (2006) Effects of vermicomposting on microbiological flora of infected biomedical waste. J Indian Soc Hosp Waste Manag 5(1):21–27

Mbongwe B, Mmereki B, Magashula A (2008) Healthcare waste management: current practices in selected healthcare facilities, Botswana. Waste Manag 28:226–233

McCormack J et al (1989) Evaluation test on a small hospital refuse incinerator at Saint Bernardine's Hospital in San Bernardino. California Air Resources Board, Sacramento, CA

Mehta G (1998) Hospital waste management, national guidelines (draft) prepared for GOI/WHO project IND EHH 001. Lady Hardinge Medical College and Associated Hospitals, New Delhi

Mindrescu TA (2010) Implementarea unui system de management al deseurilor biomedicale la Spitalul de Obstetrica-Ginecologie Rm. Valcea. Master Thesis, Faculty of Electromechanical and Environmental Engineering, Craiova

Mustafa MY, Anjum AA (2009) A total quantity management approach to handle veterinary hospital waste management. J Anim Plant Sci 19(3):163–164

Nemathaga F, Maringa S, Chimuka L (2008) Hospital solid waste management practices in Limpopo Province, South Africa: a case study of two hospitals. Waste Manag 28(7):1236–1245

Park K (1997) Preventive and social medicine, 18th edn. M/s Banarasidas Bhanot Publishers, Jabalpur. 1–10, 595–596, 599

Patan S, Mathur P (2015) Assessment of biomedical waste management in government hospital of Ajmer city – a study. Int J Res Pharm Sci 5(1):6–11

Phillips G (1999) Microbiological aspects of clinical waste. J Hosp Infect 41:1–6

Post J (1999) The problems and potentials of privatizing solid waste management in Kumasi, Ghana. Habitat Int 23(2):201–215

Praveena SM, Aris AZ (2021) The impacts of COVID-19 on the environmental sustainability: a perspective from the Southeast Asian region. Environ Sci Pollut Res 28(45):63829–63836

Pruss A, Giroult E, Rushbrook P (1999) Safe management of wastes from health-care activities. World Health Organization, Geneva

Pruthvish S, Gopinath D, Jayachandra RM, Girish N, Bineesha P, Shivaram C (1998) Health-care waste management cell. Department of Community Medicine, M.S. Ramaiah Medical College, Bangalore. Information Learning Units for Health-Care Waste

Rao S, Ramyal R, Bhatia S, Sharma V (2004) Biomedical waste management: an infrastructural survey of hospitals. MJAFI 60:379–382

Rasheed S, Iqbal S, Baig LA (2005) Hospital waste management in the teaching hospitals of Karachi. J Pak Med Assoc 55(5):192–195

Ravikant CV, Jaiswal SP, Vaidya K, Chitnis DS (2002) Effluent treatment plant: why and how? J Acad Hosp Admin 14(1):33–37

Riyaz BS, Asima B, Subhas GT (2010) Liquid waste treatment plant in tertiary care Teaching Hospitals attached to Government medical college. J Indian Soc Hosp Waste Manag 9(1):41–46

Rolando TS, Loido BM, Danilo GL (1997) Hospital waste management in the Philippines: two case studies in Manila. UWEP, Gouda, pp 1–65. http://www.waste.nl

Sah RC (2007) Bio-medical waste management practice and POPs in Kathmandu, Nepal. Center for Public Health and Environmental Development of Kathmandu, Nepal, Kathmandu. http://www.noharm.org/details.cfm

Saini RS, Dadhwal PJS (1995) Clinical waste management: a case study. J Indian Assoc Environ Manag 22:172–174

Sawalem M, Selic E, Herbel JD (2009) Hospital waste management in Libya: a case study. Waste Manag 29:1370–1375

Scholz M (2016) Biological treatment. In: Wetlands for water pollution control, 2nd edn. Elsevier, Amsterdam, pp 77–79

Sharma S, Chauhan SV (2008) J Environ Biol 29(2):159–162

Sharma RK, Mathur SK (1989) J Acad Hosp Admin 1(2):55–57

Sheth KN, Purvi M, Desai H (2006) Characterization and management of bio-medical waste in Sae Hospital, Anand – a case study. Elec J Env Agricult Food Chem Title 5(6):1583–1589

Shukla A, Shukla M, Ahuja P (2013) Int E J:8–27

Singh S (2020) Solid waste management in Urban India: imperatives for improvement. ORF Occasional Paper No. 283, November 2020. Observer Research Foundation, New Delhi

Sorrels JL, Baynham AM, Randall D, Hancy C (2017) Incinerators and oxidizers. United States Environmental Protection Agency, Washington, DC. https://www.epa.gov/sites/production/files/201712/documents/oxidizersincinerators_chapt er2_7theditionfinal.pdf

Sulmer P (1989) Defining and managing infectious waste, plant, technology & safety series, vol 4. The Joint Commission on Accreditation of Healthcare Organizations, Oakbrook Terrace, IL, pp 17–23

Thomas C, Timmreck. (2001) An introduction to epidemiology, 2nd edn. Jones and Bartlett Publishers, Toronto, ON, pp 72–73

Verma LK (2010) Managing hospital wastes. How difficult? J Ind Soc Hosp Waste Manag 9:(1);47-50

Verma P, Vasudevan V, Kashyap BK, Samsudeen TI, Meghvansi MK, Singh L, Kamboj DV (2018) Direct lysis glass milk method of genomic DNA extraction reveals greater archaeal diversity in anaerobic biodigester slurry as assessed through denaturing gradient gel electrophoresis. J Exp Biol Agric Sci 6(2):315–323

Vorapong M (2009) Awareness and management of hospital waste in developing countries: a case study in Thailand, The George Washington University, 85 p, 3349629

Wallis T (2010) Personal communication. Mr Wallis is a project manager for Hydroclave Systems Corp. Ltd, Kingston, Ontario, Canada

WHO (2020) Water, sanitation, hygiene, and waste management for SARS-CoV-2, the virus that causes COVID-19. Interim Guidance; WHO/COVID-19/IPC_WASH/2020.4. WHO, Geneva

World Health Organization (2005a) WHO waste steps. Healthcare waste management (HCWM). WHO, Geneva

World Health Organization (2005b) Preparation of national health-care waste management plans in Sub-Saharan Countries. WHO, Geneva

World Health Organization (2007) Wastes from healthcare activities Fact sheet No 253. WHO, Geneva. Accessed Apr 2008

World Health Organization (2018) Health care wastes. WHO, Geneva. https://www.who.int/news-room/fact-sheets/detail/health-care-waste

Yang C, Peijun L, Lupi C, Yangzhao S, Diandou X, Qian F, Shasha F (2009) Sustainable management measures for healthcare waste in China. Waste Manag 29(6):1996–2004

Zafar S (2020) Medical waste management in developing countries. Waste Manag 9:351–358

Zhu D, Asnani P, Zurbrugg C, Mani S (2008) Improving municipal solid waste management in India: a sourcebook for policymakers and practitioners. The World Bank, Washington, DC