The safety of non-incineration waste disposal devices in four hospitals of Tehran

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Background: The safe management of hospital waste is a challenge in many developing countries.
Objectives: The aim of this study was to compare volatile organic compounds (VOCs) emissions and the microbial disinfectant safety in non-incineration waste disposal devices.
Methods: VOC emissions and microbial infections were measured in four non-incineration waste disposal devices including: autoclave with and without a shredder, dry heat system, and hydroclave. Using NIOSH and US EPA-TO14 guidelines, the concentration and potential risk of VOCs in emitted gases from four devices were assessed. ProSpore2 biological indicators were used to assess the microbial analysis of waste residue.
Results: There was a significant difference in the type and concentration of VOCs and microbial infection of residues in the four devices. Emissions from the autoclave with a shredder had the highest concentration of benzene, ethyl benzene, xylene, and BTEX, and emissions from the hydroclave had the highest concentration of toluene. The highest level of microbial infection was observed in the residues of the autoclave without a shredder.
Conclusions: There is an increased need for proper regulation and control of non-incinerator devices and for monitoring and proper handling of these devices in developing countries.

Keywords: VOCs, Microbial quality, Waste residues, Non-incineration waste disposal devices, Hospital waste management, Autoclave, Hydroclave, Dry-heat systems

Introduction

Safe hospital waste management continues to be a challenge in many developing countries. Although significant improvement has been seen in the safe handling and disposal of hospital wastes, poor handling and inappropriate disposal methods from initial collection to the final disposal continue to be of concern and pose significant health hazards to hospital staff, the general population, and the environment.[1]

Hospital wastes accounts for approximately 1–2% of the total urban waste in Iran and requires special attention and management.[2] Prior to 20 years ago, hospital wastes management was not a concern in Iran and was treated the same as household waste. In Iran, the emergence of the HIV/AIDS epidemic attracted the attention of health authorities to hospital waste management. Until recently, incineration was the sole method for hospital waste management in Iran. However, because medical waste incineration was identified as the single largest source of dioxin pollution and a source of other pollutants, some of which are known carcinogens, including furans, heavy metals, fine dust particles, hydrogen chloride, sulfur dioxide, carbon monoxide, nitrogen, and oxides, non-incineration facilities for the treatment of medical waste were introduced and regulations related to their use were set by the Ministry of Health and Medical Education.[3]

The World Health Organization in a 2004 policy paper entitled "Health-care Waste Management" stated that "effective, scaled up promotion of non-incineration technologies for the final disposal of health-care wastes to prevent the disease burden from (a) unsafe health-care waste management and (b) exposure to dioxins and furans" should be a priority for developing countries.[4]

A major benefit of non-incineration technologies is that they cost less than traditional medical waste incinerators.[5] In the last ten years, non-incineration methods for hospital waste management have been widely accepted in hospitals in Iran and other countries around the world.

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There are four primary types of non-incinerator devices in hospitals in Iran, which work based on steam, shredding, or dry-heat. Dry-heat systems use heat (130–155°C) without steam or water, heating waste by natural or forced convection (circulation of natural gas around the waste in the chamber), and/or by thermal radiation (by means of infrared or quartz heaters). A shredder with a speed of 3000 rounds per second is used in this device. Emissions from this device pass through a carbonic filter and antiseptic container before being released into the atmosphere.

In autoclaves, heat (121–138°C) and steam pressure (5 bar) are used for waste disinfection. Autoclaves are made of a metal chamber surrounded by a steam jacket and sealed by a charging door. The steam flows into the outside jacket and the inside chamber. Heat in the outside jacket results in a condensation decrease in the inside chamber, allowing the use of steam at lower temperatures. The inside chamber is vacuumed to ensure heat penetration of the waste by omitting the air insulating effect.[4] If a shredding system is used in autoclave, it is referred to as autoclave with shredding. Autoclave emissions pass through an antibacterial filter before mixing with water and being discharged into the sewage system.[6,7]

Hydroclave is a jacketed cylindrical vessel with shredding system inside. Waste is loaded into a door on top of the vessel and high temperature steam (121–138°C and 5 bar steam pressure) enters the outside jacket to heat up the waste via the hot inner surface. A shredding system fragments and tumbles the waste. The moisture in the waste turns to steam and pressurizes the inner vessel. If there is not enough moisture, steam is added until the desired pressure is achieved. After treatment, the steam is vented through a condenser while maintaining heat input, drying the waste.[4]

