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Diagnostic Analysis of Mechanical Conditions of Small-Scale Incinerators in the Healthcare Facilities in Tanzania

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Abstract

This paper provides analytical diagnosis of mechanical conditions of medical waste incinerators used for healthcare waste (HCW) treatment in Tanzania. The main features assessed were types of incinerators, features of incinerators and incinerator house. The assessment was conducted in three levels of health care facilities (HCFs), that is, Regional, district hospitals and health centers, existed in 26 regions of Tanzania. Questionnaires, interview and checklists were used as tools for data collection. It was observed that High-Tech incinerators are mainly used in regional hospitals, while district hospital and health center use both High-Tech and De-Montfort incinerators. About 60% of the incinerators have defective doors. More than 55% of incinerators are corroded in regional and district hospitals. The chimney, top plates and grate which are good condition are 55.6% and 60% in regional hospitals and health centers, respectively. The situation is below 50% in district hospitals. The leakage of the roof and loose structures were observed in district hospitals and health center to be more than 50% of the incinerator houses. On other hand, the performance of burners and incinerator housing cleanliness are generally good. It was concluded that the incinerators in the HCFs are in bad conditions, necessitating maintenance.

Keywords

Small-Scale Incinerators, Healthcare Waste, Mechanical Conditions, Waste Generation Rate, Operation and Maintenance, Environmental Cleanliness

1. Introduction

Waste incineration has become a major method of municipal solid waste and HCW treatment and disposal worldwide [1] [2]. Although many large-scale municipal incinerators have been put in operation, there is still an acute need for building small-scale incinerators with a capacity of 100 - 150 kg/h to save for waste generated from healthcare facilities. These small-scale incinerators are vital for the purposes of disease control, environmental sanitation, and budget-saving in rural areas and remote communities. The World Health Organization (WHO), in order to obviate the spread of hepatitis, AIDS and other diseases, has been promoting the use of low-cost small-scale incinerators to dispose of health-care waste [3].

1.1. Generation and Disposal of HCW

Before the year 2000, Tanzania had extremely limited options for safe HCW disposal, especially for used and/or contaminated sharps (lancets, blades, syringes or hypodermic needles with or without attached tubing; broken glass items such as Pasteur pipettes and blood vials and other invasive devices) that can cause injury and that are associated with significant risk of infection if indiscriminately disposed [4]. Incinerators were only used in referral hospitals until when De-Montfort types were introduced around 2004 for destruction of infectious waste [5].

Infectious waste generated in hospitals include also non-sharps, e.g., materials that have been in contact with blood, its derivatives, or other body fluids, e.g., bandages, swabs or items soaked with blood. While generally less than 10% of HCW is considered infectious, many HCFs have poor waste segregation practices [6]. Even where there are well-established protocols, lack of funds and continuous supervision and improvements lead to poor segregation. This complicates waste management since mixing sharps and other infectious waste with non-infectious waste will always increase the amount of waste considered infectious that requires special treatment for safe treatment and disposal [7].

Resources are extremely limited in many HCFs, especially in remote areas where procurement of bins and bin-liners face challenges. Consequently, open pit burning is still widely practiced for HCW including sharps. This practice is objectionable due to emissions, incomplete disinfection and destruction of the waste, and community complaints [8]. The volume of HCW generated in HCFs varies by the size and type of service or activity of the clinic or hospital. Small rural clinics may generate relatively small quantities of infectious waste, e.g., 1 to 10 kg of sharps per month. Quantities can be an order of magnitude greater at large urban clinics and hospitals [9].

1.2. Risks of Infection

Improper disposal of HCWs, syringes and needles may lead to transmission of hepatitis B, hepatitis C, HIV and possibly other infections especially when scavenged and re-used [10]. In some countries (e.g., India and Pakistan), contaminated disposable needles are often scavenged, repackaged, sold and reused without sterilization. Such practices are associated with serious health implications due to the transmission of infectious disease, especially hepatitis and HIV. Several populations are at risk from poorly managed HCW, including Healthcare workers, waste handlers and scavengers retrieving items from dumpsites where HCW is inappropriately disposed of [11]. People receiving injections with previously used needles/syringes and children who may come into contact with contaminated waste and play with used needles and syringes where waste is dumped in areas without restricted access are at higher risk of exposure to infectious diseases [10].

1.3. Incinerator Performance

The more recent designs for low-cost small-scale incinerators promise effective sterilization of HCW, and these units have been constructed in a variety of healthcare settings. However, study using "rapid assessment techniques" indicates a variety of problems including lack of operator training, management and supervisor support, operation and maintenance, and wrong siting [12].

Several key problems were stated in [13] [14] as no formal HCW infrastructure, e.g., lack of clear directives, inadequate definition of responsibilities, lack of waste management budget, sporadic controls, inadequate maintenance, dispersed training; and, low skills and motivation of personnel, e.g., assignments to incineration tasks are casual, personnel are unskilled laborer's, and assignments are short term (no more than 3 to 6 months).

1.4. Best Practices for Incineration

When incinerators are used, however, the "best practices" should be promoted to minimize occupational and public health risks. "Best practices" for small-scale incineration has goals of suitably treating and disposing of waste, minimizing emissions, and reducing occupational exposures and other hazards. Best practices include the following elements:

1) Effective waste reduction or minimization, and waste segregation, ensuring that only the smallest quantity of appropriate waste types is incinerated.

2) An engineered design, ensuring that combustion conditions are appropriate, e.g., sufficient residence time and temperatures to minimize products of incomplete combustion.

3) Siting incinerators away from populated areas or where food is grown, thus minimizing exposures and risks.

