

## Sustainable Healthcare Infrastructure: An Indigenous Incinerator Design Model For Hospital Waste Management In Pakistan

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### Abstract

Healthcare institutions produce large amounts of toxic biomedical waste, such as infectious waste, pathological wastes, and contaminated equipment. When such waste is improperly disposed it can be very dangerous on population health and safety. Another difficulty in biomedical waste management in developing countries like Pakistan is the inadequate infrastructure, poor enforcement of the regulations and absence of standardized treatment plants. Research has indicated that a number of hospitals in Pakistan do not have an effective incineration plant; or have poor locally made systems, which do not meet the international environmental standards. One of the most popular ways of treating infectious medical waste is still hospital waste incineration, as it is the most efficient way of destroying the pathogens and making the mass of the hazardous materials significantly lower. The operation of modern incinerators is based on the principles of dual-

chamber combustion whereby the waste is first burnt in a primary chamber at the temperatures of between 600 -800 °C and then the secondary combustion is done at temperature that is above 900 C to make sure that the harmful emissions are completely destroyed. This study will help to investigate the construction and design of a localized hospital waste incinerator in the health care infrastructure of Pakistan. The paper focuses on architectural, environmental and technological factors when coming up with a cost effective, environmentally responsible and contextually suitable solution. The design proposed is targeted to use locally available materials, energy efficiency, environmental standards, and flexibility to small and medium-sized healthcare facilities. The proposed research incorporating principles of healthcare design with

sustainable waste management strategies will help to enhance the Pakistani hospitals in terms of infection control, environmental protection, and operational efficiency. The results will give architects, medical planners, and policymakers a viable conceptualization when building safe and affordable medical waste treatment systems in resource constrained environments.

## **Introduction**

### **BACKGROUND**

Healthcare facilities are crucial centers used to safeguard and enhance the health of the people but this also produces considerable amounts of dangerous waste that demand special handling mechanisms. Examples of biomedical wastes generated in hospitals are infectious, pathological tissues, infected sharps, pharmaceutical wastes, and residues of chemicals that can be fatal to human life and the environment unless properly disposed. Infrastructure Management of healthcare waste is thus a significant part of hospital infrastructure and environmental health systems in the world. The study shows that medical waste inappropriate handling and disposal could spread infectious diseases, pollute the environment, and present occupational health risks to medical professionals and waste managers (Chartier et al., 2014; Caniato, Tudor, and Vaccari, 2015).

Medical waste in healthcare sector is produced in millions of tons over the world each year and much of this waste must be treated properly before it can be disposed of. Incineration is among the most popular waste disposal methods used to destroy infectious and hazardous medical waste among all other technologies of waste treatment. By burning it can generate a 90 percent volume of waste and by combustion at high temperatures it destroys pathogens. The modern medical waste incinerators use a two-chamber combustion system, which means that the waste is initially burned in the primary chamber and the gasses are completely oxidized in the secondary chamber (Chartier et al., 2014; World Health Organization, 2014). The relevance of effective management of biomedical waste is especially high in developing cases when medical facilities are under-funded and regulatory controls still have insufficient strength. Pakistan is a classic example of a country in which the accelerated growth of healthcare facilities has resulted in more waste production without a change in the waste treatment facilities. Research has approximated that healthcare wastes produced in hospitals across Pakistan amount to very large amounts per year, whereas most health facilities do not have proper procedures by which they can segregate, treat and dispose of such wastes (Kumar et al., 2010; Ali, Wang, and Chaudhry, 2017).

A number of research studies carried out in Pakistani hospitals have emphasized a lot of weaknesses in the current waste management measures. As an illustration, investigations in tertiary care facilities have exposed that most of the facilities do not have efficient incinerators or they have old-fashioned ones which are not worth the required environmental safety. In other instances, hospital waste is either moved out of location without treatment or they are burnt or dumped freely. These practices contribute to heightened chances of contamination of the environment and transmission of diseases to the immediate communities (Malik, Mehmood, and Mahmood, 2022). The other problem, which is also critical with medical waste management in Pakistan, is the design and inefficiency of locally produced incinerators. Although some hospitals have incinerators that are locally made because of financial reasons, most of them miss some of the necessary requirements like a system to control the emissions, second burning chamber or a temperature regulator. Consequently, they might emit toxic pollution such as heavy metals and particulate matter into the atmosphere. Hazardous metals in ash generated by hospital incinerators have been detected in the environmental studies carried in Islamabad and Rawalpindi, and this has led to environmental hazards surrounding ill-designed systems (Khan, Bibi, and Ahmad,

2008).

Besides technology constraints, spatial and architectural assimilation of waste management systems in healthcare institutions is an understudied subject in Pakistan. Hospitals are more complicated structures and functional planning, infection control, and environmental sustainability should be well-balanced. Zoning of waste treatment facilities including incinerators, location, accessibility, ventilation and safety should be given a deliberate architectural consideration. An improperly designed incinerator systems may generate operational problems, environmental risks, and adverse effects among the neighboring communities (Ulrich et al., 2008). The international organizations like the World Health Organization advise the healthcare waste incinerators to be constructed under strict environmental and operational guidelines, such as sufficient temperatures, retention periods, as well as air pollution management systems. The general design rules include primary combustion chamber with temperatures ranging between 600 -800 o C and the secondary operating at temperatures between 900 and 1200 o C with adequate retention time so that the hazardous gases are completely destroyed (Chartier et al., 2014).