The outputs of these devices include solids (waste residue), liquids, and gases (emitted). As the input is hospital waste, inactivating infectious microorganisms is essential to reducing the threat to healthcare workers and the general population. However, in Iran, there are currently no regulations on the wastewater emissions of these devices beyond the general standards for water treatment.[8–10] Additionally, although the US EPA has identified 40 volatile compounds that should be monitored in the ambient air, some of which are produced in waste management device emissions, there is no regulation related to monitoring the pollution output of non-incinerator devices used in hospital waste management in Iran.[1,11]

Furthermore, because non-incinerator medical waste management is new in Iran, there is no research on the safety of these devices, including the infectious waste residue and volatile compounds emitted from these devices, which pose a threat to the health of hospital staff and the general population. Additionally, because these devices operate intermittently, the operating condition of these devices is a concern. There are currently no requirements regarding the regulation and monitoring of these devices.

The aim of this study was to determine the types of volatile organic compounds (VOCs) in emitted gasses and the microbial disinfectant safety of these devices in Iran. It is the first study of its kind to investigate the safety of non-incinerator waste devices in this country.

Methods

This study was conducted in four hospitals in Tehran, Iran. Selection of hospitals was based on their size and type of non-incinerator devices used for waste disposal. Table 1 shows the hospital characteristics and their waste disposal devices.

Sampling and data collection

The sampling of emitted gases was performed using sampling devices based on the NIOSH 2549 standard. For sampling purposes, thermal desorption tubes with a diameter of 1.4 inches were used. Prior to field use, all thermal desorption tubes were cleaned by heating and assigned a unique identifier number. The sampling pumps (SKC, Covington, GA, USA) were calibrated, and immediately before sampling the cap was removed and attached to a personal sampling pump with flexible tubing.

Five-liter samples were collected using a sampling pump with the flow level of 0.01–0.05 l/min.[12] Caps were replaced immediately after sampling. Humidity was also measured. An indoor air sample was collected at the same location, outside the non-incineration device, to be used as control sample. Coconut Shell Charcoal Lot 2000 was used as anasorb. The sample containers were transferred at ambient temperature and stored at −10°C until analyzed. Ten samples were taken during a 10-week period (one sample each week) to account for differences in the operation of the devices. The sampling and pump numbers, time of and

Table 1 Characteristics of hospitals and the devices they used for waste disposal

Hospital code	Number of active beds	The waste production rate (kg/bed/day)	Type of device
1	477	5.1	Autoclave without shredder
2	870	3.9	Dry-heat
3	100	7.5	Autoclave with shredder
4	50	4.57	Hydroclave

duration of sampling, humidity, wet and dry temperatures, and the date of sampling were labeled on each tube. The charcoals in the tubes were transferred to a small, stoppered vial, and the analyte was desorbed with 1 ml of carbon disulfide (from Merck Company, 102210100) for 60 minutes and stored in an ultrasonic container for 30 minutes. There was a control tube for each sample.

An aliquot of the desorbed sample was injected into Gas Chromatography (GC) detection. The GC device was equipped with a flame ionization detector (GC Chrompack CP 9001). The GC device was set on a time schedule of 60°C for 2 minutes, and then temperature increased 10°C per minute until reaching 250°C for 2 minutes. The temperature was then reduced to 60°C. The total run time was approximately 10 minutes. Using this procedure, all the VOCs were evaporated and based on their retention time on the capillary column, were identified by one or more detectors, and quantized. Results were analyzed in two stages based on US EPA (TO-14) guidelines. In first stage, the 40 target compounds were qualitatively analyzed for the presence or absence of each compound.[13] In the second stage, detected compounds were quantified. Standard calibration graphs were produced for each compound and their quantity was determined by comparing the pick on calibration graph with the standard calibration graph. Results were compared with the Occupational Exposure Limits defined by US EPA.[14]

