Bio-Medical Waste Management: An Overview of Various Technologies

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ABSTRACT: *The health care and medical facilities and services have improved enormously over the years. Though, this has benefitted the society, it has also increased the risk to human life from hazardous and toxic waste generated from the medical activities. The bio-medical waste must be disposed of or treated properly so that it does not result in spreading of infections. Also, surgical/medical instruments and equipment should be properly sterilized before reuse.non-incineration technologies are better as they are environment friendly as well as cost effective. Sterilization, one of the many non-incineration technologies, is considered very effective for treatment of medical waste, tools and equipment.Solar Autoclave, based on low temperature steam sterilization technique, one of the non-incineration technologies for bio-medical waste management,is very useful for treating hospital waste and medical instruments and equipment in a cost effective and environment friendly manner for small health care centers. The solar energy for generating steam is a renewable source of energy, environment friendly and can be used in villages as well as towns and cities. Solar Autoclave is relatively new technology for sterilization. The technology can be effectively used with power backup for so that it can be used when solar power is not sufficiently available.*

Key Words: *Non-incineration technologies, Steam Sterilization, Solar Autoclave*

Introduction

In India, the health care and medical facilities and services have improved enormously over the years. Though, this has benefitted the society, it has also increased the risk to human life from hazardous and toxic waste generated from the medical activities. The bio-medical waste like infectious needles, knives, gloves, etc., must be disposed of or treated properly so that it does not result in spreading of infections. *Infectious wastes* contain pathogens (disease-causing bacteria, viruses, parasites, or fungi) and may spread disease. It is very important to properly disinfect the infected bio-medical waste before disposal. Also, surgical/medical instruments and equipment should be properly sterilized before reuse.

The increase in number of hospitals, health care centers and increased use of disposables, the quantity of bio-medical waste generated is also rising. The bio-medical waste generated in USA is 4.5 kg / bed / day, in Spain 3 kg / bed / day, in France and UK 2.5 kg / bed /day and in India 1.5 kg / bed / day [1]. As a result, the risk to human life has also increased, particularly due to new models of profit-oriented hospitals trying to maximize profit, by reducing the cost through dumping the hospital waste in municipal bins or dumping sites. The diseases like Hepatitis B, HIV/AIDS and other life-threatening diseases are on the rise. The environmental issues are also associated with improper handling of bio-medical waste.

A survey was undertaken by L. K.Verma et.al. **(2008)** to study the management of biomedical waste [2]. A systematic analysis of current biomedical waste management practices in smaller nursing homes and hospitals in Delhi was carried out during 2005–2006. This paper discusses the relevant data indicative of current practices of healthcare waste management in the nursing homes and small healthcare facilities in Delhi. Data was collected through a questionnaire and field visits. A total of 53 nursing homes, with bed strengths ranging from 20 to over 200, were included. The survey results show that there is a marked improvement in the segregation practices of biomedical waste in small private hospitals and nursing homes. The majority of nursing homes and hospitals were found to be using a service provider for the collection, management, and disposal of healthcare wastes.

At the global level, 18 to 64 per cent of healthcare institutions are reported to have unsatisfactory biomedical waste management facilities. The factors responsible for unsatisfactory biomedical waste management include lack of awareness, insufficient resources and poor disposal mechanisms, according to Factsheet on Wastes from Healthcare Activities **(2011)** by WHO [3].

According to Draft Bio-Medical Waste (Management and Handling) Rules, **(2011)**notified by Ministry of Environment and Forests, Govt. of India, the bio-medical waste has been categorized into eight categories now as against ten categories earlier under Bio-Medical Waste (Management and Handling) Rules, 1998 [4].

The eight categories of bio-medical waste now are Human Anatomical Waste, Animal Waste, Microbiology & Biotechnology Waste and other laboratory Waste, Waste sharps, Discarded Medicines' and Cytotoxic drugs, Soiled Waste, Infectious Solid Waste and Chemical Waste. Under the new rules, every occupier or operator, irrespective of the number of patients being serviced or the quantum of bio-medical waste generation, is required to obtain authorization from prescribed authority as against earlier rule by which the institution providing service to less than 1000 patients per month were not required to take authorization from the authorities. Under new rules, every occupier shall set up requisite bio-medical waste treatment equipment before commencement of its operation or shall make arrangements to ensure requisite treatment of bio-medical waste through an authorized bio-medical waste treatment facility.