4) Construction following detailed dimensional plans, thus avoiding flaws that can lead to incomplete destruction of waste, higher emissions, and premature failures of the incinerator.

5) Proper operation, critical to achieving the desired combustion conditions and emissions, e.g., appropriate start-up and cool-down procedures; achieve-

ment and maintenance of a minimum temperature before waste is burned, use of appropriate loading/charging rates (both fuel and waste) to maintain appropriate temperatures, proper disposal of ash, and various actions and equipment to safeguard workers.

6) Periodic maintenance to replace or repair defective components, e.g., including inspection, spare parts inventory, record keeping, etc.

7) Enhanced training and management, possibly promoted by certification and inspection programs for operators, the availability of an operating and maintenance manual, management oversight, and maintenance programs.

The formation of PCDD/Fs (dioxins/furans) due to incomplete combustion in solid waste incinerators has caused tremendous public concern. Consequently, more stringent standards for combustion and emission control have been implemented in order to mitigate the formation of these substances. This change in regulations will inevitably result in shutting down many small-scale incinerators because of the expense incurred in retrofitting such systems. Yet there is still an acute need for building small-scale incinerators for the purposes of disease control, environmental sanitation, and financial savings in rural areas and remote communities. For this reason, it is still worthwhile to pursue an optimal management strategy for small-scale incinerators [15].

The results also show that the amount of waste in batch-charging and the lowest temperature of the primary chamber during the previous feeding are critical operating factors in this type of incinerator; controlling the charging amount per each feed around 30 kg is optimal for mitigating the variance of combustion status in the small-scale incinerator.

This paper focuses on the mechanical conditions of incinerators assessed in Tanzanian HCFs of different levels. In particular, HCW generation determinants were determined (bed capacities, numbers of IPD and OPDs on weekdays), technological options available for incineration [16] and age of incinerators since installation. Conditions of the incinerator mechanical parts were also assessed including doors, chimneys [17], top plates and insulation, rust conditions of the roofs iron sheets and posts, damage on the outer walls and foundations, etc. Other conditions assessed include incinerator housing cleanliness, floor and wall conditions, fire brick on the combustion chamber floors and walls.

2. Methodology

A team of National and Regional level Assessors was formed to assess regional and respective district hospitals including lower healthcare facilities within the region. The team was made of members from different institutions. The assessment of HCWM in the HCFs was conducted in all the 26 regions of Tanzania Mainland. From each region, at least four district/municipal/town councils were physically reached by the assessors, and the remaining councils were reached by calls using mobile phones.

A standardized checklist and tools were used to assess and monitor various aspects related to HCW. These were in form of ODK, which is open-source software for collection, managing, and using data in resource-constrained environments. The software was opted due to its ability to easily handle data, and it allows for offline data collection with mobile devices in remote areas. It also provides a room for data submission to a saver when internet connectivity is available. There were three tools developed: a checklist for RHMT, a checklist for CHMT, and the survey tool for facility assessment. The survey tool was accompanied by direct observation, where several pictures were taken to complement the information collected through other tools.

Since data sets were electronically prepared, they were coded with variable names, variable descriptions, variable format, etc. Thereafter, data were entered into a Statistical Package for Social Sciences (SPSS) computer software, or EXCEL sheet for further processing. This was followed by data cleaning process, which involved checking the data carefully for errors, accuracy, and identifying and handling missing values. Checking data for accuracy of the responses to questions included questions such as: are the responses legible? Are the responses complete? Are the important questions answered? Is all relevant contextual information (e.g., data, time, and place) included? Lastly, descriptive statistics such as frequencies, percentages, and means were performed and presented in tables and charts.

A wide-ranging questionnaire was developed by the Ministry of Health in collaboration with higher learning institutions and WHO's country office, and was completed for all healthcare establishments in the selected regions in order to establish the following: number of hospital beds and bed occupancy rate for each healthcare establishment; types and quantities of waste generated, personnel involved in the management of HCW, current HCW disposal practices (including segregation, collection, transportation, storage, and disposal methods).

3. Results and Discussion

3.1. Waste Generation Determinants

Results show that HCW generation rate strongly depend on bed capacity and on the daily number of IPD and OPD, as summarized in **Table 1**. Higher values of these determinants/indicators led to high HCW generation rate in the HCFs of all levels.

Table 1. Waste generation for the HCFs.

Average capacities	Regional	District	Health Centre
Bed capacity	261.3	103.4	50.5
Daily IPD	103.7	43.7	28.7
Daily OPD on Weekdays	441.4	176.9	133.0
Waste generation (kg/day)	785.7	311.6	166.0

3.2. Evaluating Technological Options

Results show that Health centres and District hospitals use a wide range of technologies for HCW incineration covering De Montfort Mark III (40% and 28.3%), respectively, and Mark I types (20% and 23.8%, respectively) and High-Tech types (40% and 47.3%, respectively).

All regional hospitals surveyed use High-Tech incinerators, which, on the other hand, do not use De-Montfort types. Figure 1 shows that De-Montfort incinerators are mainly used in district hospitals and health centres. Emission standards for modern incinerators require the use of various air pollution control devices as well as monitoring, inspection and permitting programs [16]. Such standards cannot be met by small-scale incinerators that do not incorporate any air pollution control devices (APCDs) or monitoring devices. Moreover, as typically operated, small-scale incinerators do not achieve the lowest possible missions. Installation of process monitors, emission controls, and other equipment necessary to meet modern emission standards would increase costs by at least an order of magnitude.

