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Online ISSN: 2992-5487
Print ISSN: 2992-6068

NIJEP
Publications

NEWPORT INTERNATIONAL JOURNAL OF ENGINEERING AND PHYSICAL SCIENCES (NIJEP)

Volume 5 Issue 1 Page 7-12, 2025

https://doi.org/10.59298/NIJEP/2025/51712

Engineering Solutions for Reducing Healthcare Waste

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ABSTRACT

Healthcare waste management is a growing global challenge, particularly in developing nations where infrastructure and regulations are often inadequate. Improper disposal of hazardous medical waste poses significant health and environmental risks, necessitating innovative engineering solutions. This paper examines the role of engineering in minimizing healthcare waste through sustainable facility design, advanced waste treatment technologies, and strategic waste management practices. Case studies of successful implementations highlight the effectiveness of engineered solutions in reducing medical waste, improving public health, and promoting environmental sustainability. Future opportunities for integrating emerging technologies and collaborative approaches are also discussed, emphasizing the need for policy support, investment, and continuous innovation in healthcare waste management.

Keywords: Healthcare Waste Management, Sustainable Engineering, Waste Treatment Technologies, Environmental Sustainability, Biomedical Waste, Green Hospital Design, Waste Reduction Strategies.

INTRODUCTION

Healthcare waste generation is becoming a major problem throughout the world, and the situation is deteriorating in the least developed nations. Increasing concerns regarding public health and the environment are emerging, together with the increased volume of waste generated by healthcare facilities. Used sharps and body parts, bags, and patient excretion are among the most prevalent waste groups in hospitals, accounting for 70-90% of total waste recorded. Health care waste (HCW) includes a broad array of hazardous and non-hazardous materials. Specific disaster is represented by dangerous substances, which may have implications for those who come into contact with them. Improper handling of HCWs can lead to an enhanced transmission risk. The issue has gained policy priority in recent times, particularly in developing nations, but little progress has been made to establish policies and regulations at both the national and regional levels. Efforts to protect public health from the risks posed by healthcare waste management have made progress in recent years. As a consequence, the significance of finding new and creative solutions in healthcare waste management has been highlighted, with the role of technical research in engineering contributing to the monitoring and control of healthcare waste collection. The strategic path forward considers the present state of healthcare waste management and outlines the requirements for better healthcare waste management. Healthcare management and technical engineering strategies must be combined to achieve these needs. Additionally, technological research and growth, conventional guidance, and other applicable sectors must work together in this field on the determination of efficient strategies to create general recognition and understanding. As an attempt to cover today's critical waste management concerns, limitations, and possible combat strategies, this work needs to raise awareness and start a discussion [1, 2].

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Current Challenges in Healthcare Waste Management

The growth of the global population, the management of healthcare waste (HCW) is a contemporary challenge worldwide. The need to care for human health has led to complex medical processes and in consequence, to the wider relationship between the productions of medical waste. After vaccination, a significant part of the syringes and needles used are dropped in hospital trash. The waste is mixed with household waste, which significantly worsens the environmental situation in countries with poor economic conditions. Over the years, with the increasing number of vaccinations, the problem will be more serious. Healthcare facilities (HCFs) produce a large amount of healthcare waste (HCW). HCW is defined as all types of waste generated from health-care activities. It is estimated that healthcare waste (HCWs) constitute approximately 1 to 2% of the total urban waste produced in the world. There are also reports that in some countries, the share of urban waste generated as a result of health care actions is even 10% [3, 4]. In poorer countries, on average, one in ten patients is exposed to unsafe waste injections, and that can result in more than 30% of all new infections with HIV. A total of 85% of the total amount of waste generated as a result of health-related activities is not hazardous. The remaining 15% is hazardous, infectious, radioactive, or toxic waste. High-income countries produce up to almost 11 kg of hazardous waste per hospital bed per day, while in low-income countries, the rate of waste production is up to 6 kg. In various European countries, the production range of HCWs is 0.5-2 kg. Economic conditions play an important role in the management of HCWs. Problems in the proper management of HCW are more prevalent in low-income countries that generate a total of several hundred tons of waste. In some low-income countries, 20% of the waste generated by HCFs is HCW, and this waste is mixed with general waste. Studies on the problem performed in Ethiopia have shown that 35% of HCW-producing health care institutions in that country collect and dispose of needles, syringes, and other sharp objects to put HCP and the general population at risk in a proper manner [5, 6].