To developing nations with scarce resources, however, it can be economical to conduct advanced systems of waste treatment. This state of affairs demonstrates the necessity to develop local solutions which are economically viable, technically competent and responsive to local conditions. Native design solutions involve the utilization of local materials, easier methods of construction, and systems of operation that can be serviced with current technical capabilities. They can be applied to spend a lot less on installation and enhance the sustainability and accessibility of small and medium healthcare facilities (Caniato et al., 2015). Concerning Pakistan, an urgent study should be conducted, which will combine the principles of architectural designs with healthcare waste management technologies.

This study is thus aimed at designing an indigenous hospital waste incinerator that can fit the Pakistani healthcare facilities. The paper discusses design parameters in respect to combustion technology, spatial planning, environmental safety and cost effectiveness. The research will integrate the architectural design methods with the biomedical waste management concepts to come up with a viable and sustainable solution that will help the hospitals dispose of the hazardous medical waste safely without causing a lot of environmental damage. Finally, context-specific healthcare infrastructure should be developed to enhance the development of the healthcare system in developing states. Offering an original indigenous-inspired approach to incinerators designed to suit the requirements and limitations of Pakistani hospitals, the given study aims at making a contribution to enhancing the healthcare waste management framework and advancing the environmentally friendly healthcare infrastructure construction.

## **PROBLEM STATEMENT**

Healthcare facilities produce large amounts of biomedical waste that is dangerous and has to be treated and disposed in a proper manner to safeguard human health and the environment. Such waste usually consists of infectious wastes, pathological wastes, medications, and infected sharps that could deliver the diseases in case they are not handled well. The World Health Organization has claimed that about 15-20 percent of the total healthcare waste is termed as hazardous and needs special treatment methods like incineration to avoid environmental pollution and disease spreading (Chartier et al., 2014). Nonetheless, in most developing nations, such as Pakistan, the healthcare waste management practices stay inefficient because of the poor infrastructure, the low effect of regulations, and lack of technical capacity (Ali, Wang, and Chaudhry, 2017). The swift development of health care services in Pakistan has had the effect of raising the level of biomedical waste generated but in most cases the hospitals do not have well-designed treatment units. The current incinerators deployed in healthcare facilities

are generally locally made appliances which do not burn at recommended temperatures and do not have other important features like secondary combustion chambers and emission control facilities (Kumar et al., 2010). The environmental research has also shown that environmental unfriendly heavy metals exist in any given ash generated by poorly designed hospital incinerators, which could pose serious risks to the environment and the nearby communities (Khan, Bibi, and Ahmad, 2008). Besides, architectural and spatial incorporation of waste treatment facilities in hospitals settings is also yet to be taken seriously in the planning of healthcare facilities in Pakistan. This has led to poor waste disposal methods by most health facilities including open burning or indiscriminate dumping. Thus, it is urgently required to come up with an economically viable, environmental friendly, and context-oriented design of indigenous incinerator that can enhance the healthcare waste management system, yet fit within the context of operational and infrastructural constraints of hospitals in Pakistan.

### **RESEARCH OBJECTIVES**

Following were the major key research objectives set forth:

To evaluate the current challenges along with root causes in hospital waste management and the role of incineration in it.

To develop a context sensitive incinerator design for the hospital waste incineration through a cost effective model.

### **RESEARCH SIGNIFICANCE**

The management of healthcare wastes has evolved to be a major issue of concern among the community health authorities, environment officials, and healthcare planners across the whole world. The biomedical waste produced in hospitals can pose serious effects on the environment, as well as on health, because of the infectious pathogens, poisonous chemicals and contaminated materials that can have a severe impact on the environment in case they are not disposed of properly. In developing economies like Pakistan, handling of this waste has been a thorn on the flesh because of the inadequate infrastructure, lack of financial capability and inefficiency in the institutional implementation of the environmental laws. The research carried out within Pakistani health care institutions suggests that a big percentage of hospitals do not have the right waste treatment procedures leaving them to unsafe disposal methods like open dumping, uncontrolled burning, and transportation without treatment.

The relevance of this study is that it will fill the gap between medical waste production and the presence of safe treatment facilities. Incineration is also among the most efficient technologies of treatment of infectious medical waste due to the ability to kill pathogens and the reduction of the volume of waste to a minimum. Nevertheless, a lot of the current incinerators in Pakistan are not well-designed or do not work within the recommended environmental standards. These systems can also emit toxic substances or leave dangerous ash products, which could cause pollution of the environment and threat to human health. A study of incinerator ash in the hospitals of Islamabad and Rawalpindi has shown that heavy metals are present in the garbage and this shows how waste treatment systems must be designed to meet the environmental requirements of the population. The other crucial dimension of this study is associated with the architectural and infrastructural features of waste management at hospitals. Healthcare facilities are built environments that are complex and safety, hygiene, and operational efficiency should be well coordinated. The location and construction of garbage treatment plants like incinerators have direct impact on the control of infections, safety of personnel and environmental performance in hospitals. Although it is critical, the concept of waste treatment systems integration into the healthcare architectural design has been under-researched in Pakistan.