3.3. Installation Period of Incinerators in Different Regions

Figure 2 shows the range of years the incinerators has been installed in different HCFs in the country. The highest number of incinerators were installed between 2010-2014 (26.4%) followed by years between 2015-2019 (25%) and the lowest were installed almost 30 years ago (<1994) having 2.8% and between 1995-1999 having 6.9%.

3.4. Condition of Incinerator Doors

Risk reduction during HCW incineration includes presence of doors which close firmly during operation and which are not rusted. This prevents escape of fumes and smoke from the primary chamber when the temperature and pressure increases. During this study, the incinerator doors were assessed to determine availability, locking efficiency and characteristics and rust conditions (**Figure 3**).

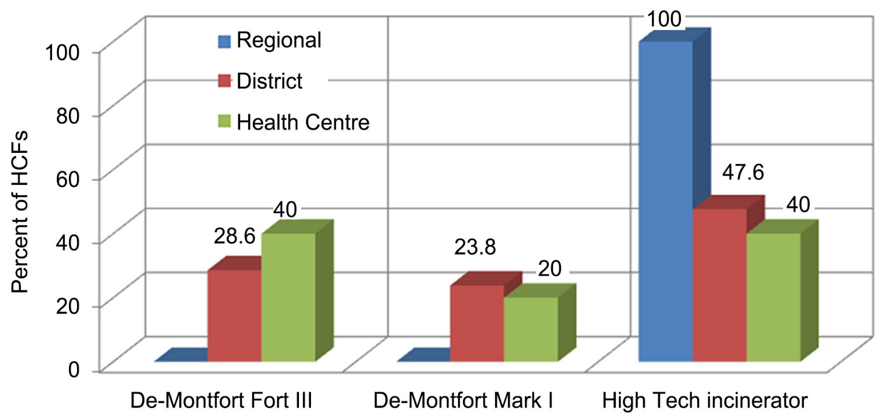

Figure 1. Technology options for HCFs incineration.

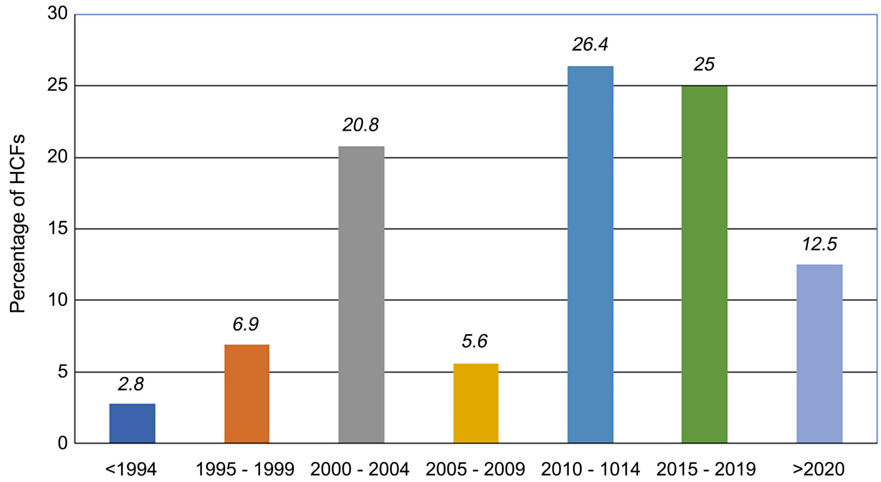

Figure 2. Range of years incinerators has been installed in different regions.

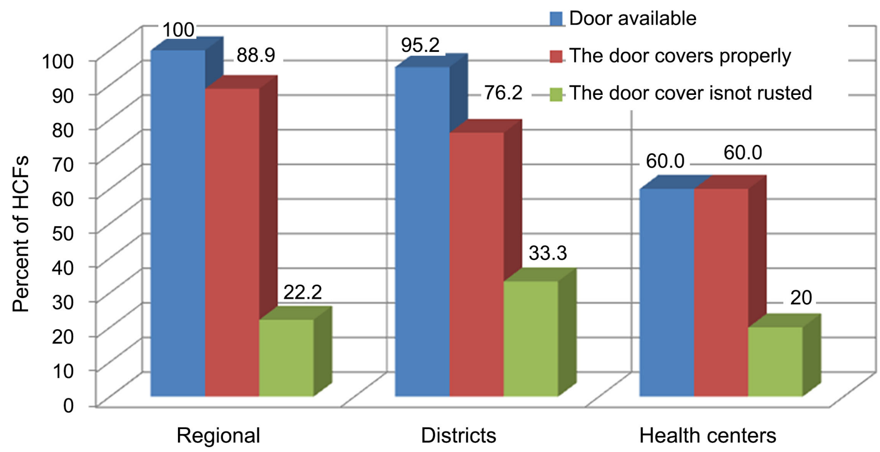

Figure 3. Availability of incinerator doors, locking efficiency and rust conditions.

Results show that 60% of incinerators installed and used in health centers do not have doors, while 40% of the incinerators have doors that do not close properly. In the regional and district hospitals, there was a higher proportion of incinerators with doors (100% and 95.2%, respectively) and also doors which cover properly (88.9% and 76.2%, respectively). Although observed at a lower percentage, rusted doors signify lack of maintenance, and propagate into door damage causing improper covering and finally leading complete dislocation from hinges. Rusted doors were observed in 22.2%, 33.3% and 20% of regional hospitals, district hospitals and health centers, respectively.