The final calculation of the VOCs was done using the following formula:

$$C = \frac{Wf + Wb - Bf - Bb}{VR} \quad (1)$$

where Wf is the mass of compound in front part of sorbent, Wb is the mass of compound in back part of sorbent, Bf is the mass of compound in front part of control sorbent, Bb is the mass of compound in back part of control sorbent, V is the sample volume, R is the percentage of desorption of compound (obtained from the sorbet catalog) and C is the concentration of the compound (mg/m^3).[15]

For calculating the concentration based on ppm under standard concentration (25°C, 760 mmHg), we used the formula:

$$\text{ppm} = \frac{\text{mg/m}^3}{\text{Mw}} \times 24{\cdot}45 \quad (2)$$

where 24.45 is the molar volume of air and Mw is the molecular weight of the compound.[15]

The potential risk of the VOCs in the emitted gases from the devices was evaluated based on the US EPA-TO14 guidelines. Compounds with the highest pick in the qualitative analysis were quantitatively analyzed.

Microbial analysis of waste residue was performed based on the guidelines of the Iranian Ministry of Health and Medical Education. ProSpore2 (a self-contained biological indicator) containing 10^6 spores of *Geobacillus stearothermophilus* ATCC7953 was used to test the efficacy of devices in disinfecting the waste residue. ProSpore2 consists of a paper disc carrier with *Geobacillus stearothermophilus* (ATCC 7953) spores. The disc is in a plastic tube with a glass vial of growth media for the bacterial spores. Bromocresol purple (a pH detector) was added to detect spore growth. The growth of spores decreases pH and changes the color purple to yellow after a 24-hour incubation period.[16]

Ten runs were conducted for each autoclave during the 10-week period, yielding 40 samples. The biological indicator in the test trial was placed in a horizontal position as far away from the heat sources as possible, as recommended by the manufacturer. At the end of cycle, the ProsPore2 indicator was cap sealed. The glass ampoule of media was crushed and the *Geobacillus stearothermophilus* disc was contaminated. Vials were then incubated at 55°C for 48 hours.

If the ProsePore2 biological indicator retained its purple color, it signified an adequate sterilization cycle and if it showed turbidity or a color change toward yellow for that sterilization cycle, it indicated inadequacy of sterilization and the chance of microbial contamination. In each round, untreated ProsPore2 biological indicators were incubated as controls.[17]

Statistical analysis

All analyses were performed using SPSS version 19.0 for Windows (IBM Corporation, New York, USA).

Results

Among the 40 VOCs tested, benzene, toluene, ethyl benzene, and xylene (BTEX) were detected. Table 2 shows the level of BTEX in the emissions of the four non-incineration devices in the hospitals. The lowest concentration of VOCs was from the non-shredder autoclave, which showed benzene in 20% of the samples with the highest concentration of 0.063 ppm, toluene and ethyl benzene in 40%, and xylenes in 30% of the samples with the highest concentrations of 994.5, 2.2, and 1.3 ppm, respectively. The BTEX concentration was in the range of 0–4.346 ppm. In dry heat system the BTEX concentration was in the range of 1.1–11.6 ppm and toluene was present in 90%, ethyl benzene and xylene in 80% and benzene in 60% of the samples. In the autoclave with shredder, ethyl benzene was the main pollutant emitted, found in 80% of the samples with a high concentration of 10.9 ppm. Xylene and toluene were observed in 70% of the samples with a high concentration of 6.7 and 4.9 ppm, respectively. In the hydroclave, BTEX was

Table 2 Concentration of VOCs (ppm) in emissions of each device in 10-week study duration

