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Review Article

Microbial Waste Management in Healthcare Settings: A Review

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Abstract

Human health is directly related to the environment and its various components. Healthcare is one sector that witnesses maximum footfalls in terms of patients, thus giving rise to a large scale of microbial waste. These microbial wastes are mostly hazardous and risk polluting the environment and putting public health at stake. Safe disposal of these wastes is a significant concern due to their associated risks. Waste management methods commonly include chemical disinfection, steam sterilization, landfilling, and incineration. These methods pose various risks to human health, possibly attributed to their characteristic property of creating secondary pollutants. Such problems have intrigued researchers to search for better alternatives and advanced techniques. The onset of COVID-19 has jeopardized the waste management system in the healthcare sector, mainly related to hazardous microbial wastes. The current review discusses the impact of microbial waste on public and environmental health. It further discusses the advantages of modern techniques over traditional ones for sustainable management of microbial wastes. Modern techniques still face certain drawbacks, so the authors invite future research activities to work towards making these techniques even better and more sustainable.

Keywords: *Environmental pollution, Healthcare sector, Microbial waste management, Modern techniques, Secondary pollutants*

Introduction

Evolving and changing lifestyle patterns and environmental conditions have made humans even more unhealthy and prone to diseases. These diseases can range from minor ailments to severe life-threatening ones. The onset of the pandemic even saw several people succumbing to the deadly virus in the form of COVID-19. In such a scenario, the healthcare sector plays a significant role in the well-being of human health. The healthcare sector, no doubt on one hand, plays a vital role but, on the other hand, is also quite a deterrent to the environment and human health (Rath & Akhtar, 2019). The negative aspects of the healthcare sector are attributed to the large-scale generation of different types of waste and their improper disposal in the environment, thus creating real health challenges. Microbial or biomedical waste is generally produced during human and animal subjects' diagnosis, treatment, and immunization (Datta *et al*., 2018). World Health Organization (WHO) has classified the wastes generated from healthcare sectors into two broad categories: non-hazardous and hazardous

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(Saxena *et al*., 2022), as depicted in Figure 1. Non-hazardous wastes account for 85%, while hazardous wastes represent 15% of the total waste generated from the healthcare sector. Among the hazardous wastes, 10% are infectious with microbial contamination. Objects contaminated with microbial entities are disposed of improperly, thus leading to the chances of severe contamination of the ecosystem (Rath, 2021). The current review analyzes the various sources of microbial waste generated from healthcare sectors, their conventional disposal strategies, and their concerns. The review further suggests strategies for sustainable disposal of such wastes.

