Reducing Medical Waste Liabilities through Mobile Maceration and Disinfection

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ABSTRACT

Commercial medical waste treatment technologies include incineration, melting, autoclaving, and chemical disinfection. Incineration disinfects, destroys the original nature of medical waste, and reduces the waste volume by converting organic waste content to carbon dioxide and water, leaving only residual inorganic ash. However, medical waste incinerator numbers have plummeted from almost 2,400 in 1995 to 115 in 2003 and to about 62 in 2005, due to negative public perception and escalating costs associated with increasingly strict regulations. High-temperature electric melters have been designed and marketed as incinerator alternatives, but they are also costly and generally must comply with the same incinerator emissions regulations and permitting requirements. Autoclave processes disinfect medical waste at much lower operating temperatures than incinerators operate at, but are sometimes subject to limitations such as waste segregation requirements.

Med-Shred, Inc. has developed a patented mobile shredding and chemical disinfecting process for on-site medical waste treatment. Medical waste is treated on-site at customer facilities by shredding and disinfecting the waste. The treated waste can then be transported in compliance with Health Insurance Portability and Accountability Act of 1996 (HIPAA) requirements to a landfill for disposal as solid municipal waste.

A team of Idaho National Laboratory engineers evaluated the treatment process design. The process effectiveness has been demonstrated in mycobacterium tests performed by Analytical Services Incorporated. A process description and the technical and performance evaluation results are presented in the paper. A treatment demonstration and microbiological disinfecting tests show that the processor functions as it was intended.

INTRODUCTION

The Med-Shred treatment process is shown in Figure 1. This process transforms medical waste into municipal landfill waste that is compliant with the Health Insurance Portability and Accountability Act of 1996 (HIPAA). Med-Shred provides a "one-touch" waste collection process. Waste carts provided by Med-Shred are filled as waste is generated at the customer facility. The Med-Shred mobile waste processor regularly visits the facility according to a pre-determined schedule to treat the accumulated waste. During treatment, the contents of these carts are weighed on-site and automatically deposited into the mobile processor. The waste is shredded, sterilized using a chemical disinfectant, and dried. The maximum processing rate is 4,000 pounds per hour. Treated waste is then loaded into the hospital's municipal waste compactor or other container for routine disposal in a municipal solid waste landfill.

Fig. 1. Med-Shred treatment process overview

In 2005, Med-Shred desired an independent evaluation of their mobile waste treatment process prior to a planned business expansion. The Idaho National Laboratory (INL) performed this assessment of the Med-Shred mobile waste technology under contract to Med-Shred. Components of this assessment included evaluations of (a) the overall processor design and design documentation, (b) the control system, (c) the chemical treatment system, (d) materials of construction, (e) the manufacturing approach, (f) maintenance and training plans, (g) subsystem design and function, and (h) overall cost-effectiveness of the processor design, manufacture, operation, and maintenance.

MOBILE PROCESSOR DESCRIPTION

Med-Shred designs, builds, and operates the truck-mounted mobile medical waste treatment processors (Figure 2). The processing equipment (Figure 3) is located inside a semi-truck trailer that is pulled by a semi-truck tractor. Bagged or boxed medical waste in carts is weighed using calibrated scales, lifted using a hydraulic lift (Figure 4), and dumped through a hydraulically-actuated sliding lid on the top of the trailer into a hopper at the top of a low-speed shredder. Once the waste is dumped into the shredder hopper, the sliding lid is closed and the waste is shredded. A High Efficiency Particulate Air (HEPA) filtered vacuum system draws air into the shredder hopper while the hopper lid is open, minimizing fugitive emissions out of the open hopper. After the waste is dumped into the hopper, the hopper lid is closed and the now-empty waste cart is cleaned, disinfected, and returned to the customer. The waste is entirely contained in the enclosed and sealed treatment processor from the time the shredder lid closes until it is treated and discharged, typically into a municipal waste compactor located at the customer hospital.