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Mean (SD)
Autoclave without shredder											
Benzene	…	…	…	0.051	…	0.063	…	…	…	…	0.57 (0.0)
Ethyl benzene	0.302	…	…	0.385	…	2.994	…	1.06	…	…	1.18 (1.2)
Toluene	…	…	…	1.722	0.604	…	…	0.097	…	2.497	1.23 (1.1)
Xylene	0.182	0.239	…	…	…	1.307	…	…	…	…	0.58 (0.6)
ΣBTEX	0.484	0.239	…	2.158	0.604	4.346	…	2.157	…	2.497	1.78 (1.5)
Dry-heat system											
Benzene	…	0.118	…	…	0.244	0.062	0.122	0.215	…	0.231	0.16 (0.1)
Ethyl benzene	0.832	0.278	0.344	…	1.022	2.626	0.53	…	0.51	2.323	1.06 (0.9)
Toluene	4.193	2.937	0.616	…	2.742	4.423	1.084	0.888	5.24	6.328	3.16 (2.0)
Xylene	0.446	3.277	1.286	0.204	0.208	…	4.716	…	1.446	5.26	2.10 (2.0)
ΣBTEX	5.471	6.61	2.246	0.204	4.216	7.111	6.452	1.103	7.196	14.142	5.47 (4.0)
Autoclave with shredder											
Benzene	0.922	…	0.622	…	…	…	0.087	0.283	0.246	0.677	0.47 (0.3)
Ethyl benzene	5.721	3.592	…	6.97	8.477	…	10.892	6.516	1.584	4.955	6.09 (2.9)
Toluene	…	0.88	4.902	7.012	1.276	2.77	0.192	…	…	2.877	2.84 (2.4)
Xylene	…	6.053	5.67	0.813	…	…	0.412	2.285	0.142	6.711	3.1 (2.9)
ΣBTEX	6.643	10.525	11.194	14.795	9.753	2.77	11.583	9.084	1.972	15.22	9.3 (4.5)
Hydroclave											
Benzene	026	…	…	0.051	…	0.04	…	…	…	0.598	5.39(11.5)
Ethyl benzene	1.582	…	1.304	2.542	…	1.468	0.585	2.107	…	1.067	1.53 (0.6)
Toluene	5.823	0.988	…	5.767	1.598	7.329	4.779	1.034	…	…	3.9 (2.6)
Xylene	1.442	0.982	…	0.681	1.801	1.548	4.3	…	…	4.155	1.8 (1.5)
ΣBTEX	8.873	1.97	1.304	9.041	3.399	10.385	9.64	3.141	…	5.82	5.5 (3.6)

in a concentration range of 0–10.4 ppm and the highest concentration was observed for toluene (5.8 ppm), which was present in 70% of the samples.

The mean BTEX concentration for the 10 weeks of measurements was 1.78 ppm in the autoclave without shredder, 5.47 ppm in the dry-heat system, 9.3 ppm in the autoclave with shredder, and 5.5 ppm in the hydroclave.

Table 3 shows the highest concentration of BTEX emissions and the devices with the highest concentrations. Emissions from the autoclave with shredder had the highest concentrations of benzene, ethyl benzene, and xylene, and emissions from the hydroclave had the highest concentration of toluene.

The results of microbial tests showed that in the autoclave without a shredder, 50% of samples showed microbial growth. In the dry-heat system and autoclave with a shredder, none of the microbial growth was positive and in the hydroclave, 20% of the samples showed microbial growth (Table 4).

Discussion

When not properly treated, hospital wastes represent a potential hazard to staff, scavenger populations working on the streets or disposal facilities, and to the health of the general population. Furthermore, it is a source of environmental exposure to toxins. Hospital waste management in developing countries has raised serious concerns due to inappropriate, unregulated, and unsupervised treatment and disposal practices.[8,12]

Hospital waste management in Iran is less than two decades old and the use of non-incineration waste devices is even newer. Non-incineration devices for waste management typically impose lower costs to hospitals, result in less environmental pollution and therefore are used in most Tehran hospitals. However, non-incineration methods of hospital waste management are still a new technology and there is no regulation for the proper handling and monitoring their function and efficacy to ensure that they do not impose hazards to individuals and/or the environment. The proper training and knowledge of staff on how to use these technologies are almost non-existent. Finally, there is no monitoring of the appropriate operation of these devices, making this study to assess the type and level of VOCs emissions and microbial quality of the waste residues of four non-incineration waste disposal devices (autoclave with shredder, autoclave without shredder, hydroclave, dry-heat system) an important first step in improving the safety of the population and the environment.

The results of this study found that BTEX were the VOCs detected in the emissions of these devices.

