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THE PROBLEM OF HUMAN WASTE DISPOSAL IN NATIONAL PARKS: A SOLAR ENERGY EXPERIMENT IN YOSEMITE NATIONAL PARK, CALIFORNIA, U.S.A.

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INTRODUCTION

Yosemite National Park in the Sierra Nevada mountains of California is one of the most used parks in the U.S.A. Within the Park are ten composting toilets open to the public at six different backcountry locations. Two of these toilets are used by over 70,000 people in the summer months alone. Approximately 5.8 metric tons of human excreta are removed from these toilets every year. Hitherto, all of this compost has been removed from these sites using either pack animals or helicopters and disposed of in a landfill outside of the boundary of the Park (Williamson, 1996).

This report presents the results of a cooperative project by the U.S. Department of Agriculture, Forest Service, San Dimas Technology and Development Center, San Dimas, California, and the U.S. Department of Interior, Park Service, Yosemite National Park, California, to assess the development and operation of a passive solar insulated box (termed the "Hot Box," or HB) to treat the end-product from composting toilets used by hikers in the backcountry (Figure 1). The primary objective is to determine if the device can heat-treat the compost and reduce pathogen levels, producing a 'Class A sludge' as determined by the U.S. Environmental Protection Agency (EPA) regulation 40 Code of Federal Regulations (CFR) Part 503 (which will be referred to as 'Regulation 503').

Numerous studies have documented innovative passive solar devices used to cook food (Telkes, 1959; Malhotra *et al.*, 1983; Vaishya *et al.*, 1985; Khalifa *et al.*, 1987; Mullick *et al.*, 1987; Pande and Thanvi, 1987; Yadav and Tiwari, 1987; Olwi and Khalifa, 1988; Channiwala and Doshi, 1989; Grupp *et al.*, 1991; Das *et al.*, 1994; Habeebullah *et al.*, 1995). The pasteurization of water using passive solar cookers has also been tested (Ciochetti and Metcalf, 1984).

However, little is known of the effectiveness of using passive solar heat for treatment of sewerage and suchlike. The end-product from backcountry composting toilets is often high in pathogens and does not meet the EPA 40 CFR 503 Regulation guidelines for beneficial reuse or land application. The reuse or surface application of the compost is restricted due to the potential contamination of surface or groundwater sources. Transporting the end-product from backcountry sites can often be expensive, time-consuming, and unpleasant. If solar energy can be used to treat toilet end-product so that it complies with EPA regulations, then the heat-treated compost can be applied to the land in the area where it is generated. This would reduce the reliance on pack animals and/or helicopter resources to transport the end-product from a site, resulting in cost savings and providing an environmentally safe means of recycling human waste back into the land.

Although the end-product from composting toilets is not specifically defined in Regulation 503, it can be compared to sewage sludge in terms of consistency and the total number of pathogens. This sludge is defined under 40 CFR 503.9 (w) general definitions as solid, semi-solid,

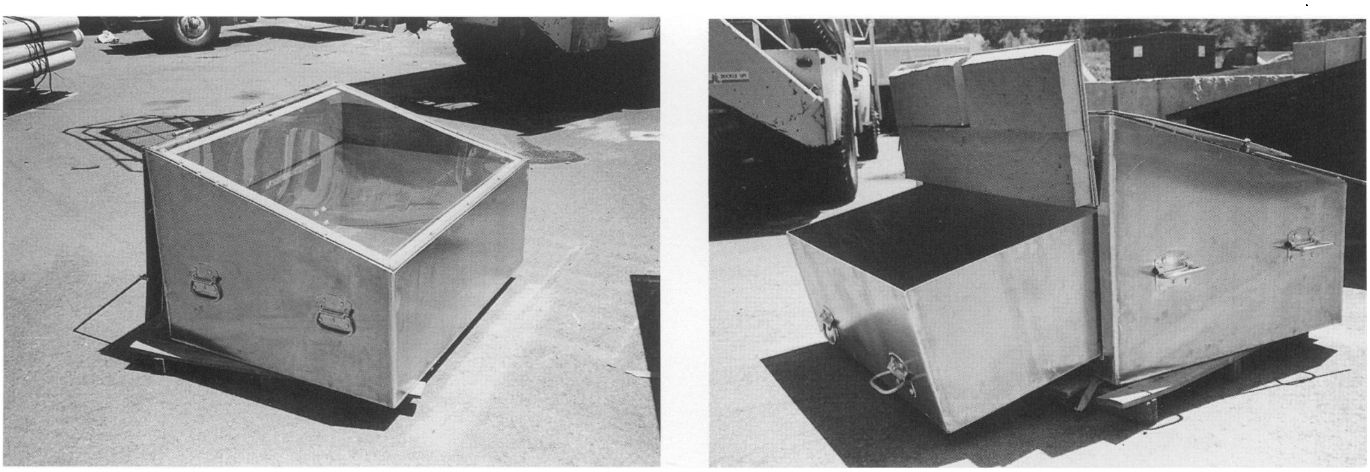

FIGURE 1. The box-type solar cooker was tested by the U.S. Forest Service and the U.S. Park Service to pasteurize the end-product from public composting toilets used by hikers in the backcountry. Photographs by Paul Lachapelle.