A case study of biomedical waste treatment plant of BMC at Deonar, Mumbai was conducted by A. S.Ghuraand C. M. S.Kutty**(2012)**[5]. They found that the hospital staff at some of the hospitals was stuffing hazardous waste in regular trash bags instead of color-coded bins. There was urgent need for new plants to be set up for waste management. The community was unaware of the hidden dangers of biomedical waste. According to them, currently, the country has 13550 hospitals, 27400 dispensaries, 717860 registered medical practitioners, 295000 nurses, 227000 auxillary nurses & midwives. There is a new category of profit-oriented hospitals as well. Indian healthcare industry is growing at a rate of 12% per annum and India generates 3 lakh tons of medical waste annually. It is estimated that in every four kilograms of waste generated in any hospital, one kilogram will be infectious. The untreated and indiscriminate disposal of biomedical wastes and sharps is leading to spreading of infectious, fatal and dangerous diseases like Hepatitis, AIDS and Cancer, etc. Only 5-10% of the institutions follow the Biomedical Waste (Management and Handling Rules) Rules, 1998 with subsequent amendments in 2000 and 2003, notified by the Ministry of Environment and Forests, Government of India.

A study has been conducted by Y.Thakur and S.S. Katoch**(2012),** at the district health care facility of a town in India to understand the characteristics of biomedical waste and its treatment [6].For safe and scientific management of biomedical waste, handling, segregation, mutilation, disinfection, storage, transportation and finally disposal are vital steps for any health care institution. The data of biomedical waste incinerated at zonal treatment facility and autoclaved at Indira Gandhi Medical College and Hospitalof Shimla town on yearly basis under present study have been collected for five consecutive years (2007 to 2011). These waste data include both indoor and outdoor patients visiting health care facilities. It appears that most of the biomedical waste is accumulated and sent for incineration. But after the year 2010 the autoclaving of biomedical waste has registered significant increase. The autoclaved waste is being recycled and its resale is also going on since 2010.

Another study conducted by INCLEN Program Evaluation Network (IPEN) study group, New Delhi, India, **(2014),** highlighted the urgent need for greater commitments at policy levels for capacity building and resource investment in biomedical waste management [7]. The study was conducted in 25 districts over 20 States of India in 2012. The information from 24 Partner Medical Colleges, 25 district hospitals and 388 (194 public and 194 private) primary care health facilities were analyzed. Bio-medical Waste Management was alarming at macro and micro levels across different parts of the country. In the 25 study districts, 82 per cent of primary care health facilities, 60 per cent of secondary care and 54 per cent of tertiary care health facilities were in the RED category i.e. absence of a credible Bio-medical Waste Management system in place or ones requiring major improvement. BMW including plastic wastes generated in secondary and tertiary care health facilities was 3 to 10 times higher every day as compared to that in primary care facilities. Infectious waste comprised of improperly segregated bio-medical waste, and mixture of material contained in blue or red and yellow colored bags.

A joint assessment by WHO/UNICEF found that just over half (58%) of sampled facilities from 24 countries had adequate systems in place for the safe disposal of health care waste**(2015)**[8].High-income countries generate on an average up to 0.5 kg of hazardous waste per hospital bed per day; while low-income countries generate on average 0.2 kg. However, health-care waste is often not separated into hazardous or non-hazardous wastes in low-income countries making the real quantity of hazardous waste much higher. Health-care waste contains potentially harmful microorganisms that can infect hospital patients, health workers and the general public. Other potential hazards may include drug-resistant microorganisms which spread from health facilities into the environment, according to Factsheet on Wastes from Healthcare Activities (2018) by WHO [9].

Thus, a number of studies in India and other countries have highlighted the need for proper and safe handling, treatment and disposal of medical and surgical equipment and tools; and healthcare waste. Some countries including India and international organizations like World Health Organization, have also issued guidelines for this purpose.

Despite the legal framework, the problems due to improper handling and disposal of bio-medical waste and lack of proper sterilization before reuse of medical/surgical equipment are on the rise. There is also lack of awareness in the society about the importance of proper treatment of bio-medical waste and the risks arising out of its improper treatment.