This study is thus of relevance to the field of healthcare architecture as well as environmental management in that it proposes a model of an indigenous incinerator

design based on the Pakistani context. The paper highlights the adoption of the locally available resources, reduce construction processes, and efficient energy consumption systems to create a cost-efficient solution that can be applied in small and medium healthcare centers. This will greatly decrease the financial cost that comes with the importation of costly waste treatment technologies and at the same time guaranteeing adherence to the environment standards.

Besides, the study gives viable advice to architects, engineers, and health care planners who may be tasked with designing hospital infrastructure. The research provides a framework on how waste treatment systems are to be integrated into the planning process of hospitals by emphasizing the use of important design parameters such as the combustion efficiency, zoning of the space, control of emissions and the safety of the operations. This interdisciplinary strategy enhances the purpose of the architectural design in the solution of both environmental and the populace health issues in the healthcare buildings. Policy wise, the results of this study can assist the government bodies and health authorities to devise better policies of managing biomedical waste in Pakistan. The study can promote the use of local and context-specific technologies that could enhance the treatment capacity of healthcare waste in the nation by proving that locally designed incinerator systems are practical. Finally, the safe and effective waste management infrastructure will help to safeguard the healthcare workers, patients, and other communities around the hospitals against the risks posed by dangerous biomedical waste.

#### **LITERATURE REVIEW:**

Healthcare waste management has emerged as a significant environmental and community health issue across globe especially in developing nations where their waste treatment systems are usually ineffective (Zahra et al., 2025). The World Health Organization states that about 15-20% of all the waste produced in the healthcare system is hazardous and is subject to the specific treatment to avoid contaminating the environment and spreading the infection (World Health Organization, 2014). Unsafe waste generated in hospitals encompasses infectious substances, pathological substances, pharmaceuticals, sharps, and chemical remnants, which may spread the diseases in case they are poorly handled. Such waste, therefore, requires proper treatment and disposal, which are part of healthcare infrastructure and environmental protection initiatives (Bhatti et al., 2024).

Incineration is one of the most widely used technologies to manage biomedical waste where waste samples are burnt in regulated chambers under high temperatures (Shah et al., 2023). Waste is also greatly reduced in incineration as pathogenic microorganisms are destroyed in the process. Studies have demonstrated that well-operating medical waste burners have the potential to minimize the weight of waste by about 90 per cent and transform the dangerous substances into rather non-toxic residual ash (Chartier et al., 2014). Due to its effectiveness in destroying infectious waste, incineration remains common in hospitals especially in areas where other treatment methods like autoclaving or microwave system are not easily available (Bhatti et al., 2025).

In spite of its benefits, careful design and operations of incineration systems are necessary in order to avoid environmental pollution (Bhatti et al., 2025). It has been shown that the improper design or improper working of incinerators can cause harmful emissions such as particulate matter, dioxins, furans, and heavy metals to be emitted to the atmosphere (Khan, Bibi, and Ahmad, 2008). These emissions are very dangerous to the environment and can have an impact on air quality in the neighboring communities (Bhatti, Mujahid, et al., 2024). Thus, recent medical waste incinerators have played with dual chamber combustion, secondary combustion, and control of air pollution to make sure that all gases are completely burnt and low rates of toxic substances are emitted. A study carried out in Pakistan has therefore described critical deficiencies in the current healthcare waste management systems. In a study carried out

by Kumar et al. (2010), it was indicated that a high number of hospitals in Pakistan do not have good waste segregations and waste treatment facilities, which result in poor disposal habits. The infectious waste is in most instances combined with municipal waste, and dumped in open dumping sites or municipal landfills. These practices raise the chance of disease spreading, as well as environmental pollution.

The second study discussing the biomedical waste management practices in the Pakistani hospitals revealed that healthcare personnel lack the proper training regarding the waste segregation and handling practices in most cases (Malik, Mehmood, and Mahmood, 2022). Misplaced segregation of waste evokes low efficiency of the treatment technologies including incineration since both combustible and non-combustible materials get inter-mixed. Waste management systems thus need to have technological infrastructure and capacity building of institutions (Bhatti et al., 2024).

The problem of incinerator design and performance has been one of the issues that have been researched in various studies. A study carried out in Islamabad and Rawalpindi evaluated the environmental effects of medical waste incinerators and found out the existence of heavy metals in the ash waste products of incinerators (Khan et al., 2008). The results showed that the majority of hospital incinerators have temperatures that are lower than the suggested international levels leading to partial combustion and release of toxic pollutants. These results indicate that better incinerator design and operational surveillance is necessary. Medical waste incinerators have international guidelines that are used to provide specific operational parameters. A medical waste incinerator should have a primary combustion chamber with a temperature range of 600 -800 °C and a secondary chamber with a temperature of 900 -1200 °C with a minimum of 2s gas retention time to achieve complete combustion (Chartier et al., 2014). These are the standards of design that are vital in reducing the emissions of toxic gases and safe treatment of waste.