3.5. Conditions of the Chimneys, Top Plates and Grates

Figure 4 compares the assessment results for the chimneys, top plate and grates for the incinerators in the regional, district hospitals and health centers. In regional hospitals, and health centers, the chimneys, top plates and grates were collectively in good conditions for 55.6% and 60% of HCFs, respectively. In the district hospitals, however, lower percentages of HCFs with good conditions of

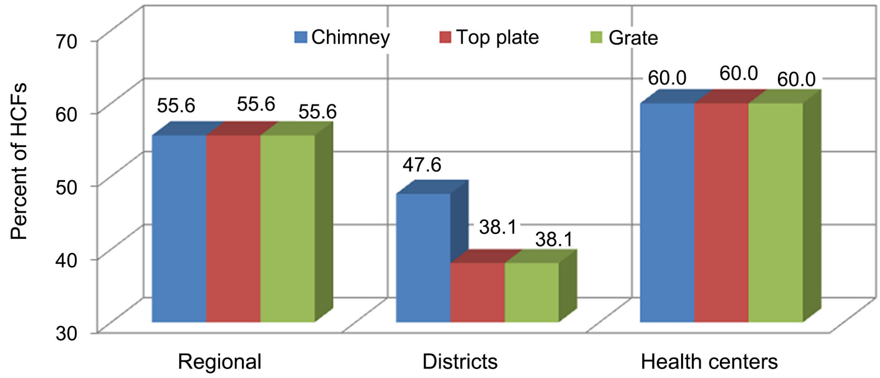

Figure 4. Conditions of chimney, top plate and grate of incinerators in HCFs.

chimneys, top plates and grate were observed only in 47.6%, 38.1% and 38.1%, respectively. Therefore, results of the assessment show that the chimneys, top plates and grate in the incinerators countrywide are not in good conditions, necessitating repairs.

The chimney has a function of transporting hot flue gases from the secondary chamber to the atmosphere. It is needed for both adequate dispersion plus draft for proper air flow. It is normally hot during operation, due to high temperature attained by hot gases, whether the chambers are self-ignited or burner-assisted ignition. Rusted chimney or chimney already having holes due to rust or any other mechanical damage, signifies that the fumes can channel out through holes and cause accidents (burns) or risk of pollutants carried by flue gases. The pollutants include dusts ($PM_{1.0}$, $PM_{5.0}$ and PM_{10}), acid gases (SO_2, CO, CO_2, NO_x, HCl and volatile organic compounds (VOCs)), and heat [17]. If allowed to channel through holes, it endangers the safety of the operators and can damage nearby structures. The flue gases must be emitted at the top of the chimney without channeling.

The De-Mont fort incinerators are normally covered at the top using a 6 mm mild steel plate, over which, a sand layer of 5 to 10 cm is normally spread to act as insulation against high combustion temperatures. The top plates for incinerators are meant to prevent hot flames from escaping at the top of the chamber, and protect the operators and the surroundings from the high temperatures. While the primary chambers for De-Montfort incinerators are only covered by top plate, High-Tech incinerator primary chamber top is covered by refractory bricks followed by insulation. Hence, damaged top plate for De-Montfort incinerators indicate a technical problem which attracts attention of the maintenance team.

3.6. Conditions of Top Plate and Insulation Sand

The top plate for De-Montfort incinerator is directly subjected to hot flame underneath and atmospheric conditions on its top surface, leading to exposure to rusting due to accelerated conditions. Conditions of the cover plate, cleanliness of the sand, and presence of blood and body fluids droplets on the sand were assessed for De-Montfort incinerators, as summarized in **Figure 5**.

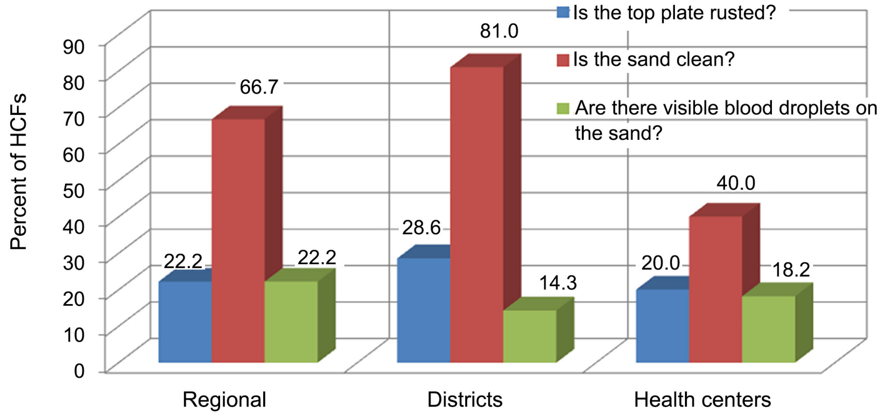

Figure 5. Conditions of top plate, cleanliness of sand and visible blood droplets on the sand.

Figure 5 shows that the sand was clean in 66.7%. 81% and 40% of regional, district hospitals and health centers, respectively. Blood droplets were visible in few cases, that is, only 22.2%. 14.3% and 10.2% of regional, district hospitals and health centers, respectively.

For the High-Tech incinerators, sand is normally not spread on the top plate, and insulation of the latter is kept inside the construction. In this study, the top plate for the High-Tech incinerator was assessed for rust (**Figure 6**), which can cause damage and channeling of the fumes and flue gases.

The conditions of top plates and fuel burners for High-Tech incinerators in different HCFs are summarized in **Figure 6**. While the top plates of incinerators in the district hospitals are only rusted in 10% of the HCFs, results show that 55.6% and 50% of the regional hospitals and health centers have the incinerators with rusted top plates. Moreover, a large proportion of High-Tech incinerators have burners in good conditions, that is, 70%, 88.9% and 100% of district hospitals, regional hospitals and health centers, respectively.