Classification and Composition of Healthcare or MedicalWaste

There are different types of wastes which are generated by the health care industry. Generally, about 85% (75% to 90%) of the biomedical waste is non-infectious and non-hazardous general waste. Approximately 10% of the waste is infectious and 5% is Chemical/Radioactive hazardous [10]. The regulated medical waste or infectious waste is about 15 percent of total hospital waste and requires disinfection before it is disposed in a landfill. There is also need for proper disinfection and sterilization of medical or surgical instruments and equipment used before their safe reuse or disposal.

Broadly, healthcare waste can be classified into sharp waste, pathological waste, other infectious wastes, pharmaceutical waste including cytotoxic waste, hazardous chemical waste, radioactive waste, and general non-risk waste.

It is the responsibility of the institution which is generating waste, to ensure the safety of its employees as well as general public by using environment friendly waste disposal techniques. The efforts should be made to eliminate or minimize waste through a policy of reduce, reuse and recycle, wherever possible. Further reduction in waste can be done through aggressive waste management actions. There should be proper Bio Medical Waste Management System in place. There is need for proper accountable operation disposal equipment, post-treatmenttechnology management and services like shredding, landfilled material, incineration ash, air and water emissions.

The impact of waste as well as the waste management techniques must be considered on the environment. The safer disposal techniques which are beneficial for the environment as well as health of the public must be given more importance than other techniques. The cost effectiveness of such techniques can further benefit the health care industry.

Techniques of Handling Medical Waste

The two basic technologies for disposal of biomedical waste are incineration technologies and non-incineration technologies.

Incineration Technologies

Incineration or burning of waste, whether it is solid or regulated medical waste, raises a number of issues. Incineration not only produces toxic ash residue, it also emits toxic air which affects distant environment as well. The landfills used for disposal of residue contaminate groundwater resulting in a number of diseases.

The burning of medical waste leads to creation of new compound, dioxins, which are associated with IQ deficits, birth defects, immune system damage, hyperactive behavior and developmental delays. It also results in mercury emissions which affects nervous system, brain, kidneys and lungs. The mercury in the air contaminates fish and wildlife as well once it enters the global distribution cycle in the environment. Moreover, the capital cost and operating cost of incinerators is very high. Installing the pollution control devices to control the emissions, the training of the qualified operator and continuous monitoring of the pollution control devices further increases the cost.

Non-incineration Technologies

There are four types of fundamental processes used by non-incineration technologies for treating the hospital waste. These are as follows:

Thermal Processes: Thermal Processes rely on heat or thermal energy to destroy pathogens in the waste.These are of three types:

Low Heat (93^{0}C – 177^{0}C) Thermal Processes – These processes use thermal energy to decontaminate the waste at temperatures insufficient to cause chemical breakdown or to support combustion or pyrolysis. It includes waste treatment through Microwave and Autoclave. The disinfection is done through wet heat (steam) in Autoclave and through dry heat (hot air) in Microwave.

Medium Heat (177^{0}C – 370^{0}C) Thermal Processes – These processes result in chemical breakdown of organic material. It includes waste treatment through thermal de-polymerization using heat and high pressure; and reverse polymerization using high-intensity microwave energy.

High Heat (540^{0}C – 8300^{0}C) Thermal Processes – These processes result in chemical and physical changes to both organic and inorganic material causing total destruction of the waste. It includes electrical resistance, induction, natural gas and/or plasma energy. It also reduces the volume of waste up to 95%.

Chemical Processes: These processes destroy waste using disinfectants such as dissolved chlorine dioxide, bleach (sodium hypochlorite), peracitic acid, or dry inorganic chemicals. The waste is shredded, grinded and mixed before putting the disinfectant on it. When liquid disinfectant is used, the waste is later passed through a dewatering section also so that the disinfectant on it can be removed and recycled.

Irradiative Processes: These processes use electron beams, Cobalt-60, or UV Irradiation. These require shielding of people handling the process from the exposures of irradiation.

Biological Processes: These processes use enzymes to destroy the organic matter.

In addition to these four processes used for non-incineration treatment, there are mechanical processes such as shredding, grinding, mixing, liquid-solid separation, hammermill processing etc., which supplement them. The mechanical processes are used to destroy the waste to make them unrecognizable and unusable and are not used standalone treatment method.