Besides the technology in combustion, another significant part of healthcare facility design is the architectural and spatial arrangement of incinerators in hospital facilities (Bhatti et al., 2025). The issue of waste treatment system placement in hospitals is a complex functional area that the positioning of the treatment system must be done in a careful manner to avoid compromising on safety, accessibility, and efficiency (Bhatti et al., 2022). Incorrect positioning of the incinerators inside hospital facilities could subject patients, visitors, and medical practitioners to damaging fumes or safety risks. The literature on healthcare facilities planning highlights the role of zoning waste management facilities in the peripheral locations of the hospital campuses without impacting on the ease of accessibility to waste transportation routes (Ulrich et al., 2008). The correct site planning would make sure that the waste treatment plants and the areas where patients are treated are isolated, and that these facilities are operational to the efficiency of the hospital staff.

Economic viability of incinerator systems is also another significant factor to be considered when developing countries (Bhatti et al., 2023). Most of the contemporary medical waste incinerators are costly and demand high operating and maintenance skills. Consequently, hospitals in the developing nations usually use locally produced incinerators that might not be in line with international environmental standards (Bhatti et al., 2025). The challenge also indicates the necessity of indigenous design solutions that are cost-effective and have better environmental performance. The use of indigenous technological development has also become a widely accepted method in dealing with infrastructure issues in resource constrained environments. Indigenous technologies have the potential to decrease the cost of construction and maintenance more than in other countries, using more accessible resources, and increasing the accessibility of the community of smaller healthcare institutions (Caniato, Tudor, and Vaccari, 2015). The case of Pakistan addresses the necessity of the interdisciplinary involvement of the architects, environmental engineers, healthcare planners, and policymakers in the development of an indigenous hospital incinerator. This type of

cooperation can contribute to the realization of the idea that the systems of incinerators do not only have to be technically efficient but also built into the infrastructure of hospitals.

Other studies carried out recently have highlighted the importance of sustainable healthcare design in considering environmental issues that are related to the activities of the hospitals. The purpose of sustainable healthcare infrastructure is to reduce the effects of the environment, enhance operational efficiency and safety of patients. Incinerators are waste management systems that are critical in attainment of these goals by ensuring hazardous waste undergo safe treatment and disposal. Moreover, the growing global concern with the environment sustainability has created even more stringent regulations of the medical waste incinerator emissions. Environmental standards that restrict the emission of particulate matter, dioxins and other pollutants can be adopted by many countries. Such standards have necessitated the design of incinerators, high efficiency in combustion as well as the application of emission control technologies.

The literature thus indicates that there are a few major gaps in the current healthcare waste management systems in Pakistan. These are poor design of incinerators, not following the environmental standards, poor incorporation of waste treatment systems in the architecture of hospitals, and financial issues that influence the use of modern technologies. In order to manage these issues, design solutions need to be novel and integrated to focus on environmental engineering and building planning.

## **RESEARCH METHODOLOGY**

This study uses a qualitative and design based approach to research on the development of an indigenous hospital incinerator that can be used in healthcare facilities in Pakistan. The methodology framework will combine and incorporate literature review, case study analysis and design development to suggest a context-fit incinerator model.

The initial stage of the study consisted of the comprehensive literature review on the current state of the knowledge in healthcare waste management, biomedical waste incineration methods, and planning of the hospital infrastructure. To find the important design parameters and operation standards of medical waste incinerators, academic journal articles, international guidelines and government reports were examined. The second step entailed research of the current practices of healthcare waste management in Pakistan. Published articles that analyzed the management systems of hospital waste were analyzed to establish the general difficulties that the healthcare facilities experience. Special interest was paid to the studies which were carried out in tertiary care hospitals and in the healthcare services which are publicly funded, as the rates of waste production are usually longer.

The third stage of the study was concerned with comparative research on the existing technologies of the incinerators applied in medical institutions. Parameters relating to design, including the configuration of the combustion chamber, temperature range, consumption of fuel, emission control, and waste loading mechanisms were examined. This discussion has assisted in establishing key elements needed when incorporating a medical waste incinerator. The fourth step entailed the creation of an indigenous incinerator design structure. On the basis of the information gained through literature analysis and case study, the main design parameters were determined in the proposed incinerator model. These parameters are efficiency in the consumption of fuel, structural design, environmental safety, cost effectiveness and the suitability to locally available construction materials.

The last research stage will entail conceptual architectural and engineering design of incinerator system. Spatial planning, material choice, and environmental factors have been used in the design process to provide safe integration of the incinerator into the hospital infrastructure. The design also takes into consideration the operational aspects like waste loading, removal of ash and accessibility of the maintenance.

The general research approach thus comprises of analytical investigation and design progression which ensures that the study may suggest a context-relevant and workable propose solution of incinerator in the hospitals in Pakistan.