The study compared the conditions of the metal parts subjected to combustion gases (that is, proportion of incinerators with corroded chimneys, rusted top plates and corroded grates) between incinerators of different makes as shown in **Figure 7**. A dependence on the incinerator make was evident from the results, whereby, all metals in the De-Montfort Mark I were corroded and/or rusted to a higher proportion), that is, in many HCFs) than those used in De-Montfort Mark III and High-Tech incinerators. Specifically, the top plates used for Mark I were highly corroded (83.3%) compared to 66.7% in both De-Montfort Mark III and High-Tech incinerators. The metal parts exposed to combustion gases in High-Tech incinerators, on the other hand, were least susceptible being corroded in 42.9% of De-Montfort Mark III and 33.3% only in both De-Montfort Mark I and High-Tech incinerators. Therefore, based on the study results, incinerator make has a strong effect on the susceptibility of chimney, top plate and grates, based on which, De-Montfort Mark III and High-Tech incinerators are thus recommended to avoid rusting of top plates and corroded chimneys.

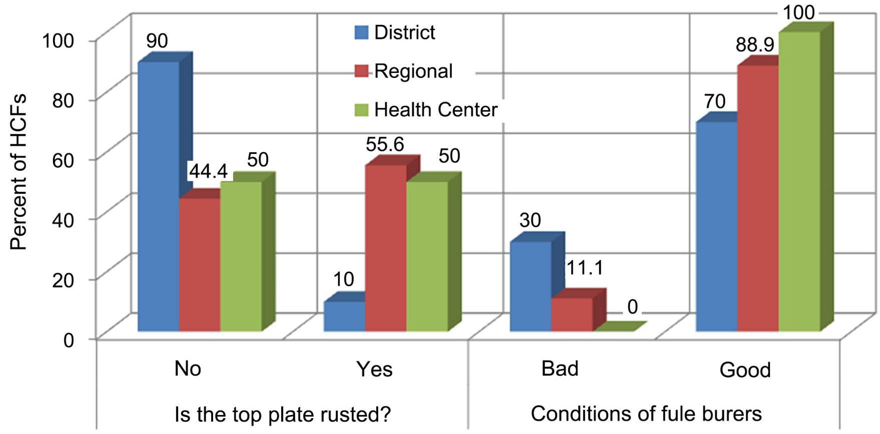

Figure 6. Conditions of top plates and fuel burners for High-Tech incinerators in different HCFs.

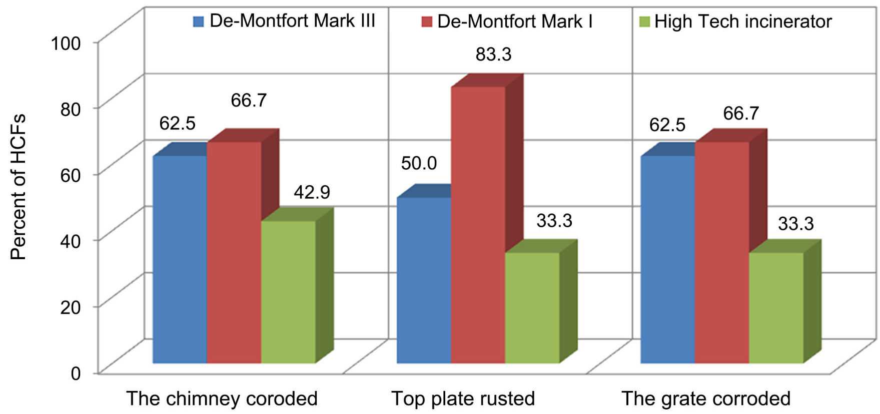

Figure 7. Effect of incinerator make on the susceptibility of metals parts from combustion gases.

Figure 8 shows the proportion of HCFs with rusted parts of incinerator housing according to the assessment results. Most of the rusted housing were observed in district hospitals where De-Montfort incinerators have been installed (that is 60% and 75% of Mark III and Mark I models). In the regional hospitals, 55.6% of the HCFs had rusted incinerator housing. Health centers had the lowest fraction of the facilities with rusted incinerator housing, where 40% and 25% of the HCFs having De-Montfort Mark III and I incinerators, respectively, were observed, and only 22.2% of the facilities using High-Tech incinerators. Moreover, district hospitals with High-Tech incinerators had lower proportion of HCFs with rusted housing structures.

Rusted incinerator housing poses a hazard for incinerator operators from collapse of the building due to weak roof support. Accidents are likely to happen due to collapse of the roof especially during rain and strong wind. Collapse of building housing a High-Tech incinerator exposes the electrical equipment (burners and blowers) to rain water, leading to electrical hazards. Planned maintenance involving painting of the metal supporting the roof is strongly recommended.

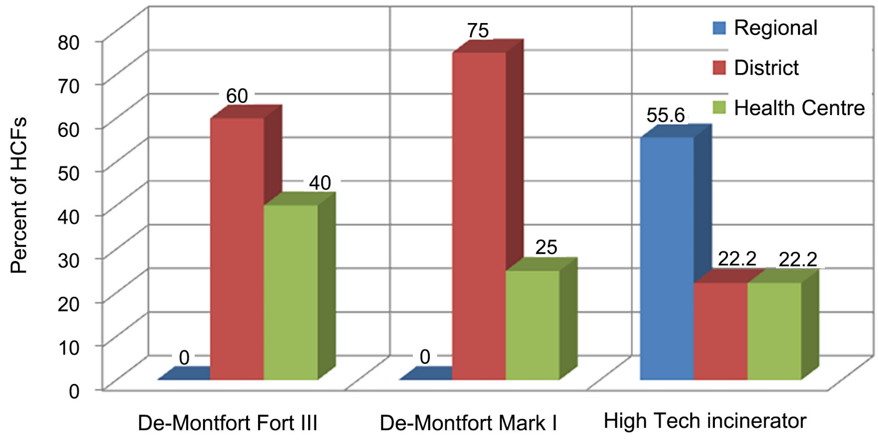

Figure 8. Proportion of HCFs with rusted parts of incinerator housing.

