ORIGINAL ARTICLE

Construction, Design and Testing of Infectious Waste Decontamination Device by Mechanical and Chemical Methods, Imam Khomeini Hospital, Sarab, Iran: A Case Study

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Abstract

Background: The aim of this study was to provide a suitable system for disposal of hospital waste and design and construction of a safe device for infectious waste using a combination of chemical and mechanical methods.

Methods: This research is a laboratory study and based on the existing problems, design and construction of a decontamination device for hospital infectious waste was performed by combination of chemical and mechanical methods in a closed reactor. To determine the appropriate mixture of different compounds of sodium hydroxide with lime and sodium carbonate with lime, three treatments were selected and used.

Results: The results of this study showed that the decontamination waste device by chemical and mechanical methods was effective in eliminating 98% of bacterial, fungal, and viral contaminants. The results showed that the neutralization rate for total bacterial contamination of the coliform, pathogenic viruses, *Escherichia, Bacillus subtilis, Salmonella,* and *Shigella* using a 30% ratio was related to the chemical composition of lime and sodium hydroxide, lime and sodium carbonate, respectively. In the designed device, the best temperature, humidity and pH conditions were determined to be 15°C, 45% and 12.8, respectively.

Conclusion: The results of the decontaminated waste tests revealed that the simultaneous application of physical and chemical methods can be used as a safe and suitable alternative in infectious waste disposal systems.

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Introduction

Infectious waste refers to those solid wastes which may cause human disease and may reasonably be suspected of harboring human pathogenic organisms, or may pose a substantial threat or potential hazard to human health or the environment.[1-3] The lack of control over the proper management of hospital waste in terms of how to collect, transport, and dispose of this type of waste can lead to the spread of various diseases and urban and rural epidemics that in addition to serious threat to public health and the environment also causes loss of costs.[4-6]

There are several ways to decontaminate waste. Studies conducted by the World Health Organization confirm that the method of steam sterilization (autoclave) only affects the infectious properties of such wastes and other properties of special and hazardous wastes are not affected by this method.

Therefore, the use of autoclave sterilization method reduces the risk of hospital waste, but does not inherently eliminate the potential risk of such waste.[7-10] Studies show that steam sterilization systems have limitations in practice. Medical waste usually contains large amounts of synthetic material, which is not a good conductor of heat, so heat penetrates slowly deeper into objects, thus prolonging the autoclaving process. In addition, water and energy consumption of this method is high and expensive and the cost of usage and maintenance is also very high.[11, 12] In the microwave method, infectious waste is disinfected by microwave waves. In this type of system, shortwaves are not able to heat the surfaces of dry, porous objects without moisture. On the other hand, the cost of use and maintenance is also high.[13-15] In the new method of disposal of infectious waste (autoclave+microwave), for avoiding the negative effects of the single use of each of the two aforementioned systems and the optimal use of the economic features of each one, the use of a combined system (autoclave+microwave) is required although the cost of its use and maintenance is very high.[16-18] Mosaferi et al. (2013) examined the situation of medical waste decontamination devices in hospitals in East Azerbaijan province and determined that the amount of infectious and sharp waste produced in hospitals in the province was not compromised due to high costs of maintenance, repair, and impairment of decontamination devices.[19]

Navaei (2012), with the aim of manufacturing a safe device for decontamination of hospital and laboratory infectious waste, designed a system of autoclave type in which hospital infectious waste was affected by pressure and temperature of 135°C during the process and all active microbes were killed in this temperature with high pressure. The final product, which has a much reduced volume (about 75%), is easily disposed of municipal waste.[20] Fahiminia et al. (2016) in the study of monitoring and disinfecting the infectious waste and its optimal management in hospitals of Qom province, according to the study of decontamination systems and changes affecting hospital waste decontamination, concluded that lower cost of operation and maintenance is an important factor for the buyers and users of a proper system in hospitals.[21] Also, a study of decontamination devices for hospital waste in Gilan province concluded that the autoclave and microwave and incinerator were used in this province.[22] Ferdowsi et al. (2013) in a study on the performance of incineration decontamination devices of hospital infectious waste in Isfahan revealed that TST (temperature, steam and time) and spore tests were all desirable and indicated good performance of the decontamination process.[23] Hydroclave device has the problem of expensive pieces, maintenance, and repair. The microwave waste decontamination device has the problem of penetrating radiation rays, and in chemical devices, there are environmental hazards and lack of complete injection of chemicals.[24] Therefore, in this study, with the aim of providing a suitable, indigenous and economic system for the elimination of hospital waste, we designed and constructed a decontamination device for infectious waste using a combination of chemical and mechanical methods.