### **DATA ANALYSIS & DESIGN INTERVENTION**

Cost-effective incinerator has been designed by the researcher according to the fourth and main research objective. Researchers provide the best solution with reference to waste treatment, like as waste reduce and waste disposed of. This incinerator is designed by researcher himself; this incinerator will be made by using simple and standard building brick material (fire brick and regular brick) and the way to make, it is also very simple. The material which will be used for this, will be easily available from everywhere. Anything that has a design cannot be called a good design, if it does not have a functional.

Design of this cost-effective brick incinerator that I made after a lot of research and discussion with experts related to this field, it is very low-cost structure, less use of energy and very functional. This incinerator is consisting of two chambers, primary and secondary chamber. Primary chamber is used for waste combustion and secondary chamber is used for smoke burning (combustion of smoke) where combustion process is completed. This incinerator can be built on hospital top roof or any building top roof, or any site by using standard building bricks. All of the other parts, such as the waste load door, ashes tray, ash removing door, or inlet pipe apertures, can also be made with basic workshop tools. A combustion temperature of 1000°C to 1100°C was required while using LPG as a fuel source. But this incinerator can bear up to 1500°C temperature.

The incinerator's output or performance will range between 30 and 40 kg per hour. This low-cost incinerator can burn almost any form of garbage, including plastics, packaging, drugs, pharmaceuticals, and sharps. After combustion process the ash is used for landing filling purpose and other option is dumped safely. Incinerator design consist of two major chambers, chamber one which is called primary chamber and chamber two which is called secondary chamber.

Primary chamber (600-800°C) is used for waste burning and secondary chamber (1000-1100°C) is used for smoke burning or produced gasses burning. This chamber is 8 feet by 6 feet inner side mean clear space for combustion purpose. Inner side wall of this chamber will be made 4½ inches thick which is made by firebrick material. After adding this wall, 4½ inches cavity wall to be added just for protection of heat, then finally outer wall 4½ thick will be added. The same structure process will be repeated for secondary chamber, 4½ thick inches wall to be added in inner and outer sided of the incinerator, cavity wall to be added between inner and outer side wall just for protection of heat. Base of this incinerator is raised 2 feet from to the ground or roof surface. Incinerator base is consisting of RCC slab structure or RCC column.

Air injector fan is provided at above of primary chamber which will be used for enhancing combustion process. Secondary chamber will burn smoke or toxic gasses which is produced after burning waste in primary chamber. Next zone is cooling chamber, in this chamber one air fan will installed for throwing air just for providing cooling. ID fan will be installed at the top of the chimney, basically this fan will be used for sucking remains smoke or remains gasses, these gasses will pass from the cooling chamber, cooling chamber will be attached with wet scrubber chamber which will be attached with water tank which is provided at bottom of the wet scrubber chamber. one water circulation pipe will be attached under the sucker fan which throw water at wet scrubber, submersible pump installed in water tank which circulate the water from scrubbers again and again.

This practice will be repeated 30 to 45 times within few minutes, repeating this process repeatedly remains gasses will be clean and overall finished. The 85 % to 90 % gasses will be dismissed and cleaned by this practice. This incinerator meets all environmental

rules, regulations, and EPA standards. After a lot of hard work, I have been able to finalize this design. This design is also very cheap, cost effective and environmentally friendly. The material which will be used to make it are readily available on the market except some rare equipment. Like some sensors and high-quality burners. The design detail and 3d views are provided below along with the cost details of this incinerator design.