3.7. Rust Conditions of Roof Posts and Iron Sheets

A roof made of iron sheets is normally provided to protect the operator and the incinerator equipment from rain. Only minimum walls are provided to limit water from flowing into the incinerator base leaving the upper part of the building open to increase ventilation. The metal pipes are normally used to support the roof, leaving the former susceptible to weathering and corrosion.

In this study, the rust conditions for roofs support and the iron sheets were assessed results of which are presented in Figure 9. The roof posts and support structures were rusted in 62.5%, 25% and 40% of HCFs for regional, district and health centers, respectively. The iron sheets were observed to be rusted in 37.5% of regional hospitals and in 40% of both district hospitals and health centers.

Further analysis of the conditions of the roof posts and iron sheets revealed two major problems that is, leakage of the roof and loose structure supporting the roof. Figure 10 summarizes the comparisons of the proportion of incinerators types with leakage and those with loose structures in HCFs of different levels. The conditions of incinerator roofs were worse in district hospitals (high proportion of both leakage and loose structures for all incinerator types) compared to regional hospitals. Despite the fact that no leaking roof was observed in the health centers, all roofs on De-Montfort Mark I constructed in district hospitals were leaking. Therefore, results show that more efforts are needed to repair the incinerator roofs (roof posts and iron sheets).

3.8. Damages on the Incinerator Outer Walls

The assessment included whether the plaster was intact and presence of any cracks on the chambers, as summarized in Figure 11. Compared to district and regional hospital incinerators, construction in the health centers was of poor quality, such that the plaster was observed to be intact only in 40% of the facilities, while 77.8% and 95% of the HCFs in regional and district levels had incinerators with intact plaster on the walls and foundation. Non-intact plaster can be caused by poor construction or use of sand contaminated by salt, especially when ocean sand is used, which is likely to happen in the facilities near the ocean or in coastal areas.

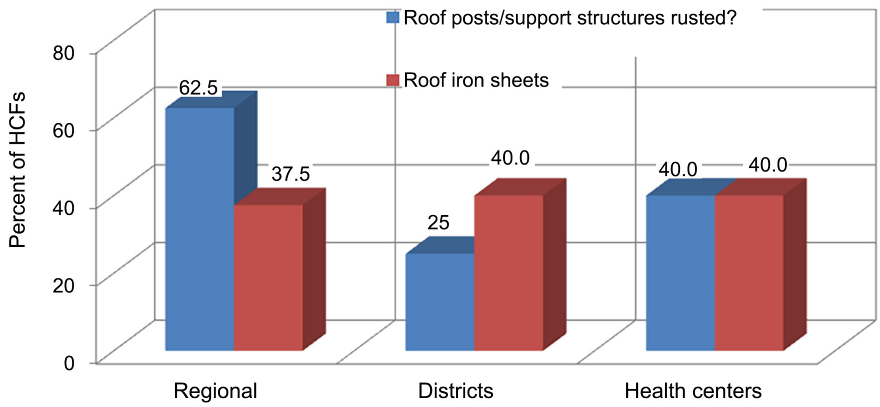

Figure 9. Proportion of incinerator housing in the HCFs with rusted roof posts and iron sheets.

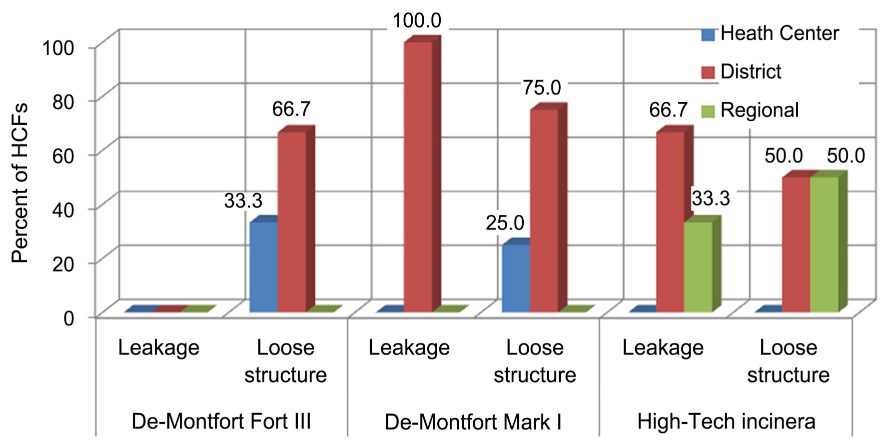

Figure 10. Proportion of the HCFs with defective incinerator housing structure leading to leakage and loose structure.