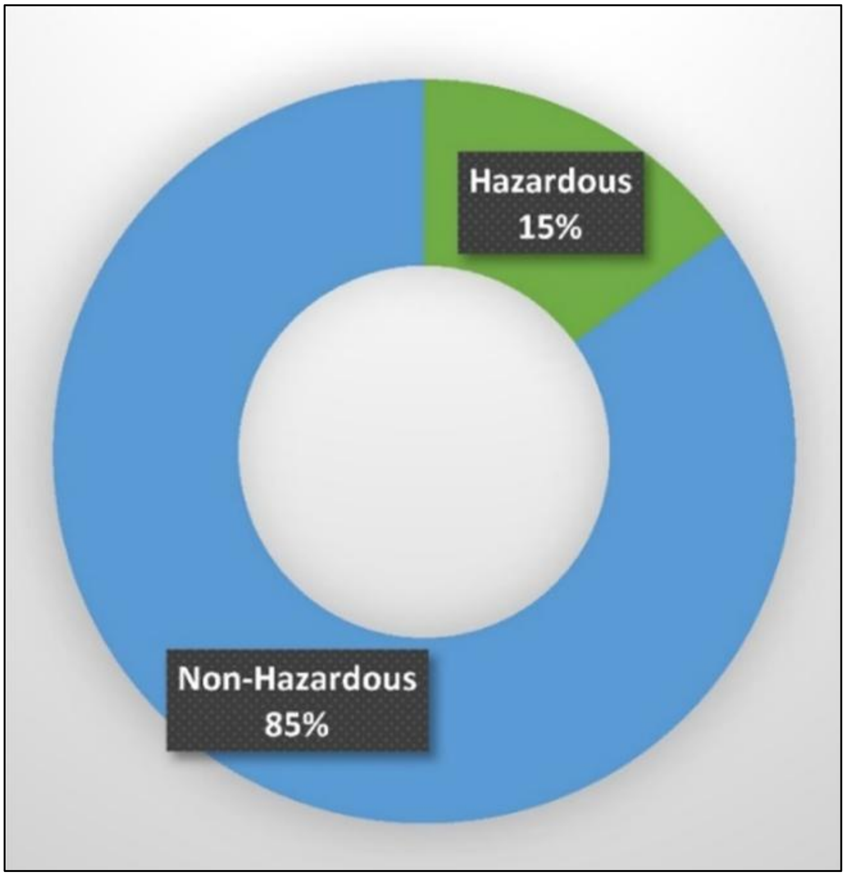

Figure 1. Categorization of wastes generated from healthcare sectors.

Sources of microbial wastes in healthcare settings

Healthcare wastes with chances of microbial contamination are mainly generated from hospitals, research centers, and animal testing facilities and are categorized as infectious waste (Figure 2). These wastes include objects contaminated with human or animal blood and body fluids. Pathological wastes like human tissues, body parts, or animal carcasses pose greater chances of contamination with microbial entities, thus compounding the problem. Hospital utility wastes like sharps (syringes, scalpels, blades, and needles), catheter bags, ventilator tubes, and saline bottles mostly pose the chances of being contaminated with microbes. As per the WHO (WHO, 2015), the administration rate of injections is 16 billion per year, of which not all are disposed of systematically. Needle stick injury due to improper disposal of contaminated syringes poses a risk of causing hepatitis-B virus (30%), hepatitis-C virus(1.8%), and human immunodeficiency virus (0.3%).

Contamination with microbial wastes poses several threats, including the chance of causing potential infections. Feces or vomit contaminated with *Enterobacteriaceae* species are responsible for causing gastrointestinal infections in healthy humans. Herpes virus-infected samples are primarily responsible for causing ocular and genital infections. Cross-contamination with certain species of *Staphylococcus* and some deadly and contagious viruses can readily cause septicemia and other life-threatening diseases (Padmanabhan & Barik, 2019).