The high-torque, low-speed shredder (Figure 5) shreds the waste. Bags or boxes that contain medical waste are torn open and shredded along with the waste. Shredded waste falls from the shredder through a proprietary screen that allows smaller pieces to fall through, but retains larger pieces so they can be re-shredded. A disinfectant is sprayed onto the shredded waste as it falls through the shredder screen. This disinfectant is relatively dilute (>5,000 ppm, equivalent to 5 g/L, or roughly 0.07 M) sodium hypochlorite (household chlorine bleach, NaOCl) in water, acidified to pH 4-6 with relatively dilute phosphoric acid (H_3PO_4, corresponding to about 2 g/L or 0.02 M H_3PO_4). This begins the disinfecting process.

The shredded waste, wetted by the disinfectant spray, is then immersed in the disinfectant solution in a vat positioned directly below the shredder. Immersion is intended to more fully wet all of the shredded waste particles.

A spinning feed auger picks up the shredded, wet waste and transports it out of the vat. The centrifugal force of the auger, which operates at over 100 rpm, separates some of the disinfectant solution from the wet waste material.

Fig. 2. Typical truck-mounted Med-Shred medical waste treatment system seen during a treatment capability demonstration

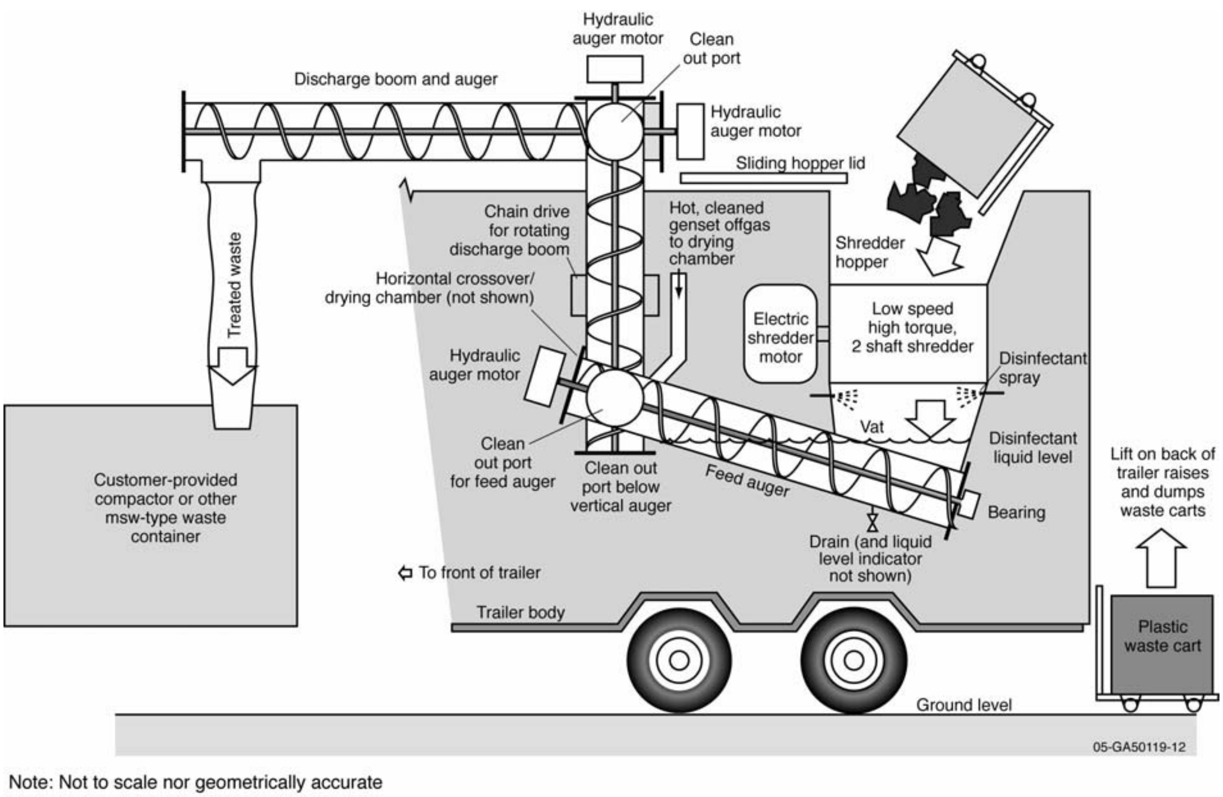

Fig. 3. Med-Shred medical waste treatment process flow diagram

Fig. 4. A plastic cart containing surrogate medical waste is lifted and dumped into the shredder hopper during a treatment capability demonstration