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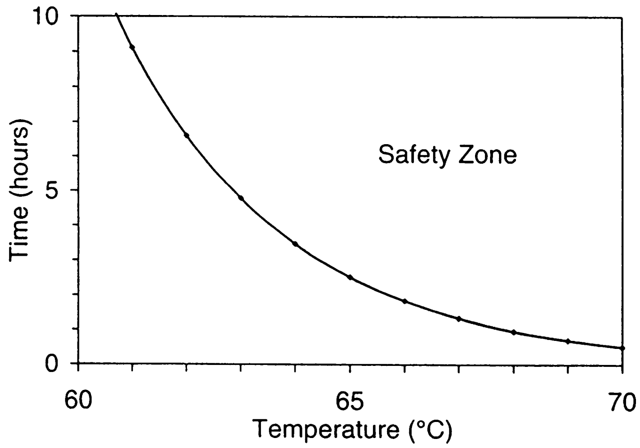

FIGURE 2. U.S. Environmental Protection Agency (EPA) 40 Code of Federal Regulations (CFR) Part 503, time–temperature relationship for the heat-treatment of sewage sludge.

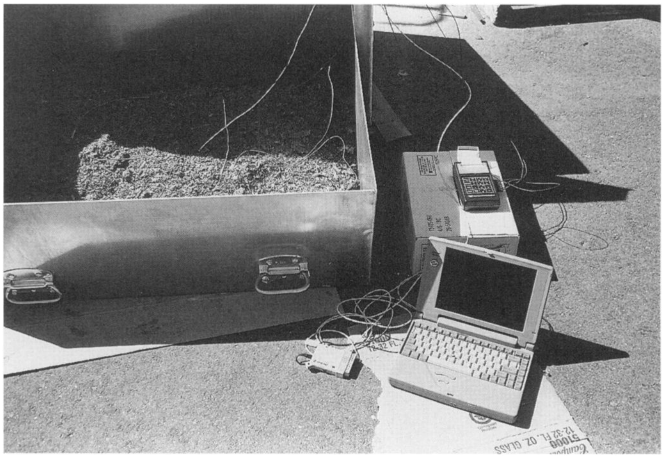

FIGURE 3. Two time–temperature data loggers were used to record and compare temperatures within the Hot Box. Temperature probes were inserted into various sections of the compost pile through a small hole in the back of the Hot Box. A laptop computer was used to download and display the data from the data loggers. Photograph by Paul Lachapelle.

or liquid residue generated during the treatment of domestic sewage in a treatment works, a device or system used to treat sewage (U.S. EPA, 1994). Heat treatment is one method to ensure pathogen reduction and comply with Regulation 503. This heat treatment is a function of time and temperature according to the following formula:

$$D = \frac{1.317 \times 10^8}{10^{0.14t}}$$

D = time in days
t = temperature in degrees Celsius

The time–temperature relationship is calculated using this formula (Figure 2).

Pathogen survival in composting toilet end-product depends upon the time–temperature characteristics within the compost pile. Feachem *et al.* (1983) report that while enteroviruses and *Ascaris* sp. eggs are the most hardy of enteric pathogens, destruction is guaranteed (with the possible exception of hepatitis A virus) when a time–temperature relationship of at least one hour at 62°C is reached. However, the EPA requires a substantially higher time–temperature relationship of over 6 hours at 62°C (Figure 2).

DESCRIPTION OF EQUIPMENT

In the study box-type solar cookers were constructed as follows: the outside walls and floor were cut and arc welded from a 0.64 cm aluminum sheet. The removable tray used inside the Hot Box (HB) was cut and arc welded from a 0.48 cm aluminum sheet. The inside of the tray was painted with a heat-resistant flat-black paint. A single 122 × 94 × 0.64 cm transparent Lexan® Thermoclear polycarbonate sheet was used for the solar glazing. The glazing was bolted to the HB and secured at a 15° angle which was specifically designed to maximize the angle of incidence during the summer solstice for the latitude of Yosemite National Park (38° North). The four inside walls and floor were insulated with 5 cm polyisocyanurate closed-cell foam with a black tar paper coating facing the inside of the HB (R-value 14.4). Six L-shaped bars support the tray above the floor and secure the glazing to the top of the HB. Air gaps between the glazing and the top of the HB were sealed with heat-resistant silicone sealant. A door was positioned at the back of the HB in order to gain access to the tray. The HB measures 122 × 94 × 69 cm at the highest end and 46 cm at the lowest end. The tray measures 109 × 81 × 38 cm. Two temperature loggers (Model SmartReader 2 with one ET-016 thermistor, ACR Systems Inc., Surrey, British Columbia; and Model 50 with three Type J thermocouples, Electronic Controls Design, Milwaukie, Oregon) were used to record and compare internal temperatures[1]. Temperature probes were inserted into various sections of the compost pile through a small hole at the back of the HB. A laptop computer was used to download and display the data from the data loggers (Figure 3).