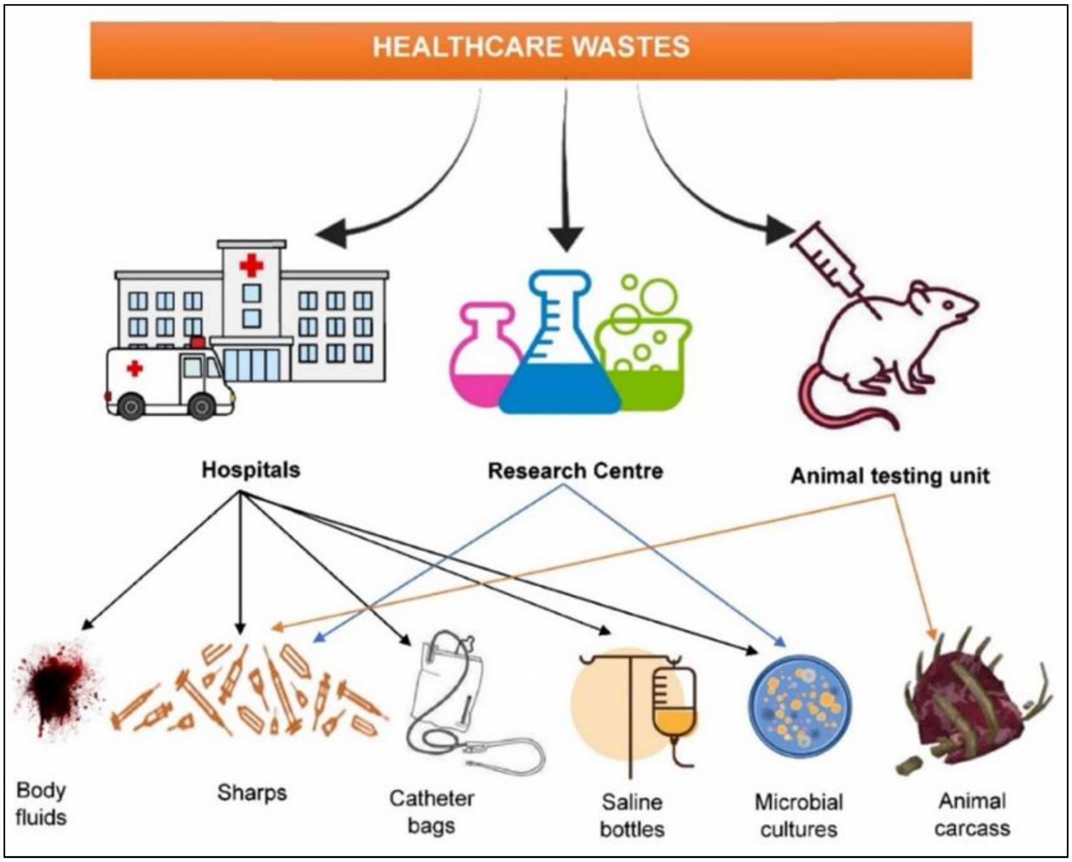

Figure 2. Sources of healthcare wastes generated with chances of microbial contaminations.

Status of Microbial Waste Production in India

Estimates suggest mortality rates above 5.2 million, including around 4 million children, due to diseases caused by exposure to medical waste (Rahman *et al*., 2020). As a country, India has been grappling with biomedical waste management practices.This may be attributed to the need for more technicalities, practical applications, and, more importantly, insufficient finances. The problem has even compounded with the onset of COVID-19 and a rapid surge in the volume of waste generated (Saxena *et al*., 2022; WHO, 2021). The annual growth rate of biomedical waste generation in the country is around 7%, with a further estimate of reaching up to 775.5 metric tonnes per day by 2022. As per the 2018-2019 biomedical waste management report released by the Central Pollution Control Board (CPC, 2019a), 619 tonnes of waste were generated by 3,22,425 healthcare institutes and facilities. Among the generated biomedical wastes, only 544 tonnes were processed and disposed of daily. On the other hand, with such a massive generation of biomedical waste, several biomedical waste management facilities have been found to flout the regulatory guidelines for managing such waste, thus leading to a chaotic situation (CPC, 2019b).

Methods for treatment of microbial wastes in healthcare

Management of microbial wastes in the healthcare sector is essential as it is much needed for the well-being of the environment, including humans. The healthcare sector in India heavily relies on traditional techniques, which include autoclaving, incineration, and deep burial. Among the various categories comprising regulated medical waste, microbiological waste, such as untreated cultures, stocks, and amplified microbial populations, presents the highest potential for transmitting infectious diseases. At the same time, sharps carry the most significant risk of causing injuries (Agbere *et al*., 2021). Untreated stocks and cultures of microorganisms are part of the clinical laboratory or microbiologic waste stream. Suppose it is necessary to cultivate and amplify the microorganism to a high concentration for working with the specimen. In that case, it is advisable to consider on-site decontamination, preferably within the laboratory facility. In the past, this was achieved through autoclaving (steam sterilization) or incineration. In the case of using steam sterilization in a healthcare facility for waste treatment, it may be necessary to expose the waste to temperatures of up to 250°F

(121°C) in an autoclave for up to 90 minutes, depending on the load size and container type, to ensure thorough decontamination. Following steam sterilization, the residue can be safely managed and disposed of with other non-hazardous solid waste in compliance with corresponding solid-waste disposal regulations. Improper incineration of waste with high moisture and low energy content (e.g., pathology waste) can result in emission issues. State medical-waste regulatory programs specify approved methods for deactivating amplified stocks and cultures of microorganisms, some of which may involve technology rather than steam sterilization or incineration (Egbenyah *et al*., 2021).