Importance of Non-Incineration Technologies for Safe Treatment and Disposal of Medical Waste, Tools and Equipment

The non-incineration technologies are preferred for disinfection of medical waste and surgical instruments because of the following reasons:

- The incineration technologies are not environment friendly whereas non-incineration technologies are environment friendly;
- The incineration technologies cause health problems and are costly.
- The use of non-incineration technology reflects the commitment of health care organizations towards protection of public health as well as environment.

Various studies suggest that non-incineration technologies are better than incineration technologies.

According to the report on Non-Incineration Medical Waste Treatment Technologies, by Health Care Without Harm, USA **(2001),** non-incineration technologies are better as they are environment friendly as well as cost effective [11]. Medical Waste incineration has been identified by the U.S. Environmental Protection Agency as the third largest known source of dioxin air emissions and contributes about 10 percent of the mercury emissions to the environment. Dioxin exposure has been linked to disrupted sexual development, birth defects and damage to the immune system. Mercury is a potent neurotoxin, that is, it attacks the central nervous system of the body and harms the brain, kidneys and lungs. A report on Non-Incineration Medical Waste Treatment Technologies in Europe, by Health Care Without Harm Europe, Czech Republic, **(June 2004),** also suggests that non-incineration technologies are environment friendly and, therefore, should be preferred over incineration technologies [12].

According to a study by V. Gautam, R. Thapar and M. Sharma **(2010),** public concerns about incinerator emissions, as well as the creation of federal regulations for medical waste incinerators are causing many health care facilities to rethink their choices in medical waste treatment [13]. Most medical waste is incinerated, a practice that is short-lived because of environmental considerations. The burning of solid and regulated medical waste generated by health care creates many problems. Medical waste incinerators emit toxic air pollutants and toxic ash residues that are the major source of dioxins in the environment. Development of waste management policies, careful waste segregation and training programs, attention to materials purchased, are essential in minimizing the environmental and health impacts of any technology. The alternatives for waste treatment rather than incineration such as a locally made autoclave integrated with a shredder should be evaluated and implemented.

The study conducted by S. Patnala et. al. **(2017)** investigated the existing practices of biomedical waste management by focusing on the methods of waste separation, quantification, transportation and disposal in a hospital in Karnataka state of India [14]. Data was collected from the waste management department of the hospital including the hospital staff members in order to identify the factors that facilitate and constrain the existing practices of biomedical waste management with the end goal of identifying sustainable measures that could be taken up to improve the existing practices of waste management in the hospital. The results showed that solid waste (blood contaminated items) is generated in high quantities (207 kg/day) whereas discarded medicines and cytotoxic drugs contributed the least quantity of 3.5 kg/day. Colour coded polyethylene waste bags are provided at the point of waste generation to avoid waste mixing while also ensuring that the different waste types are disposed properly. Furthermore, the hospital staff members responsible for waste generation and handling adhere to the prescribed waste management protocol and receive training in that regard. According to the participants, the training that is provided is not monitored and there is possibility of mixing of hazardous waste with general waste. This act not only poses a threat to the waste handlers but to the patients as well because when the waste is being transported, trolleys usually

pass in between the wards. The hospital has an incinerator to disinfect contaminated hazardous waste and the ash after incineration ends up in the landfill site which is managed by the municipality. The ash from the incinerator is transported by the trucks to a landfill site for disposal. The findings show that there is some degree of management of biomedical waste in the hospital. However, training of the staff responsible for waste handling needs to be monitored and evaluated frequently. The hospital could consider owning and operating its landfill site to reduce the carbon foot print caused by fuel consumption during transporting of waste to the landfill sites including the costs involved. Generally, an incinerator emits pollutants such as furans, dioxins, carbon monoxide, nitrogen oxide which pose environmental and health concerns. However, the design of the incinerator in hospital allows the scrubbing of these toxins through the use of caustic soda prior to discharge into the atmosphere such that very minute concentrations are released. There are other types of thermal treatments which could be considered and these include non-burn technologies such as an autoclave, hydroclave, microwave, plasma pyrolysis and electro-thermal deactivation. These technologies are as effective as an incinerator, however, the type of the bio-medical waste generated or that requires treatment often determines the preferred technology including maintenance, operation and the availability of the financial resources.