METHODS AND PROCEDURES

Samples used in the tests were taken from several backcountry composting toilets in Yosemite National Park (YNP). The samples were delivered in double plastic bags and stored in a shaded outside location at the National Park Service El Portal Wastewater Treatment Plant (EPWWTP). The compost consists of a carbon source (softwood shavings used as animal bedding, approximately 0.3–1.3 cm in diameter) intermixed with the urine

[1]Any references made herein to materials and/or apparatus which are identified by means of trademark, trade names, etc., are included solely for the convenience of the reader and are not intended, or to be construed, as an endorsement of said materials and/or apparatus.

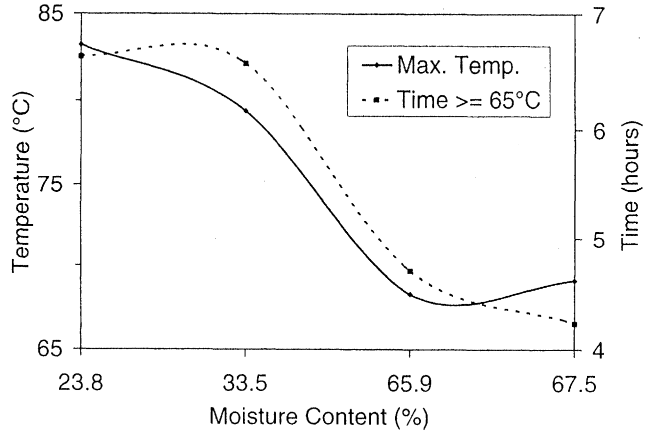

FIGURE 4. Comparisons are made between percentages of moisture content, the maximum temperature attained, and the duration in hours at or above 65°C. All pile depths are equal (8 cm). Temperature readings are taken from the middle of the compost pile.

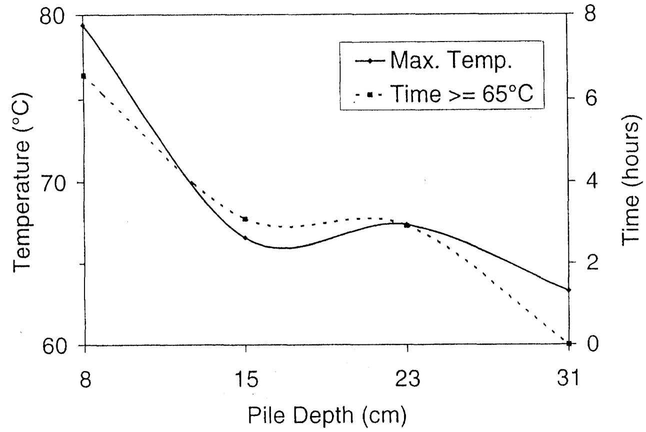

FIGURE 5. Comparisons are made between pile depths, the maximum temperature attained, and the duration in hours at or above 65°C. Moisture content of the compost pile is equal (33.5 %). Temperature readings are taken from the middle of the compost pile.

and feces. These samples were of uniform texture and there was no excess liquid in the sample bags. Small clumps of unmixed feces (approximately 7 cm diameter) were noted in the samples.

The El Portal Laboratory at the EPWWTP tested the pre- and post-HB samples to determine (1) total coliform, (2) fecal coliform, and (3) moisture content (percentage of solid material). Total coliform and fecal coliform were determined using the multiple-tube fermentation technique (Greenberg *et al.*, 1995). The moisture content of the compost was determined using a moisture balance. The compost was emptied into the HB tray and mixed thoroughly with a potato rake to obtain a uniform consistency. For testing purposes, pre-HB samples were taken from the middle of the mixed pile in order to obtain a representative sample.

A temperature of 65°C was arbitrarily chosen to compare the time–temperature characteristics of the compost pile to Regulation 503. At 65°C, the time needed to comply with Regulation 503 is 2 hours 30 minutes (Figure 2). Tests were conducted between 5 June and 23 July, 1996 at the YNP headquarters in El Portal, California (518 m), the maintenance area in Yosemite Valley, YNP (1,219 m), and at the Tuolumne Meadows Wastewater Treatment Plant, YNP (2,682 m). The HB was tested at various altitudes to determine changes in performance.