Methods

This descriptive-analytical study was carried out through face-to-face referral, gathering information on the methods of decontamination of infectious waste in medical centers by observing and examining the non-hazardous waste systems and interviewing with officials and experts in charge of decontamination of hospital waste regarding effective variables on selection of a decontamination waste equipment. Then, the quality of hospital infectious waste decontamination devices was evaluated. Based on the existing problems of hospital waste disposal devices, the design and construction of a decontamination device for hospital infectious waste was performed by combination of chemical and mechanical methods in a closed reactor as follows:

Design Criteria

In designing the decontamination device for infectious waste, issues such as the amount and time of disinfection, water and electricity consumption, the capacity of the device, the amount of waste reduction, price, shredding the waste and chemical composition were considered. Therefore, according to these criteria, all parts and components of the device were designed in such a way that it had the most optimal quality of neutralizing and the lowest cost.

The parameters that were evaluated in the system design were as follows:[25, 26]

- The weight of the received waste
- The volume of the received waste
- The temperature and humidity of the received waste
- Physical composition of the waste
- Type of chemical compounds and amount of chemicals used
- The extent of shredding the particles, mixing, and removing the leachate
- Sampling, sample cultivation and control of the device output
- Output waste packaging

The Method of Performing Experiments

To determine the appropriate chemical composition, we used different compositions of lime (CaO)-sodium carbonate (Na_2CO_3) and lime-sodium hydroxide (NaOH).[27] Regarding the fact that by increasing the pH in the compounds used the total Endo-fecal coliform and the total coliforms count

were reduced, in order to obtain the appropriate pH, we selected the ratio of lime-sodium carbonate and lime-sodium hydroxide compounds as 10, 20 and 30 percent. Temperature, humidity, and pH were the variables measured during the experiment. The envelope of biological indicator strip was placed inside a large paper envelope. The envelope was marked and placed near the center of the waste bag. Then, it was placed in a new bag in which the shredded waste was collected, so that it does not crush. At the end of the process, the waste bag was removed from the device and opened using appropriate personal protective equipment; the marked paper envelope was removed from it and the strip inside the envelope was removed in the laboratory next to a flame with a sterilized pen (Aseptic conditions). Then, the sample was cultured. The petri dishes (lactose broth) were then placed in an incubator. In order to study the growth of coliforms and *B. subtilis,* we incubated the sample at 35°C for one week in an incubator.[21, 28, 29] Chemical test by turnsole paper based on the color change from blue to pink indicates the correct operation of the device and can be used to detect the injection or non-injection of disinfectant (a mixture of sodium hydroxide-lime and sodium carbonate- lime).[21, 27, 30] Therefore, chemical testing should be performed during the operation of the device to ensure that the chemical compound is injected into the disposable waste.