Role of Engineering in Healthcare Waste Reduction

Healthcare waste is a broad category of wastes derived from medical activities within hospitals, clinics, and other sites devoted to healthcare. In a hospital setting, the amount of waste generated is substantial and with a variety of types. The waste generated in healthcare facilities consists of plastic, rubber, glass, metals, paper, cloth, and organic materials. The category also includes biomedical waste, a hazardous subcategory of healthcare waste. Engineering professionals can be part of the solution by "innovating new technologies, devices, and/or integrated systems to solve complex problems". One of the ways the existing waste can be minimized is to design healthcare facilities to enhance waste management. The design of facilities can serve as the foundation for the proper installation of systems and processes vital for efficient and sustainable waste management. Designers and engineers of healthcare facilities should incorporate sustainable practices and technologies in the design process to reduce the amount of waste and to ensure its proper treatment [7, 8]. By altering how healthcare facilities are designed, the generation of waste can be diminished. The layout of a healthcare facility and the technologies used in it can exacerbate or alleviate problems normally faced with the management of waste. Engineering professionals can help in the reduction of healthcare waste and its proper treatment through a collaboration with healthcare professionals. This collaboration can provide an understanding of both the waste generated and the requirement imposed to create a viable solution. The design of healthcare facilities can be realized to address sustainability challenges faced with the management of healthcare waste through new and innovative approaches either in design or in technology. After the current preliminary insight, healthcare waste management, sustainable facility design, and waste treatment technologies will be further elaborated [9, 10].

Designing Sustainable Healthcare Facilities

Design of sustainable healthcare facilities is fundamental to the ecologically-friendly management of any healthcare system. In the United States, construction activity in the healthcare industry generates an estimated 7,000 tons of waste each day, costing nearly half a billion dollars annually for waste disposal. Considerations of green building practices must be brought into the early planning phases of new construction and large renovation projects. Healthcare facilities have high material and energy intensity, so the use of environmentally responsible building design is of paramount importance. LEED certification and other green design building rating systems can be of great use to facility managers with little knowledge of green building to understand all the components of green design building. The need for environmentally friendly building designs is to design buildings that consume resources, and materials

efficiently, and provide for low waste generation during construction and operation as well as the reutilization of waste products. In recent years the last function has been subject to consideration under the so-called EPA's resource recovery hierarchy. Traditionally, building designers recognized building waste as the off-cuts of materials used in the construction process. Development of waste management systems focuses on strategies for reducing such waste, namely designs that allow for efficient separation and the recycling of excess materials [11, 12]. Hospitals and clinics now account for a growing percentage of the large commercial buildings in the United States. Over 145 million Americans visit a hospital a year, and over 28 million undergo outpatient surgery each year. The cold, harsh lighting, constant noise, and lack of scenic views of many healthcare facilities can create a stressful and uncomfortable environment. A case study has shown that biophysically sound and sustainable architecture can not only improve operational efficiency and healthcare delivery but also increase directly related measurements of wellness, productivity, and safety. As a result, it is extremely important for architects and engineers to become involved in the planning process of healthcare facilities in order to implement design strategies that can create eco-friendly, high-quality buildings, enhancing regional care. With thoughtful and careful planning, the development of sustainable healthcare infrastructure can significantly reduce the environmental impact of healthcare delivery while improving the well-being of the people who are most in need of care [13, 14].