Microbial wastes or equipment contaminated with microbial specimens can be treated using chemical disinfectants like alcohol, glutaraldehyde, hypochlorites, hydrogen peroxide, ortho-phthaldehyde, phenolics, and quaternary ammonium compounds. Besides chemical disinfection, exposure to UV light also leads to the disinfection of microbial wastes in many cases. Table 1 briefly overviews the different disinfectants, their effective concentrations, and associated advantages and disadvantages.

Table 1. Activity of different disinfectants in microbial waste management

Disinfectant	Effective concentration	Activity	Disadvantages	References
Alcohols	60 – 90%	Bactericidal Fungicidal Virucidal	Unable to destroy bacterial spores	Ali *et al*., 2001
Sodium hypochlorite	1:10 dilution of 1.25% to 6.15% solutions	Antimicrobial disinfectant	Skin irritant	Rutala*et al*., 2006
Glutaraldehyde	2% or more	Bactericidal Fungicidal Virucidal Sporicidal	Too toxic and expensive	Mbithi *et al*., 1993
Hydrogen peroxide	3-6%	Bactericidal Fungicidal Virucidal Sporicidal	Skin irritant	Mahaseth *et al*., 2017
Ortho-phthalaldehyde	0.3%	Better activity as compared to glutaraldehyde	Turns exposed skin into a grey colour	Miyajima *et al*., 2010(16)
Phenols	-	Bactericidal Fungicidal Virucidal Tuberculocidal	Causes hyperbilirubinemia in infants	Tyan *et al*., 2022
Ultra-violet rays	100-280 nm	Bactericidal Fungicidal Virucidal	Low efficiency in the presence of organic matter	Rastogi *et al*., 2007

Incineration is the best possible method among all the available microbial waste management methods. Incineration relies on high temperatures to eliminate pathogens and break down the waste materials in which these harmful microorganisms colonize (Mattiello *et al*.,2021). On-site incineration is another treatment option for microbiologic, pathologic, and anatomic waste, provided that the incinerator is designed to completely burn these types of waste and adhere to environmental protection agencies emissions standards. While this method effectively neutralizes pathogens, it generates a range of hazardous by-products, notably incomplete combustion products and dioxins. During the incineration process and subsequent cooling phase, the various components of the waste disintegrate and recombine, giving rise to new particles known as PIC. These PIC particles are toxic and pose a significant environmental threat. Furthermore, the metals present in the waste are not destroyed by incineration; instead, they are dispersed into the environment, leading to serious health concerns (Datta *et al*., 2018). Among the hazardous by-products, dioxins are a particularly concerning group. Dioxins are unintentional by-products of waste combustion that are produced during the operation of incinerators. This group comprises 75 different chemicals and coexists with another set of toxins known as furans. One alarming characteristic of dioxins and furans is their tendency to accumulate in fatty tissues, and they can subsequently move up the food chain, posing risks to both human and ecological health (Chen *et al*, 2021).

A significant contributor to environmental dioxin production is the incineration of medical devices constructed from polyvinyl chloride (PVC) (Vilavert *et al*., 2015). This material, when incinerated, releases significant amounts of dioxins into the atmosphere. Furthermore, the metals in medical wastes catalyze dioxin production during incineration. The dioxins have an extensive half-life of 7 – 11 years, thus making them persistent in the environment (Schecter *et al*., 2006). The toxicity of dioxins cannot be overstated; they are well-documented carcinogens and have been linked with damaged immune and endocrine systems in humans. In summary, the initial solution for microbial waste disposal through incineration, which gained popularity in India in the late 1990s, presents a range of serious environmental and health concerns. While it effectively eliminates pathogens, it generates toxic by-products such as PIC and dioxins. The dispersion of metals into the environment also contributes to health issues. Dioxins are highly toxic and can accumulate in the food chain, posing a significant risk to human and ecological well-being. Therefore, alternative, and more environmentally friendly methods for microbial waste disposal should be explored to mitigate these harmful consequences associated with incineration (Datta *et al*., 2018, 21).