Fig. 5. A top view looking inside a low-speed, high torque shredder. Teeth on counter-rotating discs bite into and pull material between the two shafts, cutting the material into smaller pieces

The wet waste is partially dried and "fluffed" in a drying chamber by hot off-gas from the engine-generator set (genset) used to provide power for the mobile processor. The genset enables the processor to be independent from any customer power. The hot off-gas is piped from the genset catalytic converter to the waste drying chamber.

The partially-dried, fluffed waste is picked up by the vertical auger, which transports the waste vertically up to the discharge auger. The discharge auger transports waste through a boom that extends 15 feet or more radially away from the mobile processor (Figure 6) to a downspout that is designed to allow the treated waste to drop into a container such as a municipal waste compactor.

The treated waste is generally shredded into pieces that typically range under one inch, although some pieces larger than one inch may occasionally occur (Figure 7).

Fig. 6. The boom is used to transport treated waste from the processor to a hospital compactor or other container for the treated waste

Fig. 7. Typical appearance of shredded and disinfected medical waste. This photo shows shredded and treated surrogate medical waste materials, consisting of non-contaminated paper materials, plastic materials (plastic drinking cups), cloth materials (shop rags), and glass materials (glass drinking cups)

MOBILE PROCESSOR SUBSYSTEMS

The processor contains several subsystems: (a) the operating, monitoring, and control system, (b) the fugitive emission control system, (c) the electrical power generating system, (d) the chemical disinfectant supply system, and (e) the hydraulic system.

The operating, monitoring, and control subsystem includes the instrumentation and controls that are needed to power the processor, control engine, motor, and pumps, and monitor and control the processor.

The fugitive emissions control system is designed to prevent hazardous emissions from the shredder hopper while the hopper lid is open. This system draws a vacuum on the system, especially when the lid to the shredder hopper is open, minimizing any fugitive hopper emissions. The evacuated air is HEPA-filtered and exposed to ultraviolet light before it is discharged above the trailer roof.

Electrical power needed by the processor is provided by a diesel-fueled genset. This eliminates the need to request up to 175 kW shore power from the customer facilities. All genset controls are mounted on the genset, and the genset is designed for remote on-off operational control by the genset power switch on the operator control panel. The genset system includes a catalytic converter to clean the genset off-gas.

The chemical supply system (Figure 8) includes on-board tanks for fresh water, for sodium hypochlorite, and for phosphoric acid. The operator blends these reagents into a relatively dilute disinfectant solution in the feed tank. The operator monitors the pH and the reported Cl^- concentration as he prepares a batch of solution. A pump feeds the disinfectant solution to the process.

Fig. 8. The on-board disinfectant chemical solution supply system tanks and other components

Much of the current processor design is hydraulically powered, taking advantage of the hydraulic power philosophy proven for decades in the mobile garbage truck industry. Hydraulically powered components include (a) the waste cart lift/dump and related equipment, (b) the shredder lid, (c) the three augers – the feed auger, the vertical auger, and the discharge auger, and (d) the discharge boom to raise it from its mount on top the processor trailer.

WASTE PROCESSOR TREATMENT PERFORMANCE

The effectiveness of the waste processor to treat disinfect medical waste depends on the ability of the processor to contact the waste with the disinfecting solution, and the ability of the disinfecting solution to kill harmful microorganisms. The processor ensures contact between the waste and the disinfectant by first shredding the waste, which destroys barriers that could prevent disinfectant contact, and then vigorously contacting the waste with disinfectant of a known concentration for a minimum residence time.