Table 3 The highest concentrations of VOCs and devices with the most VOCs concentration

	Highest concentration observed (ppm)	Device with the most concentration
Benzene	0.922	Autoclave with shredder
Ethyl benzene	10.89	Autoclave with shredder
Toluene	7.33	Hydroclave
Xylene	6.71	Autoclave with shredder
ΣBTEX	15.22	Autoclave with shredder

Table 4 Results of microbial growth tests during 10-week study

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Autoclave without shredder										
Microbial growth	+	−	−	+	+	+	−	−	+	−
Dry-heat system										
Microbial growth	−	−	−	−	−	−	−	−	−	−
Autoclave with shredder										
Microbial growth	−	−	−	−	−	−	−	−	−	−
Hydroclave										
Microbial growth	−	−	+	+	−	−	−	−	−	−

Note: +, microbial growth; −, no microbial growth.

BTEX frequently occur together. Toxicokinetic studies in humans and animals indicate that these chemicals are well absorbed, distribute to lipid-rich and highly vascular tissues such as the brain, bone marrow, and body fat due to their lipophilicity, and are rapidly eliminated from the body. The available knowledge on toxic or carcinogenic responses to mixtures of BTEX is insufficient. All four components can produce neurological impairment; in addition, benzene can cause hematological effects associated with aplastic anemia and the development of acute myelogenous leukemia. Results of different studies showed that joint neurotoxic action is expected to be additive of BTEX concentrations below approximately 20 ppm of each component.[9]

Iranian standard Threshold Limit Value (TLV) for benzene is 0.5 ppm, for toluene is 0.50 ppm, ethyl benzene is 100 ppm, and for xylene is 100 ppm. The results of this study showed that the concentration of benzene in emissions of 10% of samples of hydroclave, 30% of samples of autoclave with shredder, and 10% of samples of dry-heat system were higher than the Iranian standard TLV, but the concentration of BTEX, toluene, xylene, and ethyl benzene were lower than the TLV. However, it is likely that staff in close contact with these emissions is also exposed to BTEX from other sources in a polluted city like Tehran. A study by Bahrami of air of Tehran City showed that the concentrations of benzene, toluene, and xylene were 2.7, 201.2, and 110.7 $\mu g/m^3$, respectively, much higher than the bio-environmental standards.[10]

This research showed that there was a wide variation in the concentration of BTEX by non-incineration device. The lowest concentration of VOCs was from non-shredder autoclave. Emissions from the autoclave with shredder had the highest concentration of benzene, ethyl benzene, xylene, and BTEX, and emissions from the hydroclave had the highest concentration of toluene. Different types of waste materials, heat and pressure levels, and shredding system may partially explain the observed variations.[18] The results of this study showed that shredding, while decreasing the volume of the waste and sterilization process, has an important impact on increasing VOCs production, likely related to shredding plastics.[19] Also, wide variation in the level of BTEX in this study may be due to a lack of proper operation of these devices by staff who have not been trained to operate these devices. We recommend increased training and operation monitoring in hospitals. Results from a study by Gaika and Luger raise concerns that as the age of the devices may be related to pollution output.[6]

The results of the microbial tests showed that half of samples in the autoclave without a shredder and 20% of the hydroclave samples had microbial growth. The absence of shredding may prevent heat from effectively reaching the waste, and steam may not adequately penetrate waste resulting in an incomplete disinfection process.

A study by Coulter *et al.* to assess the knowledge and training of medical personnel in England and Wales on autoclave use, as well as to examine the effectiveness of their autoclaves, found that 2% of the autoclaves did not kill spores, suggesting the need for increased monitoring of autoclave performance.[7]

Linscott has reported that tests on steam autoclaves in Louisiana have repeatedly results in undesirable results, with bacterial growth occurring in 18 of 22 ampules, and chemical indicators failing in 19 of 22 locations. It was concluded that steam did not fully penetrate the load and therefore the waste was not adequately disinfected. This study recommended that institutions considering autoclaves test carefully and regularly.[18]

Lee *et al.* suggested that when using steam sterilization, cycle times should be readjusted based on the waste load, with large bulky loads of bio-hazardous waste requiring a minimum of 60 minutes, while standard 121°C, 15-psi, and 15-minute dwell times are adequate for sterilization of clean items or smaller loads. They also recommended that the autoclave bag never be over-packed or sealed too tightly, the use of an autoclave logbook to maintain records, annual general maintenance (or as recommended by the manufacturer), and proper training for all autoclave users.[12]

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