Advanced technologies for the treatment of microbial wastes

Incineration offers a better solution than other methods, as discussed above. However, considering the environmental impacts it poses, researchers shifted their attention toward cleaner technologies for treating microbial wastes generated from the hospital sector. This includes pyrolysis, microwave technology, pressure steam sterilization, plasma technology, and torrefaction. Table 2 accounts for different advanced techniques for microbial waste treatment and their advantages and shortcomings.

Table 2. Advantages and shortcomings of advanced technologies for the treatment of microbial wastes in healthcare settings.

Treatment techniques	Advantages	Drawbacks
Pyrolysis	Limited generation of pollutants as compared to incineration	Produces toxic dioxins, energy-demanding process
Microwave	It prevents loss of heat and reduces environmental pollution	High cost
Pressure steam sterilization	Complete degradation of microbial wastes, Cheap, Low maintenance	Limited waste processing capacity Releases several toxic pollutants
Plasma sterilization	Pollution-free, Insignificant residue formation	Energy intensive and High cost of operation
Torrefaction	Efficient depolymerization of biomass	Time and temperature-dependent

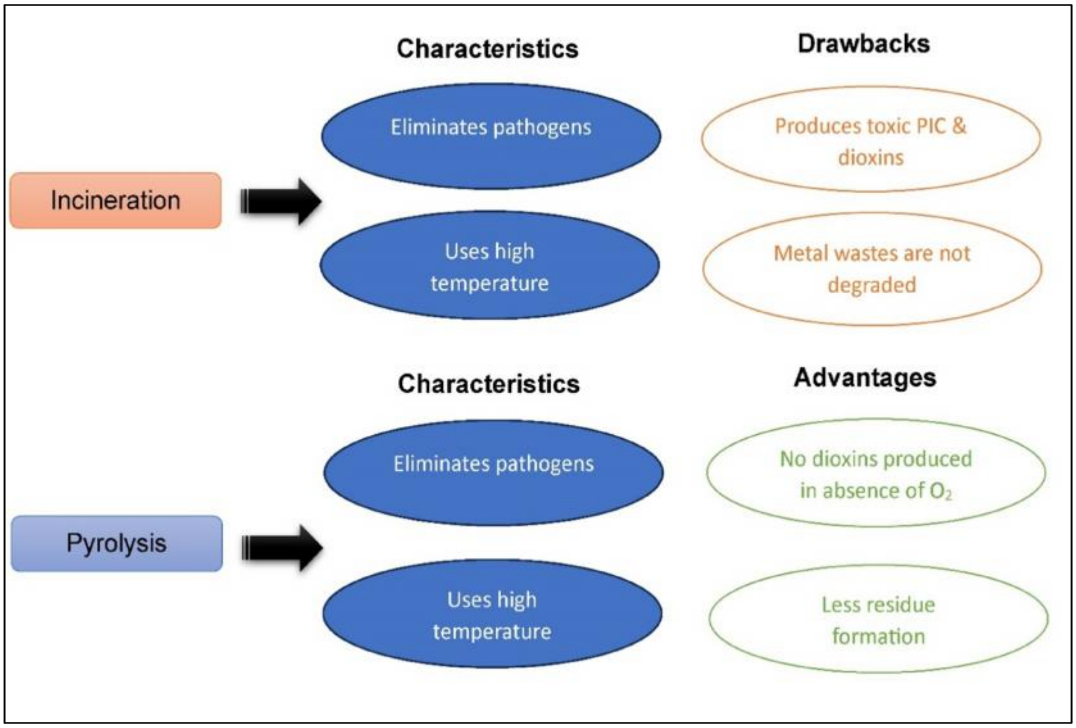

Figure 3. Advantages of Pyrolysis over incineration process.