Results

The system has been designed to be turned on 5 min before the operation to be prepared and warmed up (Figure 1). Then, the waste is placed in the chamber and after closing the lid, the device is ready to receive the infectious waste. First, the received waste is directed by a bar to the reactor of the device which is a cutting mill. The shredding mill includes fiery steel blades with the length of 18×3 cm^2 which starts to rotate by the rotor with adjustable rpm. Also, the rotor is connected to the storage of the chemicals mixture and includes a control hatch into the reactor. In this device, two mechanical (shredding) and chemical (adding chemicals) methods are used to decontaminate the infectious waste. A mill with vertical shredding (for the first time in the world) with fiery steel blades was used. In order to decontaminate the infectious waste, we used the mixtures of sodium carbonate-lime and sodium hydroxide-lime. In the designed system, the powder of chemicals mixture is sprayed on the shredded waste and the waste is mixed with the chemicals while being shredded and the three operations of removing the leachate, disinfecting and reducing the volume of the waste are done simultaneously. Then, the decontamination process is finished and the waste is discharged. The discharge system is electrical, and the waste discharge is done by the output of the shredding mill device. At the end, the powdered waste can be collected manually or mechanically and packed. The ratio of sodium carbonate and sodium hydroxide in the mixture with lime depends on the temperature, moisture content, and the leachate of the waste which is measured by moisture meter. Therefore, if the moisture content caused by the leachate of the waste is more than 60%, the amount of the chemicals used will be half of the weight of the waste. If the moisture content is less than 20%, the amount of disinfecting compounds will be a quarter of the weight of the waste. The adjustment of the chemicals used is done by a graded valve.

The results of the waste disposal at 15°C, 45% moisture content, and 2 kg of received waste at the device with an increase of 10% sodium carbonate and 90% lime showed that the pH of the destroyed sample was 9. Therefore, it was necessary to increase the pH for better effect. For this purpose, 20% sodium carbonate and 80% lime were added in the second stage and the pH was 11.2. To increase the pH again in the third stage, we added 30% sodium carbonate and 70% lime, and the pH value was increased to 12.5.

In another experimental study, the effect of chemical compounds on the wastes disposed by mixing sodium hydroxide and lime was investigated (Table 1).

In this method, a temperature of 15°C, 45% moisture content, and 2 kg received waste and a combination of 10% sodium hydroxide and 90% lime were used. PH of this mixture reached 9.5. To increase the pH for better effect on microorganisms, we used a combination of 20% sodium hydroxide and 80% lime. The pH of this mixture reached 11.5. To

Figure 1: Designed and constructed decontamination device for hospital waste by chemical and mechanical methods

further increase the pH of the disposal chamber in the designed device, we used a mixture of 30% sodium hydroxide and 70% lime, resulting in a pH of 12.5 (Table 1).

According to the results obtained in the parameters of the injection of chemical compounds to the designed decontamination device, the color change from blue to pink in the mixtures in which the percentages of sodium carbonate were 10, 20 and 30 showed that the injection of chemical compounds and increase in pH were done well. Also, in the second experiment, in the results obtained from the mixtures with the sodium hydroxide percentages of 10, 20 and 30, the color change from blue to pink happened which showed that the injection of chemical compounds and increase in pH were done well.

The results of microbial cultures performed in the first experiment showed that the 30% amount of lime and sodium carbonate eliminated 98% of all total Endo-fecal coliforms, pathogen viruses, *Escherichia*, *B. subtilis*, *Salmonalla* and *Shigella*. This result indicated the better effect of lime-sodium carbonate and lime-sodium hydroxide as the most desirable composition for disinfection of the infectious waste in the designed device (Tables 2 and 3).

The results of microbial cultures showed that when sodium carbonate was used as 10% of the chemical compounds, only 2 positive cases were observed, but in the results of microbial cultures from 30% sodium carbonate the culture of *B. subtilis*, total Endo-fecal coliforms, *Salmonalla* and *Shigella* were negative. This microbial result was observed for the mixture used, sodium hydroxide, as well.