Thus, studies show that non-incineration technologies are better as they are environment friendly as well as cost effective. Sterilization, one of the many non-incineration technologies, is considered very effective for treatment of medical waste, tools and equipment, according to various studies.

Importance of Sterilization Process as Non-Incineration Technology

The steam sterilization of medical waste and surgical instruments through Autoclave isconsidered to be the most dependable and widely used non-incineration technology. Steam sterilization is nontoxic and inexpensive [15].

Autoclaves require certain minimum exposure time and temperature to achieve proper sterilization. The common exposure temperature – time criterion for autoclaves is 121^0 C for 30 minutes. The exposure times are generally based on twice the minimum time required to achieve a 6 $\log_{10}$ kill of bacterial spores under ideal conditions. Color-changing chemical indicators or biological monitors are placed at the centre of the test loads to verify that sufficient steam penetration and exposure time have occurred [16].

Infectious/Biomedical Waste Management Plan, by members of UW Infectious Waste Committee and UW Institutional Biosafety Committee, University of Washington **(2005)** provides the guidelines for development and improvement of infectious waste management plans and programs [17]. Accordingly, the Infectious/Biomedical Waste has been classified into various categories and methods of their treatment have been provided, as shown in Table 1.

Table 1: Methods of Treatment to Decontaminate Infectious/Bio-medical Waste [17]

Infectious/Bio-medical Waste Type	Treatment
Cultures, Stocks of Etiological Agents	Steam sterilization
Infectious Lab Waste	Steam sterilization
Sharp Containers	On-site steam sterilizing or off-site treatment
Infected Body Fluids	Chemical decontamination
Human Body Fluids	Chemical decontamination, steam sterilization, sanitary sewer, or absorbed
Human Pathological Waste	On-site cremation, Pathology or O.R. pathological discard station
Recombinant DNA Lab Liquid/Solid	Chemical decontamination, steam sterilization, off-site treatment
Prions	Contact the Biosafety Officer
All Other Infectious/Bio-medical Waste	On-site steam sterilizing or off-site treatment
ABSL-3 Animal Tissue/Carcasses/Bedding	On-site steam sterilization, then off-site incineration
ABSL-2 Animal Tissue/Carcasses/Bedding	On-site steam sterilization or off-site incineration
Non-Human Primate Bedding	On-site steam sterilization.

According to the Environmental Health & Safety Guidelines **(2008)** issued for researchers and laboratory personnel by University of Colorado Boulder, an autoclave is a high pressure device used to allow the application of moist heat above the normal-atmosphere boiling point of water[18].Steam Sterilization in an

autoclave is the process of sterilization by the use of heated steam under pressure to kill vegetative microorganisms and directly exposed spores. Common temperature and pressure for being effective is 121^0C at 15 psi (103.4 kN/m^2) over pressure for 15 minutes. Special cases may require a variation of the steam temperature and pressure used.Sterilization isthe complete elimination or destruction of all forms of life by a chemical or physical means. This is an absolute not a relative term.

Autoclaving at a temperature of 121^0C, at 15 to 20 psi is one of the most convenient and effective means of sterilization available. The time is measured after the temperature of the material being sterilized reaches 121^0C. Care must be taken to ensure that the steam can circulate around articles in order to provide even heat distribution. The success of the sterilization is very time-dependent in liquid media, with large volumes requiring longer periods of time to reach the effective temperature within the media itself. Additionally, there should be no void spaces in the load that could insulate against the steam – this condition could prevent the transference of heat to the vessels resulting in no sterilization of the contents.

Every year there are 50-60 million people in the developing world suffering from wound injuries, according to a report by WHO**(2010)**. Even in areas where surgeries are already performed, one fifth of the patients suffer from post-operation infection, due to, among other causes, the use of improperly sterilized equipment used in the procedure [19].