Waste Processor Shredding Performance

The low-speed, high-torque shredder used in the waste processor is an appropriate shredder for this application. Shredding is necessary to open sealed containers and to size-reduce the waste to enable contact of the waste with the disinfectant. Among several choices of size reduction equipment including ball mills, hammer mills, and grinders of various types, the low-speed shredder configuration has been shown to be superior for size-reducing heterogeneous solid waste materials [1]. Compared to high speed shredders like hammer mills, low speed shredders can tolerate a wider range of dry, wet, hard, and soft materials. Low speed shredders are less prone to damage from hard materials like titanium artificial joints. While hospitals normally segregate such metallic items, metallic items are occasionally inadequately segregated.

The shredder performance was observed during the INL assessment. Surrogate waste consisting of uncontaminated paper materials, plastic materials (plastic drinking cups), cloth materials (shop rags), and glass materials (glass drinking cups) was processed. The shredder generally produced individual shredded pieces of one inch in size or less, except for occasional longer strips up to a few inches long occurred when these pieces fell through the narrow space between the teeth. Med-Shred reports that softer materials such as organic matter are ground to unrecognizable pieces much smaller than one inch. Softer materials are both cut and macerated.

Efficacy of the Disinfectant

The efficacy of the chemical disinfectant depends on three factors – the concentration of "chlorine", the amount of time that the chemical solution is in contact with the medical waste, and the chemical form of the chlorine. The waste processor continuously measures the disinfectant solution pH and oxidation-reduction potential (ORP, using a Hach Company sc100 Differential pH and ORP sensor). ORP sensors measure the oxidizing potential of the chlorine in solution, rather than the concentration of chlorine.

The oxidizing potential is a measure of the disinfectant solution's ability to disinfect the waste. This is an important distinction, because the chemical form of the chlorine in solution is very important. The amount of chlorine contained in the solution can remain constant, but its ability to disinfect waste will vary widely, depending on the pH of the solution. For example, at a pH of 6.0, more than 95 percent of the available chlorine in the chemical solution is in a form that is most effective, while at a pH of 8.5, only 10 percent is in this form, resulting in an almost ten-fold reduction in ability to disinfect, even though the amount of chlorine remains the same. Control of the pH of the chemical solution is critical. This is why Med-Shred acidifies the otherwise essentially pH-neutral dilute sodium hypochlorite solution with dilute phosphoric acid.

A review of the U.S. EPA's Registered Antimicrobial Products for Medical Waste Treatment shows that there are only six products registered for broad disinfecting application with the EPA. These products are based on active chemical ingredients that do not include sodium hypochlorite (calcium oxide, sodium chloride, glutaraldehyde and others). Clorox Bleach (5.25% sodium hypochlorite active ingredient) appears on the Registered Tuberculocide List. CPPC Tsunami, a Clorox product containing 0.55% sodium hypochlorite as the active ingredient, appears on the Registered Antimicrobial Products Effective Against Mycobacterium tuberculosis, Human HIV-1 and Hepatitis B Virus List. These lists can be found at: www.epa.gov/oppad001/chemregindex.htm. This review indicates that while other choices of disinfecting solution are available, the acidified sodium hypochlorite solution is accepted as a disinfectant. Med-Shred reports that this solution is relatively inexpensive and widely used and accepted when compared to other disinfecting chemicals.

Treatment Residence Time

Treatment residence or contact time in the Med-Shred mobile waste processing system is not measured, but it can be inferred from the average time taken to process a given batch of waste material. Contact between the chemical solution and the waste is indicated in part by this residence time, but also facilitated by grinding or maceration of the waste done by the shredder and by the mixing action provided by the chemical solution sprays and the augers. A conservative (low) residence time definition would be the residence time of waste in the vat and in the feed auger, since most of the disinfectant solution is separated from the waste in or prior to the drying chamber located between the feed and vertical augers. This residence time is defined primarily by the speed of the feed auger, the feed auger flights, the diameters of the feed auger shaft and the feed auger tube, and the volume of the vat under the disinfectant liquid level. Assuming a relatively high liquid level in the vat, and assuming an auger rotational speed of 140 rpm, the average waste residence time in the vat and feed auger is about 14 seconds. The actual average residence time is probably longer because some material will float on surface of disinfectant in the vat, and material will progress axially in the auger at a speed somewhat lower than the speed defined by the auger rpm and flights.