The results obtained from Tables 2 and 3 showed that temperature, moisture and pH had an important role in the effect of chemical compounds on the

Table 1: Mixture of chemical compounds used in the disposal of infectious waste in the reactor of the designed device

No.	Moisture content (%)	Waste weight (kg)	pH	Percentage of chemical compounds	pH	Percentage of chemical compounds	Temp. (^{O}C)
1	45	2	9	Na_2CO_3 (10%) and CaO (90%)	9.5	NaOH (10%) and CaO (90%)	15
2	45	2	11.2	Na_2CO_3 (20%) and CaO(80%)	11.5	NaOH (20%) and CaO (80%)	15
3	45	2	12.5	Na_2CO_3(30%) and CaO(70%)	12.5	NaOH (30%) and CaO (70%)	15

Table 2: The results obtained from microbial tests of lime-sodium carbonate in the designed decontamination device, 2019

No.	Sampling date	Sampling hour	The mixture of 10% sodium carbonate and 90% lime				The mixture of 20% sodium carbonate and 80% lime				The mixture of 30% sodium carbonate and 70% lime			
			Total Endo-fecal coliform	B. subtilis	Salmonella	Shigella	Total Endo-fecal coliform	B. subtilis	Salmonella	Shigella	Total Endo-fecal coliform	B. subtilis	Salmonella	Shigella
1	11.11.2019	11	_	+	_	_	_	+	_	_	_	_	_	_
2	16.11.2019	17	_	+	_	_	_	_	_	_	_	_	_	_
3	21.11.2019	13	_	_	_	_	_	_	_	_	_	_	_	_
4	24.11.2019	10	_	_	_	_	_	_	_	_	_	_	_	_

Table 3: The results obtained from microbial tests of lime-sodium hydroxide in the designed decontamination device, 2019

No.	Sampling date	Sampling hour	The mixture of 10% sodium carbonate and 90% lime				The mixture of 20% sodium carbonate and 80% lime				The mixture of 30% sodium carbonate and 70% lime			
			Total Endo-fecal coliform	B. subtilis	Salmonella	Total Endo-fecal coliform	B. subtilis	Salmonella	Total Endo-fecal coliform	B. subtilis	Salmonella	Total Endo-fecal coliform	*Salmonella*	*Shigella*
1	11.11.2019	11	_	+	_	_	_	+	_	_	_	_	_	_
2	16.11.2019	17	_	+	_	_	_	_	_	_	_	_	_	_
3	21.11.2019	13	_	_	_	_	_	_	_	_	_	_	_	_
4	24.11.2019	10	_	_	_	_	_	_	_	_	_	_	_	_

decontamination of infectious waste. The increase in pH of the environment led to the optimal effect of chemical compounds and the moisture content of 45% was the most optimum percentage for the composition of chemical compounds for decontamination of waste in the device. The results indicated that with increase in the amount of chemical compounds, pH increased, so the pH values in the sodium carbonate mixtures with 10, 20 and 30 percent were 9.0, 11.2 and 12.5, respectively. Also, the pH values in the sodium hydroxide mixtures with 10, 20 and 30 percent were 9.5, 11.5 and 12.8, respectively. Since the high pH values destroy the cell wall of all bacteria, fungi and pathogen viruses, 30% sodium carbonate-70% lime with the pH of 12.5 and 30% sodium hydroxide-70% lime with the pH of 12.5 were selected as the best mixtures used in the designed device.

Discussion

The results of the present study showed that the decontamination device for infectious waste designed by a combination of chemical and mechanical methods were suitable according to the results of the experiments obtained in the elimination of all microorganisms in the decontaminated waste. Also, due to its indigenous technology and the short decontamination cycle as well as its low production cost, the designed device can be a good option for replacing other devices. Overall, the results of this research showed that the simultaneous use of physical and chemical methods could be a good alternative to conventional decontamination systems. The capacity of the device is based on 30 kg per hour; According to the loading times of the device and the wasted time (30 minute), 250 kg of infectious waste can be disinfected daily. After disinfection operations, microbial testing, and finalization of disinfection operations, the waste can be finalized as the normal waste and in a specific place in the waste landfill of the city. Based on the production of infectious waste and at the request of urban and rural health centers, the designed device can provide services to other centers.