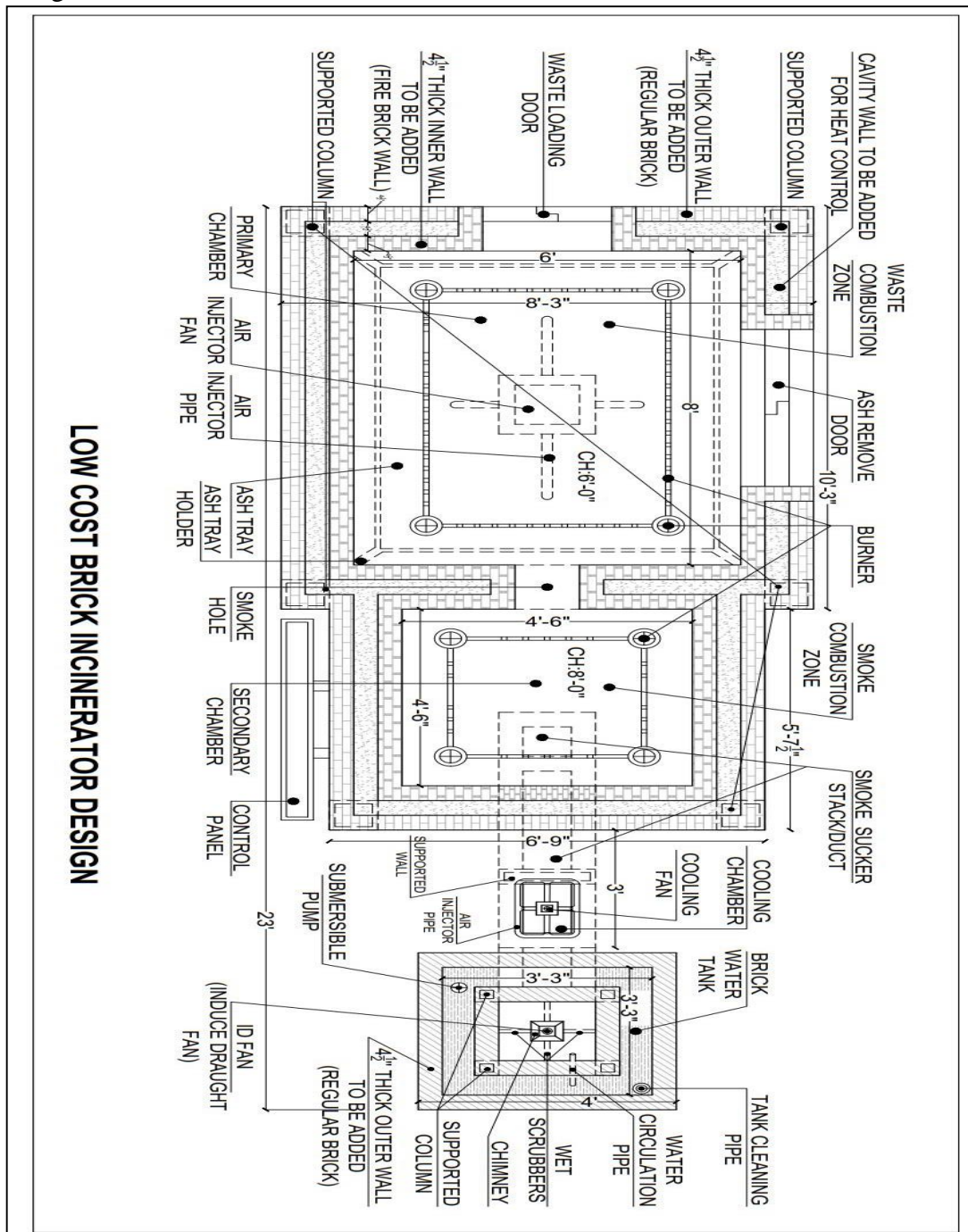
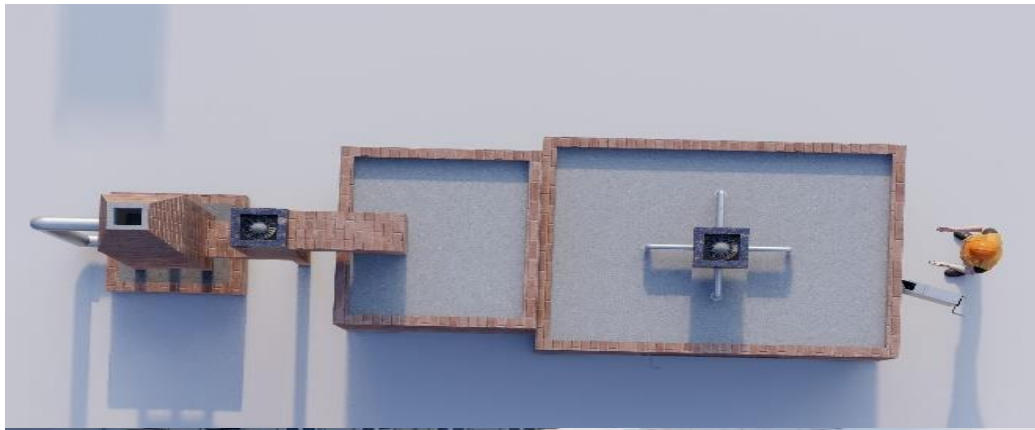


Figure 01 Detail Design of the Incinerator

3D perspective views along with Top view, side view, front view, bird eye view and isometric views are shown below:



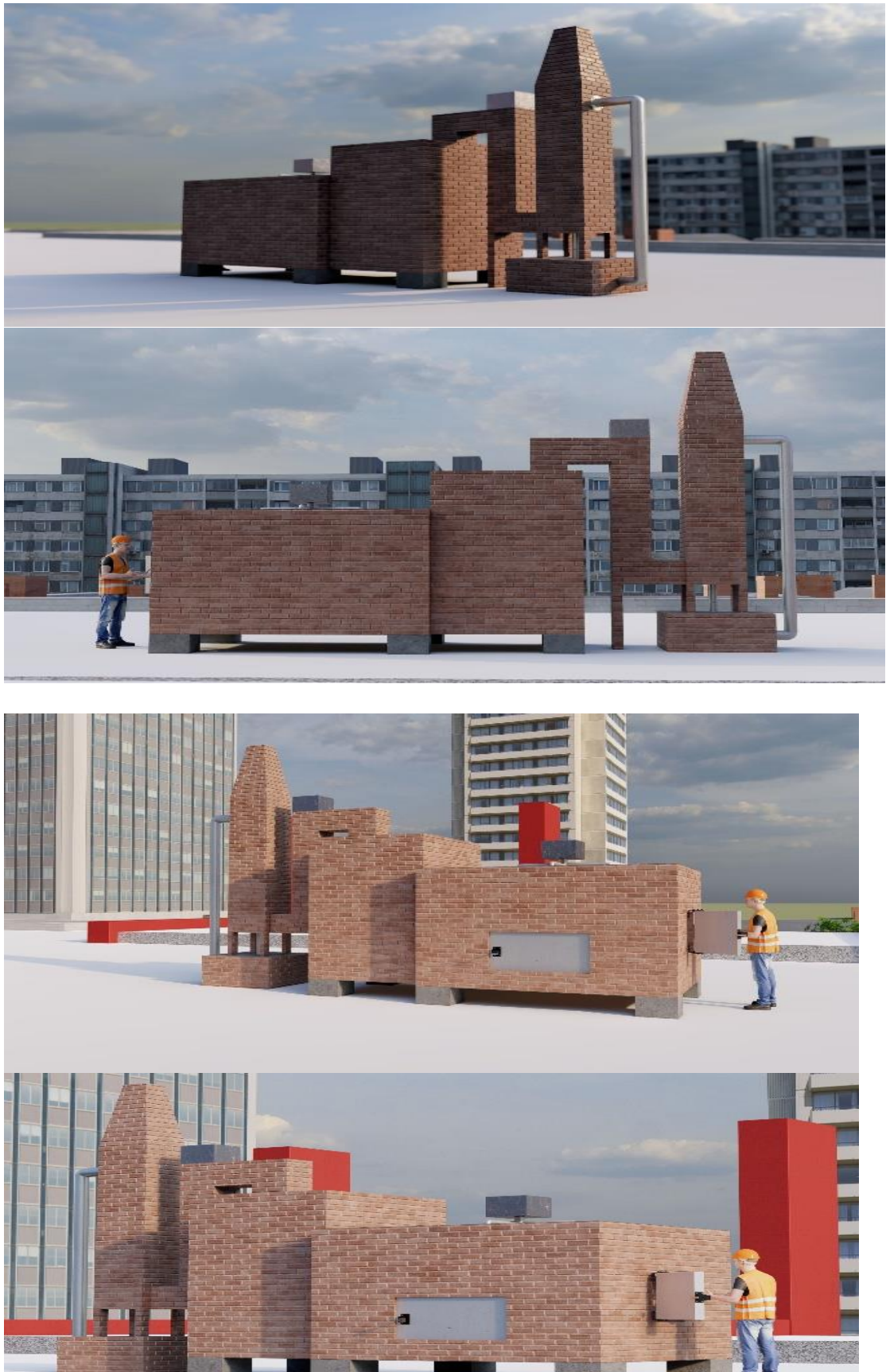


Figure 02 Perspective images of the proposed design

The detail all of material which will be used in this incinerator structure is mentioned in table 01. The Fire bricks that will be used in this incinerator can bear up to 1500°C temperatures. These values have been calculated before six months ago. Due to current inflation, the current values of these items have changed a lot. Even if the rates of all

these things increases, brick incinerator will be cheaper than other incinerator that we import from foreign countries.

**Table 01 Material details**

SR.NO	ITEMS DETAIL	ITEMS PRICE	TOTAL PRICE
1	Fire bricks cost	1770 X 140	247,800
2	Mortar cost (12 bag) 20 kg	5000 X 12	60,000
3	Regular standard brick cost	2212 X 14	30,968
4	Regular mortar cost (7 bag) 50 kg	700 X 7	4,900
5	Labour cost	50,000	50,000
6	Burner price (4 burner used)	250,000 X 4	1,00,0000
7	Waste loading door price + Ash remover Door (used stainless steel)	30,000 X 2	60,000
8	Air injector fan (combustion fan)	40,000	40,000
9	Cooling blur Fan	6,000 X 8	48,000
10	Wet scrubber (stainless steel)	40,000 X 2	80,000
11	Induce draught fan (ID fan)	100,000	100,000
12	Brick Water tank	10,000	10,000
13	Submersible pump	30,000	30,000
14	Control panel (automation)	500,000	500,000
15	Installation price	200,000	200,000
<b>Total price of Low-cost brick incinerator (Rs)</b>			<b>2,461,668</b>

Local incinerator which is available in Pakistan is approximately Rs. 4,500,000 to 5,500,000. The best quality imported incinerator is approximately Rs. 12,500,000 to 13,500,000. The brick incinerator that have been designed will save maximum cost. By using this incinerator, we can save 50 to 60 % cost. Then we can say the man-made incinerator is cost effective and cheap as compared to other factory-made incinerators.

### SUMMARY OF FINDINGS

The study was able to come up with an original and cost-effective design of an incinerator to treat hospital waste that can be used in the healthcare system of Pakistan. The proposed incinerator has been constructed by utilizing the locally available construction material like fire bricks, ordinary bricks, mortar, and the mechanical components which are commonly available. The overall estimated cost that should be used to build the incinerator is about PKR 2.46 million which is very low when compared to the cost of locally manufactured incinerators that are present in the Pakistani market with an estimated cost of between PKR 4.5 million to PKR 5.5 million and the imported incinerators that cost around PKR 12.5 million to PKR 13.5 million. This observation means that the proposed design has the potential to save up to 5060 percent of the costs of installation and, thus, is economically feasible to install in small and medium healthcare centers.