A less conservative residence time definition takes credit for the time that the waste is in the vat, feed auger, drying chamber, vertical auger, and discharge auger. The basis for this residence time is that, although most of the free liquid is separated from the waste by the time the waste exits the drying chamber, the waste is still damp with the disinfecting solution. This total residence time is calculated at 33 seconds, when the speed of all three augers is 140 rpm. The actual average residence time is somewhat longer because the material will progress through the system at a somewhat lower rate than the rate defined by the auger speeds and flights.

An even less conservative residence time definition would take credit for not only the time in the processor, but also for an estimated effective treatment time that treated waste remains damp with the disinfectant solution. This estimated residence time could easily extend into minutes or longer.

Disinfectant Test Results

Several separate tests have been performed by Med-Shred to quantify the disinfecting performance of the treatment process. These tests include a measurement of the degree to which micro bacterial viability of paper test strips is prevented using a standardized micro bacterial procedure [2]. The test strips are first inoculated with live mycobacterium terrae, which is a non-hazardous surrogate for microbes that could be present in medical waste. The test strips are treated with actual or surrogate medical waste under normal processing conditions. The micro bacterial viability of cultured prepared from the treated test strips is compared with the viability of cultures prepared from similarly-prepared test strips that are handled as control samples.

Tests are routinely performed by Med-Shred as an ongoing verification of the treatment process. No viable micro bacterial colonies have been detected on treated test strips in any tests. One additional test was performed in 2005 [2,3]. Results of this test are shown in Table 1. No viable micro bacterial colonies were detected, and the disinfecting factor for eight treated test strips averaged $>3.7x10^6/1$. Several blank and control samples showed that some variability, and loss of microbial viability, can occur from handling, shipping, and treatment in control tests where no disinfectant is used. However, no treated samples exhibited any microbial viability, and the degree of disinfection of treated samples was still at least 6 orders of magnitude below the detected viability of the control samples.

Table I. Micro Bacterial Disinfection Test Results for the Med-Shred Medical Waste Treatment Processor

Sample	**Average result, CFU/g**	**Average result, $\log_{10}$ value**	**Average $\log_{10}$ reduction (LR)**	**Average disinfecting factor**	**References**
NC	1.9×10^8	8.28	---	---	Krisiunas 2005, Analytical Services, Inc., 2005
LC	4.2×10^8	8.62	---	---	
FC	2.5×10^8	8.40	---	---	
UC	2.2×10^8	8.34	---	---	
TS	$<5.9 \times 10^1$	<1.77	≥6.57	≥3.7 million	

Notes:
1. NC = neutralizer control, LC = laboratory control, FC = field control, UC = untreated control, TS = treated sample.
2. CFU/g = Colony Forming Units per gram.
3. Each “average result” is the average of three or more separate inoculated paper samples. Triplicate blank and control samples were performed. Eight treated samples were performed. Culture plates were prepared in triplicate for each sample.
4. $LR = \log_{10}(\text{untreated control}_{mean} / \text{treated sample}_{mean})$.

CONCLUSION

The Med-Shred medical waste processor comprises several subsystems. A treatment demonstration and microbiological disinfecting tests show that the processor functions as it was intended. The current processor design is a result of many years of medical waste treatment experience. A number of innovations, developed through practice, trial, and error, enable the processor to effectively disinfect medical wastes. When operated properly, consistent with how the processor was designed, the processor should perform as intended to effectively treat medical waste according to the Med-Shred claims.

INDEPENDENT EVALUATION FOLLOW-UP

The Idaho National Laboratory (INL) identified and recommended improvements to Med-Shred that could enhance the Med-Shred process even further. Med-Shred embraced these findings and have since made various upgrades, including a fully automated, self-adjusting chemical delivery system, self-cleaning waste augers, a shredder screen advancement that delivers reduced particle shred size and use of improved materials that will increase equipment life and lower operating and maintenance costs.

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