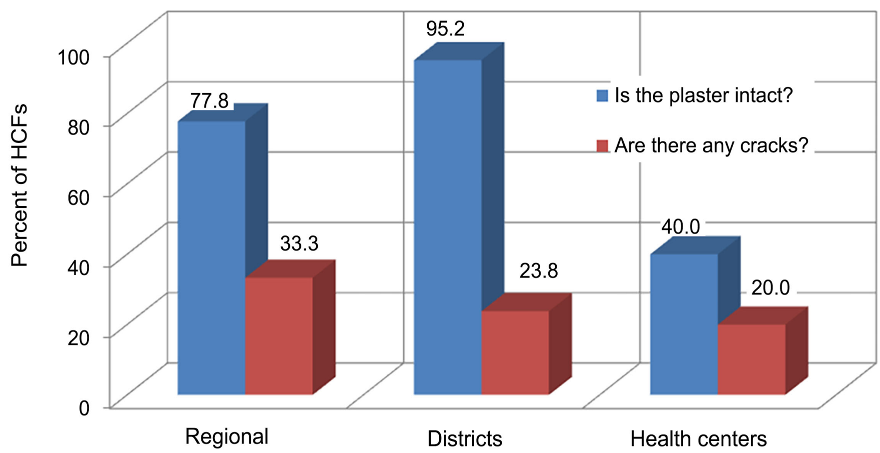

Figure 11. Conditions of the incinerator walls including plaster and presence of cracks.

On the other hand, presence of cracks on the incinerator walls was observed at lower extent, that is, 33.3%, 23.8% and 20.0% of regional and district hospitals, and health centers, respectively. The HCFs' maintenance teams are required to conduct frequent maintenance on the parts of incinerators which do not need specialized works, likes cracks on the walls and foundations. Presence of cracks is an indication of weaknesses in the construction of the chambers, and that the chamber is likely to cause channelling and leakage of the flue gas in the near future.

The masonry, bricks and particularly mortar joints tend to crack, while grills get damaged or go missing due to vandalism. In this study, the location of cracks on the outer wall of the combustion chambers was assessed as summarized in Table 2.

3.9. Incinerator Housing Cleanliness, Floor and Wall Conditions

Figure 12 summarizes the assessment of cleanliness in the incinerator unit, conditions of the floor and walls of the building. The percentage shows the HCFs whose incinerator units were determined to be in good conditions. The incinerator units in 70% - 87.5% of the HCFs were clean, while 60% - 100% had floors in good conditions, with the lowest proportion resulting from health centers. About 80% - 87.5% of the HCFs had walls in good conditions. The challenges observed on incinerator housing cleanliness require the attention of the environmental cleaning supervisors, while the poor conditions observed in the HCFs require good supervision during construction by professional masonry (high temperature walls) and mechanical technicians (metal wo. Since such professions may not be available at a local level, requesting such professionals from the district level is recommended.

Table 2. Assessment results for plaster and cracks on the foundation and incinerator walls.

Name of Facility	Incinerator Make	Year constructed	Location of cracks on the outer wall	Is the foundation plaster intact?	Are there any cracks on the foundation?
Ligula Referral Hospital	High-Tech incinerator	2010	Secondary Chamber	No	Yes
Manyara RRH	High-Tech incinerator	2013	Primary chamber	Yes	Yes
Mbeya Regional Referral Hospital	High-Tech incinerator	2010	Primary chamber	Yes	No
Tandahimba District Hospital	De-Montfort Mark I	2008	Secondary Chamber	No	Yes
Urambo District Hospital	De-Montfort Mark I	2007	Secondary Chamber	Yes	Yes
Mpwapwa District Hospital	De-Montfort Fort III	2001	Primary chamber	Yes	No
Ilula Lutheran Hospital (CDH)	De-Montfort Mark I	2010	Primary chamber	Yes	Yes
Newala District Hospital	High-Tech incinerator	2012	Primary chamber	Yes	No
Misungwi DC Hospital	High-Tech incinerator	2010	Primary chamber	Yes	Yes
Gairo Health Centre	De-Montfort Fort III	2016	Primary chamber	No	Yes

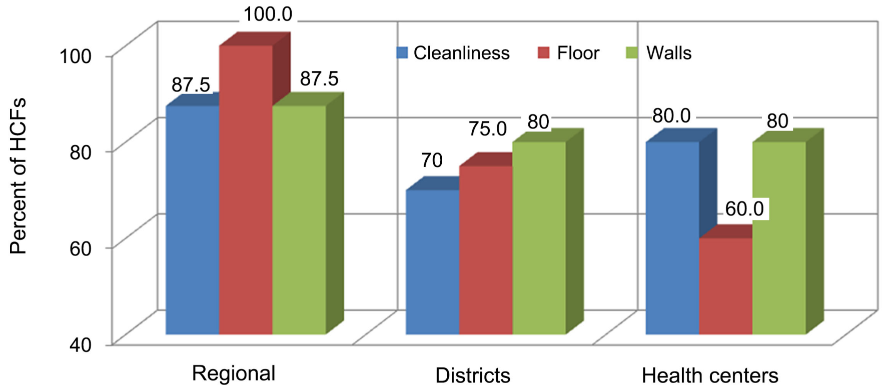

Figure 12. Cleanliness conditions of the unit, floor and wall conditions in the incinerator housing observed in HCFs of different levels.

3.10. Conditions of Firebricks on the Wall and Floor of Combustion Chambers

The combustion chamber of a De-Montfort incinerator is constructed from firebricks, without any mortar, and is clamped together to provide strength and reduce the possibility of bricks being pushed out of alignment during waste loading and incineration. A standard fire brick approximately 230 mm × 115 mm × 75 mm and capable of withstanding temperatures of at least 1300˚C are commonly used in Tanzania. Because the walls and the bottom are made without mortar, the assessment was done to check if the firebricks have been displaced or damaged. **Figure 13** compares the proportions of HCFs with incinerators having firebrick walls and floor of the combustion chamber in good conditions between district and regional hospitals and health centers. In general firebrick walls and floor in the combustion chambers are in good conditions for more than 80% of the HCFs.