According to a survey by S.B.Abitha and R.Dhanapal **(2014),** biomedical wastes prevailing in hospitals must be separated and disposed in hygienic and cost effective manner such that it minimizes the risk to public health and environment[20]. Biomedical wastes cause 10-15% of infection among public. Among all biomedical wastes in hospital 5.7% are deep buried, 23.8% are incinerated, 9.5% are burned. About 61% of biowaste disposal is unknown due to insufficient equipment, lack of access to electricity etc. in rural areas leading to poisoning of greenhouse gases and surrounding environment. Therefore, solar powered thermal autoclave technique is proposed so that it minimizes the risk of environmental pollution and contamination without electricity and cost effective. This technique collects the solar energy and transfers into heat and by conduction thermal energy is generated which sterilizes the biomedical wastes. Other proposed methods like chemical and radiation sterilization also induce different type of environmental hazards. Solar autoclave is an initial step to save our greenhouse gases and preserve earth from the environmental pollution occurring due to biomedical waste. Solar thermal powered autoclave with early warning system (EWS) is suitable for wet sterilization of medical instruments in remote and rural areas of developing countries. This system acquires energy from sunlight collected through semi parabolic black mirrors. The extracted energy transferred to aluminium plate through forced transmission. The high pressurized autoclave in presence of water kills all microbes, spores and viruses.

According to a report on Radiant Cooling, Solar Heating and Solar/Waste Heat Cooling**(2016)**, autoclaves kill different pathogens by subjecting the equipment and tools to steam at 121^0C for 15 minutes or at 134^0C for 3 minutes [21]. The steam of the autoclave can be provided from a solar concentrator or from thermal storage. Rural areas where electricity is not available to generate steam could greatly benefit from solar autoclaves.According to Guidelines by Indian Society of Hospital Waste management **(2018),**biomedical wastes are the waste generated during the diagnosis, treatment or immunization of human beings or animals, or in research activities pertaining thereto, or in the production of biological[22]. The different hospital waste categories, according to Indian Society of Hospital Waste management are shown in Table 2.Disinfection and sterilization are important procedures in biosafety. Disinfection refers to procedures which reduce the number of microorganisms on an object or surface but not the complete destruction of all microorganism or spores. Sterilization on the other hand, refers to procedures, which would remove all microorganisms, including spores, from an object. Sterilization is undertaken either by dry heat (for 2 hours at 170^0C in an electric oven – method of choice for glass ware and sharps) or by various forms of moist heat (i.e. boiling in water for an effective contact time of 20 minutes or steam sterilization in an autoclave at 15 lb/sq inch at 121^0C for 20 minutes).

Table 2: Categories of Hospital Waste and Disposal Techniques [22]

Category	**Type of Waste**	**Treatment and Disposal Options**
Category 1	Human Anatomical Waste (Human tissues, organs, body parts)	Incineration/Deep Burial
Category 2	Animal waste (Animal tissues, organs, body parts, carcasses, bleeding parts, blood and experimental animals used in research)	Incineration/Deep Burial
Category 3	Microbiology and biotechnology waste(waste from lab culture, specimens from microorganisms, vaccines, cell	Local Autoclaving/ Microwaving/

	cultures, toxins, dishes, devices used to transfer cultures)	Incineration
Category 4	Waste Sharps (Needles, Syringes, scalpels, blades, glass)	Chemical Disinfection Autoclaving/ Microwaving, Mutilation and Shredding
Category 5	Discarded medicines and cytotoxic drugs (outdated, contaminated, discarded drugs)	Incineration/Destruction and disposal in land fills
Category 6	Soiled waste (contaminated with blood and body fluids including cotton, dressings, soiled plasters, linen)	Autoclaving/ Microwaving/ Incineration
Category 7	Solid waste (tubes, catheters, IV sets)	Chemical Disinfecion/Autoclaving/ Microwaving, Mutilation and Shredding
Category 8	Liquid waste (Waste generated from laboratory and washing, cleaning, disinfection)	Disinfection by chemical treatment and discharge into the drains
Category 9	Incineration ash	Land fills
Category 10	Chemical waste	Chemical disinfection and discharge into the drains

Thus, out of the various processes used for treating hospital waste and medical instruments and equipment through non-incineration technologies, steam sterilization using Autoclave, a low heat thermal processhas many benefits. The technique is not only environment friendly; it is also low cost, non-toxic and very effective method of disinfecting medical waste and surgical instruments. Autoclaves are easily available in different sizes and the process of sterilization through steam is well established. The pollution through this process is minimal and capital costs are low. Moreover, surgical instruments and equipment can be reused after sterilization as against some of the methods in which the equipment have to be destroyed during the process of their treatment for safe disposal.