Innovative Waste Treatment Technologies

Introducing innovative techniques to treat healthcare waste effectively is crucial. It will improve the segregation and processing of healthcare waste into the categories of hazardous and non-hazardous waste. Novel technologies may reduce the health risks associated with malpractices in treating healthcare waste. Limitations of these approaches may also remain, particularly for developing countries. This is emphasized by different experts in healthcare waste, who implied the need for technological development in the treatment of healthcare waste. Engineering is crucial for the development of appropriate technologies with the required quality standards for treating healthcare waste to reduce the health risks to the general population and to almost eliminate the residual environmental impact of most technologies. The country should encourage the development and use of innovative technologies to treat healthcare waste. Alongside this, it is important to encourage the use of new technologies to treat healthcare waste effectively so that the general population can obtain the benefits of this development [15, 16]. A range of available innovative and under-development waste treatment technologies have been considered. Developed countries have already explored a variety of technologies, some of which are further evolving. These include traditional methods such as incineration and autoclaving, microwaves, and chemical disinfection. Further innovative technologies such as plasma gasification and pyrolysis continue to be developed. Newer technologies include shredding and ground hydroclave. Technologies that use steam, solvents, or both devices to treat waste and achieve the sterilization of recycled products have been developed. Similarly, waste treatment technologies with microwave use are under development. There is a trend to encourage the organic disinfection of healthcare waste. However, it would be advisable to ensure that adequate testing is carried out on the respective application pathogens, and this process should mimic the standard procedures for the medical devices' sterilization process to avoid possible risks. New waste treatment technologies are continuing to develop for the treatment of each type of medical waste to produce low health hazards and to minimize the impact on the environment. Some waste-to-energy technologies are believed to be economically more feasible and will take into account the energy efficiency of the process. The government should encourage research and development in the field of healthcare waste treatment. Naturally, these postures are motivated by the underlying appreciation that engineering solutions offer alternatives to the current, cost-intensive, health-hazardous disposal practices and that they can provide a general boost to a developing society's technical adequacy and infrastructure efficiency [17, 18].

Case Studies of Successful Engineering Solutions

The case studies will showcase real-world applications of successful engineering solutions. These solutions have been implemented in different healthcare systems, and they cover different waste challenges. The context, the engineering solution, the achieved results, and the lessons learned are presented concisely. The case studies have resulted from collaboration with different stakeholders. The metrics and indicators have been used, and the effectiveness of the engineering solutions is assessed. The aim is to inspire other healthcare providers and stakeholders to implement innovative engineering

strategies, to better understand the role of each stakeholder, and to provide information about what needs to be improved. Furthermore, a reflection on the most important factors that have influenced project implementation is made. The selected cases have considered different waste compositions, volumes, and management practices, and they may help other healthcare providers and stakeholders identify the most appropriate engineering interventions. In short, these cases demonstrate the positive outcomes that engineering solutions may bring in terms of waste reduction and management efficiency in healthcare facilities [19, 20].

Future Trends and Opportunities

Healthcare waste management as an engineering discipline is still under development. Various areas of focus and challenges encountered based on the lack of engineering applications are discussed below. This narrative review suggests better addressing the existing and emerging problems through engineering means. Healthcare activities lead to waste production, with 85% being general and 15% infectious. Medical waste is unique in terms of its hazardousness compared to municipal solid waste and industrial waste, leading to national classifications and rendered riskier by the incapacity to resort to recycling techniques, while its incineration, the most common management practice, is targeted by regulations. This state of recognition, combined with the current inadequate operations, is considered illustrative of the underestimated engineering aspects of the whole process management. Staff of the health sector lack training. The multi-step safety protocol is executed in a poor discard infrastructure. Manufacturers aim at selling increasingly complex products, while regard for their after-use is limited. Policies, in turn, don't sufficiently prioritize R&D directions. A global assessment report is missing, and volumes at non-pandemic times had never seriously been faced with any-willful responsible action at any of the steps so far [21, 22].