4. General Discussion

Regardless of how well equipment is designed, wear and tear during normal use and poor operation and maintenance practices will lead to the deterioration of the components, resulting in a decrease in both combustion quality, an increase in emissions, and potential risks to the operators and public at large. Lack of operation and maintenance plans in the HCFs negatively affect reliability, effectiveness and life of the equipment. Essentially all components of small-scale incinerators are prone to failure and require major maintenance. To be effective, maintenance on semi-annual or quarterly schedule is required. **Table 3** shows the typical schedule for incinerator maintenance suggested by the US-EPA [18].

For small-scale low-cost incinerators, components particularly prone to failure that are mentioned in several reports [14] include: firebox access doors and frames that warp, hinges that seize and break, and assemblies that break free of mortar. On the other hand, parts directly exposed to high temperature flames and flue gases like grates (that can be distorted, broken or become clogged) and chimneys or stacks (which are rendered badly corroded). The chimney supports or guy wires become inadequately attached, broken, lose or missing due to exposure to high temperatures for a long time. The steel tops that warp and short-circuit the secondary combustion chamber of the De-Montfort incinerator, will always be affected by the high temperatures, leading to corrugation and loss of closing capability. De-Montfort incinerators typically require major maintenance after 3 years, costing approximately 70% of initial construction costs [14]. Funds must be made available in the HCFs to provide for both routine and major maintenance of incinerators. The use of service contracts may be appropriate, which are however, not common in public HCFs.

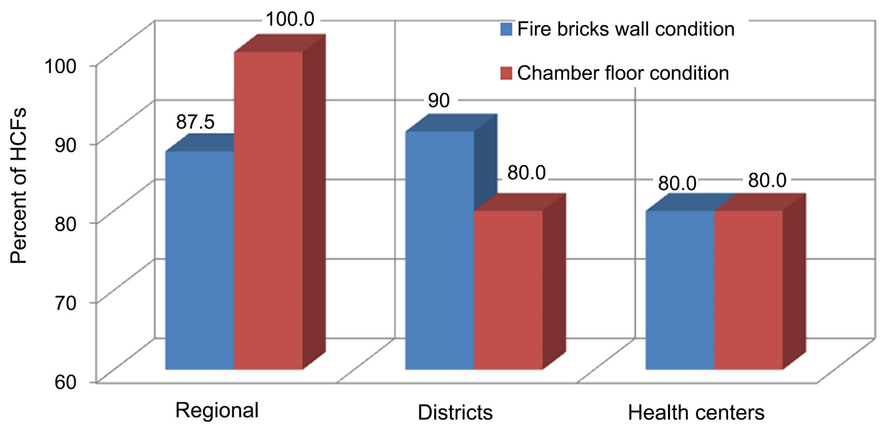

Figure 13. Proportion of HCFs with incinerators having firebrick walls and floor of the combustion chamber in good conditions.

Table 3. Typical maintenance schedule for incinerators [18].

Activity Frequency	Component	Procedure
Hourly	Ash removal	Inspect and clean as required
	Temperature, pollution monitors, if any	Check operation(Use control box) or physical stuck emmission)
Daily	Underfire air ports	Inspect and clean as required
	Door seals	Inspect for wear, closeness of fit, air leakage
	Ash pit	Clean after each shift
Weekly	Latches, hinges, wheels, etc.	Lubricate if applicable
Monthly	External surfaces of incinerator and chimney (stack) Refractory Upper or secondary chamber	Inspect external hot surfaces. White spots or discoloration may indicate loss of refractory. Inspect and repair monitor wear with refractory cement. Inspect and remove particulate matter accumulated in chamber floor. Surface cleaning
Semi-annually	Hot external surfaces	Inspect and paint with high temperature paint. Change own out parts
	Ambient external surfaces	Inspect and paint as required

5. Conclusions and Recommendations

HCW generation in the HCFs of different levels increases with bed capacity and number of IPD and OPD. The HCFs are still facing challenges on HCW treatment using incinerators and final disposal. Regional hospitals are currently not using De-Montfort Incinerators, and has upgraded to High-Tech incinerator types to accommodate the higher generation rate of HCW as a well the need to attain high treatment efficiency. De-Montfort incinerators were observed only in district hospitals and in the health centers.

The incinerators in the HCFs are currently old necessitating maintenance or phase out to construct new ones. This has increased poor conditions of the incinerator parts, as observed in this study.

Incinerator doors, are in good conditions in more than 80% of the HCFs, but more than 80% of incinerator door covers are rusted. Incinerator chimneys are in bad conditions in district hospitals compared to regional hospitals. Incinerator chimneys, top plates and grates are also in bad conditions in most of the HCFs, due to age and rusting. For High-Tech incinerators, the fuel burners were in good conditions in more than 70% of the HCFs, while the top plates were rusted in more than 50% of the regional hospitals and health centers. In comparison, the De-Montfort incinerators Mark I was observed to be highly susceptible to corrosion of top plates and chimneys compared to Mark III and High-Tech incinerators models. On the other hand, grates, chimneys and top plates used in High-Tech incinerators were least corroded compared to De-Montfort incinerators. The sand used as insulation for De-Montfort incinerators top plates was clean without visible blood droplets in large number of HCFs.

The incinerator housing structures were generally defective leading to leakage and/or loose structure, both of which pose hazards to operators. Most of the incinerators in the HCFs had non-intact plasters with cracks on the walls and foundations. A general weakness in the operation and maintenance of incinerators in the HCFs have been identified. Together with the need for having proactive maintenance teams, funds must be made available within the HCFs to provide for both routine and major maintenance of incinerators. The use of service contracts may be appropriate, which are however, not common in public HCFs.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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