Pyrolysis

Pyrolysis involves the use of high temperatures (540 – 830°C). The process converts organic wastes under oxygen-deprived or limiting conditions into gases or liquids with combustible properties (Datta *et al*., 2018). The efficiency of the pyrolysis process is dependent on conditions like temperature and time. Besides, it also depends on the pyrolyzed wastes' humidity content and particle size. Although pyrolysis produces dioxins, it can be minimized by performing it without oxygen or by eliminating acid gas (Xu *et al*., 2020). As an advanced technique, pyrolysis has several advantages over incineration and is preferable (Dharmaraj *et al*., 2021; Khaskhachikh *et al*., 2021). Figure 3 provides an overview of the advantages of pyrolysis over the traditional incineration process.

Microwave technology operates within a medium temperature range (177 - 540°C) and utilizes high-energy microwaves (wavelength ranging between 1 mm to 1 m). The microwave disinfection technique uses a nitrogen atmosphere within, thus preventing the combustion of oxygen and reducing the loss of heat and pollution of the environment. Some specially designed microwave equipment can neutralize SARS–CoV2 (Wang *et al*., 2020). Such microwaves can facilitate on-site disinfection of COVID-19 microbial wastes, thus reducing the hazards related to their transportation (Ilyas *et al*., 2020).

Pressure steam-based sterilization

This technique processes crushed wastes contaminated with microbial entities for 20 minutes at 121°C and 100 Kpa. The large amount of steam generated penetrates the wastes, thus denaturing the microbial proteins. The decontaminated waste materials can then be further processed for incineration or landfilled. The technique is cheap and has low maintenance costs, but it faces several drawbacks. These drawbacks include the limited volume of waste processing and the release of several toxic chemicals (Cai & Du, 2021).

Plasma sterilization

The plasma sterilization technique utilizes a two-step combustion process wherein a gas cloud is obtained from the ionization of an inert gas. The gas is composed of charged particles that release enormous heat when an electric current passes through it. The resultant heat creates high temperatures (up to 3000°C), thus rapidly heating the microbial wastes. The first combustion cycle leads to the generation of gases such as carbon dioxide, hydrogen and alkanes. The second combustion cycle destroys any microbes if present. It leads to almost zero pollutant production and a significant decrease in residues, which can be safely used for landfills. Moreover, the heat energy produced in the process can be recycled (Cai & Du, 2021; Erdogan & Yilmazoglu, 2021), thus providing a sustainable option for the energy balance. The only demerit is the cost of operating a plasma sterilization unit, which requires a lot of energy.

Torrefaction

Torrefaction is generally used for depolymerizing biomass such as cotton wastes from medical or clinical sources. Cotton is highly rich in cellulose (~95%), is quite challenging to degrade, and can be easily carried out by this process. Residence time and temperature collectively define the degree of torrefaction. The residence time in a torrefaction reactor starts only when the biomass reaches 200°C (Giakoumakis & Sidiras, 2017).

Conclusion

Microbial wastes generated from healthcare facilities are highly contagious and threaten public health. Pandemic situations like COVID-19 have even increased microbial waste generation in the healthcare sector, thus making their management a critical issue. Traditional methods of managing microbial wastes have become obsolete and pose the risk of further environmental pollution, thus putting the life of the regular public at risk. Research in this regard has given way to several advanced methods that pose fewer risks to human health and are environmentally sustainable. The advanced techniques still need certain drawbacks, like the high establishment and maintenance costs. Further research in this regard is necessary to make these advanced techniques even better. This would help create a sustainable environment and prepare us for large-scale microbial waste management in another pandemic like COVID-19.

Abbreviations used:
CPCB- central pollution control board; WHO- World health organisation; PVC- polyvinyl chloride.

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Conflict of Interest:

The First author has maintained all the rice lines, as Research Associate, PMCG Section, Bose Institute. There is no conflict of interest with anybody or organization.

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