One of the parameters of decontamination devices is their maintenance and repair. In this study, no specific problem was observed during the study process. However, regular periodic service will be provided by the operator according to the loading. The results of comparison of the decontamination device designed by chemical and mechanical methods by the research of the Malakootian et al. (2015) showed that 16% of the decontamination devices had non-desirable efficiency because of impairment and high usage cost.[30] In another study, it was identified that 25.7% of the decontamination devices had non-desirable efficiency because of the lack of heat penetration and incorrect application.[31] Also, in a study, the proper maintenance and use of safe devices was examined and emphasized.[11] Burning waste disposal devices cause environmental pollution and other devices have problems due to high off time, supply of pieces, repairs, and costly and labor-intensive use.[32] In a study conducted in Mashhad, the results revealed that 66.6% of the hospitals had autoclaves and in 16.67% of them they were not used due to the high cost, maintenance, and problems.[33]

Another parameter that should be considered in these devices and the final waste is to ensure the absence of microorganisms, especially pathogens. Tiller (2004) in the evaluation of autoclaves for the safe decontamination of medical waste showed that there was bacterial growth in 18 out of 22 cases of cultured samples from the disposed waste. The results indicated the poor condition of autoclaves for decontamination due to lack of heat penetration and non-conductivity of some infectious wastes.[28] Jette (2010) in Canadian hospitals evaluated the chemical and mechanical performance of incineration decontamination devices as good.[27] Nowadays, various systems such as Autoclaves, Hydroclaves, Microwaves, and Chemicals are used to dispose the hospital waste, each of which having problems (As mentioned earlier). For example, autoclaves have a problem with heat penetration into waste and heat dissipation plastic.[21, 27] However, in this device, the operation problems have been decreased due to the simple design, low cost, and localization of the pieces and low cost of use and maintenance. Also, the results of the study showed that the elimination of all total Endo-fecal coliforms, pathogen viruses, *Escherichia*, *B. subtilis*, *Salmonalla* and *Shigella* contaminations in waste was 98% by the mixture of 30% sodium hydroxide and sodium carbonate with lime.

The result of the present study showed that the sample of the designed device for decontamination of infectious wastes by the combined chemical and mechanical method, as presented in Figure 1, was suitable according to the test results obtained in decreasing of all microorganisms in the waste. Due to its native technology and short decontamination cycle as well as its low production cost, it can be a good option to replace other devices used. In general, the results of the experiments on destroying the waste showed that the simultaneous use of physical and chemical methods could be appropriate methods to replace conventional destruction systems.

Conclusion

The result of this research study was the design and construction of a hospital waste disposal device chemically and mechanically. Due to the fact that disinfection operations must be performed on all wastes, it is necessary to pay attention to all the three parameters

(type of loading, time, and the ability of disinfectants to penetrate to all points). Therefore, it is recommended that low load waste should be used in suitable conditions to ensure the completion of the decontamination process from 1 minute or operation of the device; due to the uneconomical operation in these conditions, the use of 15 minutes is the preferred option. Comparison of decontamination capacity and manpower required in the hospital, according to the calculations performed, showed that the decontamination capacity of the waste in the hospital was 2 kg per minute (low load). Also, considering the 4-hour work shift, in the hospital, 800 kg of waste per shift could be eliminated by the device, respectively. In fact, the hospital, with its active device, is able to dispose of 800 kg of waste at the same time in each shift. Due to the fact that in this hospital the waste decontamination capacity in each 4-hour work shift is more than the total infectious waste generated during the day, according to the rest time, the presence of one operator is enough to dispose of all waste. The device used in the hospitals has such problems as clogging, blade failure, need to sufficient time for each cycle, and dependence on the technology of other countries; therefore, the new device is recommended due to the low cost, lower maintenance, and favorable results in the removal of pathogens.

Equipping all hospitals in the country with safe devices is inevitable due to legal requirements and their importance in providing a healthy environment and promoting community health. Also, by considering the reservation device for each hospital, it is possible to prevent the accumulation of waste or their improper disposal during the breakdown of the main device or in emergency situations.

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