The other significant study discovery is the working efficiency of the two-chamber combustion system incorporated into the proposed incinerator system. The incinerator is made up of the primary combustion chamber where the biomedical waste is combusted at temperatures between 600-800 o C and the secondary combustion chamber whereby gases generated in the initial combustion process undergo combustion in the secondary combustion chamber at temperatures of between 1000-1100 o C. This is a two stage combustion process that guarantees increased oxidation of waste waste materials as well as a significant reduction in the emission of toxic gases into the atmosphere. Fire bricks of the design are also designed to endure temperatures up to 1500 o C which will not only guarantee the structural stability but also long-term durability of incinerator structure.

The operational performance of the proposed incinerator implies that the waste treatment level is about 3040 kg of waste in every hour, and that is suitable to small- and medium-sized healthcare institutions like district hospitals, private clinics, and simple health units. Besides the efficiency of the combustion, the design also has an emission control system which involves a cooling chamber, wet scraper system and an induced draught (ID) fan. Wet scrubber system, which is backed with a water circulation mechanism, assists in the removal of the toxic gases and the particulate matter that is produced during the combustion process. According to the study results, it means that about 85-90 percent of harmful gases may be eliminated due to this emission control system, and it will be possible to improve the state of the environment, as well as reduce the risks associated with air pollution.

In addition, the structure is very adaptable as far as installation and construction is concerned. Depending on the space conditions of hospitals, the incinerator can be built on the roof of the hospital buildings or in the nearby waste management areas. The material used to construct the incinerator can be locally sourced hence the structural components of the incinerator are derived using the simple methods of masonry construction, and the construction can be executed using conventional building materials by the locally available labor force. The design can also be easily fabricated to produce mechanical parts like waste loading doors, ash trays and air inlets using normal workshop tools. Such characteristics render the incinerator simple to build, use, and maintain in resource-based restrictive settings.

## **RESEARCH CONCLUSIONS**

The results of the current study indicate that the creation of an indigenous healthcare hospital waste incinerator may be used to offer a viable and sustainable way of helping to resolve the healthcare waste management issues in Pakistan. The suggested design confirms that technologies developed locally can address functional and environmental demands as well as help healthcare institutions significantly decrease their financial expenditures. The incinerator design provides a viable alternative to the expensive imported incineration technologies by making use of easily available construction materials and simplified engineering systems.

The study also comes out that the implementation of a dual-chamber combustion system has a profound impact to the overall performance of the incinerator in that it ensures excellent combustion of the biomedical waste and minimization of the harmful gases. Other features that enhance better environmental performance are the addition of other components like cooling chamber, wet scrubber system, and induced draught fan that help in ensuring that toxic gases are filtered and their release to the atmosphere is limited. These characteristics will allow the proposed incinerator to be in line with the recommended healthcare waste treatment standards that should be taken to the recommended environmental standards.

The other critical study conclusion is that architectural and spatial integration of waste treatment systems in healthcare facilities is essential towards enhancing the hospital waste management system. The proposed design will provide flexibility as it will be able to fit the various hospital layouts by allowing installation on hospital roofs or in specific areas of the hospital that will be used as waste treatment facilities. This practice will emphasize the role that waste management infrastructure should play in hospital planning and environmental design.

On the whole, the study establishes the fact that the suggested variant of the indigenous incinerator is a cost-efficient, environmentally-conscious, and technically successful project that can be successfully implemented in the context of promoting the practice of biomedical waste management in Pakistan-based healthcare institutions.

## **RESEARCH FUTURE DIRECTIONS**

Regarding the results and conclusions provided by the research, some

recommendations can be made concerning the purpose of enhancing the healthcare waste management systems in Pakistan. To begin with, the healthcare facility must think of incorporation of locally designed and affordable incinerator technologies to increase the waste treatment capacity, especially in small and medium healthcare institutions where budget constraints are minimal. The function of indigenous incinerator design like the one suggested in this research can greatly save the cost of installation and still be functional.

Secondly, environmental agencies and the government should encourage the production and certification of incinerators that are locally produced that meet the environmental standards. With the help of technical guidelines and quality control mechanisms of indigenous waste treatment systems, the safe and environmentally responsible operation will be ensured.

Thirdly, the waste management infrastructure should be incorporated by healthcare architects and planners into the initial phases of designing and planning hospitals. The safety and efficiency of the waste treatment systems in healthcare facilities can be enhanced by proper spatial zoning, ventilation planning and accessibility of the waste handling operations.

The second point that will be mentioned as an important suggestion is training and awareness programs that should be implemented among healthcare workers and waste management employees. The correct segregation of biomedical wastes in the source is the only way of ensuring that the incineration is done properly and that the risks are not that many to the environment. Safe handling procedures, waste segregation methods and operational management of incineration systems need to be trained.

Lastly, the proposed incinerator design should be studied further and tested on a pilot basis in a real hospital setting. The field tests and performance monitoring will also assist in testing the efficiency of the operations of the system, the emission level and the long term sustainability. Such research will lead to the refining of the design and its popularization in the healthcare facilities within Pakistan.

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