RECOMMENDATIONS

Effective management of healthcare waste is crucial for safeguarding public health and ensuring environmental sustainability. The potential of engineering solutions for healthcare waste management in Bangladesh has been analyzed. The conclusion is drawn considering all the empirical investigations and research findings related to healthcare waste management. National and international data and evidence have been correlated to reveal the critical needs that must be addressed. Given the toxic and hazardous attributes of healthcare waste, its inappropriate management can lead to severe health problems for healthcare providers, patients, waste handlers, and the wider community. Healthcare waste also adversely externalizes environmental health risks. Recognizing the adverse repercussions of healthcare waste, healthcare waste management guidelines have been institutionalized by the Government of Bangladesh, focusing on waste minimization, waste segregation, treating waste at source, safe handling, decontamination, and disposal of healthcare waste. However, existing healthcare waste management guidelines in Bangladesh have not addressed most of the healthcare waste management issues effectively. Healthcare waste management is critically neglected compared to waste collection, segregation, transportation, and disposal. As an alternative disposal method, open burning is suggested by the existing guidelines, which is highly controversial due to its environmental pollution and public health implications. Comprehensive healthcare waste management action is required to reduce the risks and threats posed by healthcare waste. The proper adoption of engineering solutions could play a vital role in risk reduction, environmental health assurance, and environmental sustainability. Engineering solutions for waste management comprise varied dimensions, encompassing symbolization (e.g. color-coding for different waste categories), separate bin facilities, incineration facilities for healthcare settings, autoclave to treat sharps/other plastic waste, shredder for sharps waste, shredder for plastic waste, and reliable dust control system for incineration facilities. Evaluation of healthcare waste management from an engineering perspective can foster validation of effective working models and subsequently can enhance the formulation of policy or recommendations to improve healthcare waste management status. Considering these contexts, a number of viable recommendations are suggested for implementing healthcare waste management engineering solutions that could have a lasting and extensive impact. Interplays are essential in the effective execution of these recommendations and the transformation of an action plan for healthcare waste management in Bangladesh. Collaboration is critically needed between healthcare service providers, relevant engineers, waste management experts, and policymakers. The stratification states the need for the investment in contemporary technologies and sustainable practices for the environmentally sound disposal of healthcare waste. The training and awareness regarding the

guidelines of healthcare waste management are needed to be dispersed to the healthcare providers. Counting on the hospital space limitation and varied capacities, an encouragement is required for the expansion of existing hospital waste management facilities. Ongoing training and awareness should be provided for healthcare workers to consolidate and sustain the waste management procedure. In 27,000 small clinics throughout Bangladesh, segregation is surprisingly low because weekly waste collection occurs only in 1% of clinics. Non-rural areas and presence of a doctor increases the odds of proper waste disposal by more than half. Furthermore, patients often respect doctors, which is instrumental in behavior change efforts. Capitalizing on doctor-patient relationships can help reduce societal risk and foster new habits of trash disposal. To reinforce waste reduction efforts in healthcare wastage, constant supervision and monitoring are fundamentally required to guarantee an appropriate disposal and treatment of healthcare wastage. Modern technologies and waste management practices should be gradually capitalized and synchronized with the broader hospital waste management strategy. Considering the healthcare waste management data to propose appropriate policies or recommendations for better engineering of healthcare waste management where there is a severe lack. Hence, the data must be collected throughout the country employing a national healthcare waste management program. Besides, the specific recommendation for healthcare waste needs to be treated by the appropriate engineering approach. Both analysis indicates a broader progress of the healthcare waste management problem that can pave the way for a solving strategy and eventually catalyze command over healthcare waste [23, 24].

CONCLUSION

Effective healthcare waste management is crucial for protecting public health and the environment. Engineering solutions provide innovative pathways to address this challenge through sustainable facility design, advanced waste treatment technologies, and improved waste management practices. Case studies demonstrate that the successful implementation of these strategies can significantly reduce medical waste while ensuring regulatory compliance and environmental responsibility. Future advancements in healthcare waste management should focus on integrating emerging technologies, fostering collaboration between engineers and healthcare professionals, and implementing comprehensive policies. By prioritizing engineering-driven solutions, healthcare facilities can enhance waste reduction efforts, minimize environmental impact, and contribute to a safer, more sustainable healthcare system.

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CITE AS: Mubanza Zunguka J. (2025). Engineering Solutions for Reducing Healthcare Waste. NEWPORT INTERNATIONAL JOURNAL OF ENGINEERING AND PHYSICAL SCIENCES, 5(1):7-12. https://doi.org/10.59298/NIJEP/2025/51712