However, the technology has some limitations as well. It does not reduce the volume of waste and makes the waste heavier after treatment because of condensed steam. Also, barriers to direct steam exposure or heat transfer (like, inefficient air evacuation, excessive waste mass) affect the effectiveness of the autoclave. Despite some of these limitations, sterilization through autoclaves is preferred because of its numerous advantages. The effectiveness of autoclaves can be improved by making sure that an effective waste segregation plan is in place, proper waste load is used, worker training is provided and regular maintenance of the autoclave is done.

To generate steam for sterilization in the autoclave, some form of energy is required. Traditionally, it is coal, gas, oil and electric power. Changes in climate and the depletion of fossil fuels have forced the world to look for renewable sources of energy. The cost, unreliability or unavailability of fuel and electricity in many areas adversely impacts the ability of medical facilities to autoclave medical/surgical instruments and infectious waste.

In recent years, therefore, the world is looking towards environment friendly renewable sources of energy. The solar energy is one such renewable source of energy that is easily available in most parts of the world. There are a number of countries, like, India, Pakistan, Bangladesh, South Africa and Nigeria, where sun light is abundant for most of the time during a year. This sun light is now being converted into energy for being used for a number of purposes.

The importance of using solar energy for healthcare has been emphasized by a study conducted by Aditya Ramji and others **(2017)** [23] and is one of the first evaluations in India of the role of electricity access on health outcomes in the state of Chhattisgarh. Of the sample 147 Primary Health Centres (PHCs), 56% are solar PHCs. Of these, about 45% are power-deficit PHCs. Among these, the average duration of a reported power cut is about three to five hours. The solar system is designed to provide backup for a similar duration. The power-deficit PHCs using diesel generators as backup run the generator for about three to four hours each day. It would be beneficial both economically and environmentally to opt for solar over diesel. A cost comparison shows that one unit of electricity from a diesel generator costs about INR 24–26 per kWh, while using solar with battery costs around INR 12–14 per kWh. With the cost of solar panels coming down in

thelast few years, the significant other cost is that of storage. The low-cost, low-emission option provided by solar offers overall benefits to both society and the health system. About one-third (36% of the sample) of all sample PHCs reported that their electricity needs were not met by the available sources of electricity supply. About 22.4% of power-deficit PHCs rely exclusively on solar as a backup to run cold chain equipment. About 21% of power-deficit PHCs do not have solar backup to operate newborn care equipment. About 37% of the sample PHCs reported that their water supply was adversely affected due to lack of electricity supply. The lack of adequate and quality water supply compromises the ability to provide basic, routine services such as child delivery, and also undermines the ability to prevent and control infections About 46% of PHCs were in the power-deficit category and without the support of solar PV systems. This affects the ability of PHCs to transition to higher standards of providing 24x7 health services The PHCs that do not have any power deficit (that is, access to reliable electricity for adequate duration) have better performance metrics than those without electricity access. This is seen across indicators like provision of emergency services, deliveries conducted, and in-patient as well as out-patient care. Further, it was found that these improvements in service delivery are correlated with better health outcomes for the community. The current study finds that solar systems play a pivotal role in the functioning of equipment and in the maintenance of cold chain services across PHCs in Chhattisgarh. On an average, power-deficit PHCs with electricity supply augmented by solar perform significantly better in terms of service delivery than those without such systems. Priority should be given to power-deficit PHCs, especially those that have been designated to provide 24x7 services.

Thus, this study also highlights the role of solar energy in healthcare. The solar energy can be effectively utilized for running an autoclave for sterilization of medical waste, surgical and other medical instruments, equipment and tools.The solar energy is environment friendly, low cost, easily available (e.g., in most parts of India in Uttar Pradesh, Madhya Pradesh, Maharashtra, Gujarat, Rajasthan, Haryana, Bihar, Orissa, West Bengal, Karnataka, Tamil Nadu, Telangana, Andhra Pradesh, Kerala, etc.) and is a renewable source of energy.

Conclusion

Therefore, Solar Autoclave, based on low temperature steam sterilization technique, one of the non-incineration technologies for bio-medical waste management,is very useful for treating hospital waste and medical instruments and equipment in a cost effective and environment friendly manner for small health care centers. The solar energy for generating steam is a renewable source of energy, environment friendly and can be used in villages as well as towns and cities. Solar Autoclave is relatively new technology for sterilization. The technology can be effectively used with power backup for so that it can be used when solar power is not sufficiently available.

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