RESULTS AND DISCUSSION

A total of 13 test 'runs' were conducted. The various tests compared the moisture content of the compost (67.5–23.8%) and the pile depth in the HB tray (8–31 cm) to the maximum pile temperature attained, the reduction of coliform bacteria in post-HB samples and the ability of the HB to sustain a temperature of 65°C or above. Tests runs containing low compost pile depths (less than 15 cm of compost) or having a low moisture content (less than 40%) were able to achieve peak temperatures in excess of 99°C and sustained temperatures of 65°C or above for over six hours. When empty, the HB attained a temperature of 122.4°C.

Figure 4 illustrates the comparisons between tests with equal pile depth (8 cm) but differing moisture contents (23.8–67.5%). Both the maximum temperature and the ability of the pile to sustain a temperature at or above 65°C are compared. As the moisture content of the pile decreases (percentage of solid material increases), there is an increase in both the maximum temperature and the duration at or above 65°C within the middle section of the compost pile.

Figure 5 illustrates the comparisons between tests with an equal moisture content but differing pile depths (8–31 cm). Again, both the maximum temperature and the ability of the pile to sustain a temperature at or above 65°C are compared. As the depth of the compost pile decreases, there is an increase in the maximum temperature and the duration at or above 65°C within the middle section of the compost pile.

Comparisons were made between tests with similar pile depths and moisture content but at various altitudes. Higher temperatures occur at higher altitudes in the top section of the compost pile. However, temperature differences between middle and bottom sections of the pile are marginal.

The moisture loss between pre- and post-HB compost samples occurs as a result of the heat and moisture differential between the inside and outside of the HB. The HB is not air-tight and condensation collected on the solar glazing and escaped through the door seal. It was noted in all of the tests that as internal HB temperatures rose, condensation would run down the outside of the HB starting from the top of the door hinge.

Pre-HB compost samples exceeded federal standards for land application. Laboratory results of post-HB compost were negative (less than three organisms per 100 mL, most probable number) for indicator organisms in all tests regardless of the maximum temperature attained.

Therefore, these tests revealed that the destruction of coliform bacteria was possible without meeting Regulation 503. A sample of post-HB compost was tested for concentrations of the ten metals required by Regulation 503 (arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc) as well as total nitrogen, total kjeldahl nitrogen, nitrate, phosphorus, and ammonia. All test results pass federal regulations for land application.

It is apparent from these tests that the limiting factors in complying with Regulation 503 are (1) the amount of moisture in the compost and (2) the depth of the compost pile in the HB tray. The study reveals that a decrease in the pile depth and/or a decrease in the moisture content of the compost corresponds to higher overall maximum temperatures. Optimum pile depth appears to be less than 15 cm and optimum moisture content appears to be less than 40%. All of the tests that exhibited these characteristics met Regulation 503. Thus, drier and shallower compost inside the HB corresponds to higher internal temperatures and a longer overall duration at or above 65°C.

CONCLUSIONS

Testing of the Hot Box in Yosemite National Park by the U.S. Forest Service and the U.S. Park Service proved to be successful in demonstrating the application of the solar-assisted HB to pasteurize the end-product from composting toilets. It was demonstrated that the EPA 40 CFR Part 503 (i.e., Regulation 503) time–temperature requirements could be met and that a Class A sludge could be produced with minimal labor under optimal operating conditions. The developed HB technology required a minimum level of attention and maintenance by the operator. The HB operation met or exceeded expectations during the time it was monitored. Thus, when operated under optimal conditions, the HB is a practical and efficient method of compost pasteurization.

Laboratory results revealed that post-HB compost was negative for indicator organisms after several hours of heat-treatment. Maximum temperatures were achieved when either moisture content of the compost pile was low or pile depth within the HB tray was low.

The project demonstrated that a direct correlation exists between the depth of the compost pile in the Hot Box, the moisture content of the pile, and the maximum temperatures attained. It was noted that as the volume (pile depth) of the compost increases, there was a decrease in the internal temperature of the compost pile. In addition, as the moisture content of the compost pile increased, there was a decrease in the internal temperature. The study also demonstrated that the altitude of the HB had little effect on the temperature in the middle of the compost pile and that coliform organisms could be destroyed without meeting Regulation 503.

Future design changes could improve the performance of the solar Hot Box. For instance, the HB could incorporate a larger glazing (increased surface area) and the box could be shorter in height (decreased internal air volume) in order to maximize overall solar gain. Also, a separate action to dry the compost could precede HB runs in order to increase compost pile temperatures. Variables such as outside ambient temperatures, wind, and the angle of solar incidence may affect temperatures within the HB. More thorough field testing is needed to determine future design considerations and operation methods.

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