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IN-VESSEL COMPOSTING OF SIMULATED LONG-TERM MISSIONS SPACE-RELATED SOLID WASTES

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ABSTRACT

Reduction and stabilization of solid wastes generated during space missions is a major concern for the Advanced Life Support – Resource Recovery program at the NASA, Kennedy Space Center. Solid wastes provide substrates for pathogen proliferation, produce strong odor, and increase storage requirements during space missions. A five periods experiment was conducted to evaluate the Space Operation Bioconverter (SOB), an *in vessel* composting system, as a biological processing technology to reduce and stabilize simulated long-term missions space related solid-wastes (SRSW). For all periods, SRSW were sorted into components with fast (FBD) and slow (SBD) biodegradability. Uneaten food and plastic were used as a major FBD and SBD components, respectively. Compost temperature (°C), CO2 production (%), mass reduction (%), and final pH were utilized as criteria to determine compost quality. In period 1, SOB was loaded with a 55% FBD: 45% SBD mixture and was allowed to compost for 7 days. An eleven day second composting period was conducted loading the SOB with 45% pre-composted SRSW and 55 % FBD. Period 3 and 4 evaluated the use of styrofoam as a bulking agent and the substitution of regular by degradable plastic on the composting characteristics of SRSW, respectively. The use of ceramic as a bulking agent and the relationship between initial FBD mass and heat production was investigated in period 5. Composting SRSW resulted in an acidic fermentation with a minor increase in compost temperature, low CO2 production, and slightly mass reduction. Addition of styrofoam as a bulking agent and substitution of regular by biodegradable plastic improved the composting characteristics of SRSW, as evidenced by higher pH, CO2 production, compost temperature and mass reduction. Ceramic as a bulking agent and increase the initial FBD mass (4.4 kg) did not improve the composting process. In summary, the SOB is a potential biological technology for reduction and stabilization of mission space-related solid wastes. However, the success of the composting process may depend of the physical characteristics (particle size, porosity, structure, texture) of the SBD components which would require pre-processing of solid wastes before placing them in the SOB.

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INTRODUCTION

Evaluation of biological technologies to reduce and stabilize space related solid wastes has been the focus of different studies by the Advanced Life Support – Resource Recovery Program, National Aeronautics and Space Administration (NASA), at Kennedy Space Center (KSC). Solid wastes are substrates for pathogen proliferation, produce strong odor, and increase storage requirements during space missions. Previous experiments have shown the presence of *Escherichia coli, Bacillus spp., Salmonella spp, Klebsiella pneumoniae*, and other undesirable microorganisms in solid wastes generated in short-term space mission (Kish et al, 2002). For that reason, the biostability of solid wastes generated during space missions may represent a health issue for the crew. Because of storage limitations, space wastes produced on long-term and short-term mission will need to be reduced in volume as well. According to Maxwell and Drysdale (2001) a 6 men crew may produce 10 and 5 kg/d of solid wastes during long-term and short-term space missions, respectively. Therefore evaluation of alternatives to reduce and stabilize space-related solid wastes requires further evaluation.

Aerobic composting is a biological processing technology that has been identified as a possible mechanism to provide biochemical stabilization and mass reduction of solid wastes generated during space missions (Drysdale and Finger, 1997; Atkinson et al., 1998; Roberts et al, 2002, *In press*). Composting also has the potential to enable nutrient recycling, water reclamation, pathogen reduction, and to reduce storage requirements. For solid wastes composting, one design under evaluation is the Space Operations Bioconverter (SOB), a small scale, *in-vessel* composter that may potentially function as a sub-system within an integrated advanced life support recycling strategy (Drysdale and Finger 1997; Atkinson et al., 1998). In previous research, the SOB was utilized to evaluate the composting characteristics, and microbial community composition and diversity of alfalfa and aspen shavings composted at different temperatures and initial C/N ratios with excellent results (Roberts, et al., 2002, *In press*). However, the solid wastes of space-related missions include components with both low (trash, packaging material, tape, paper) and high biodegradability (inedible plant biomass, human feces). Because of differences in material composition, quantity, and degradability, we cannot extrapolate the composting characteristics of inedible biomass into wastes generated in space missions. Presently, not intent to compost space missions solid wastes have been performed. This research reported here was designed to evaluate the composting characteristics of solid wastes generated during simulated long-term space missions using the SOB.

EXPERIMENTAL PROCEDURE

A five periods experiment was performed in the Advanced Life Support -Resource Recovery – Integration Laboratory at KSC. The Space Operations Bioconverter (SOB; Figure 1), an *in -vessel* composting system with rotating drum, thermal control, gas monitoring, in *situ* mixing, leachate collection, and air recycle capability was used in the experiment. The *in-vessel* composting unit has been described and evaluated earlier with positive results (Roberts et al, 2002, *In press*). For all periods, a simulated long-term mission space-related solid waste (Maxwell and Dystdale, 2001) was prepared with components sorted for slow (SBD) and fast biodegradability (FBD, Table 1).

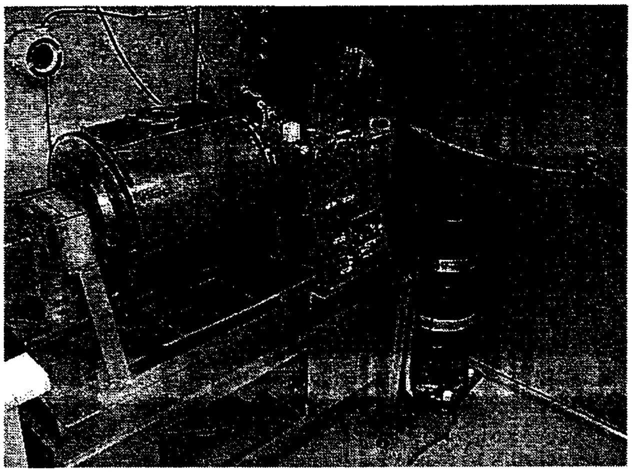

Figure 1. Space Operations Bioconverter – SOB

Table 1. Stimulated long-term mission space-related solid wastes

Fast Biodegradability	(55 %)	Slow Biodegradability	(45 %)
Carrots	7.69	Food Packaging Material	13.78
Tortillas	11.54	Paper	29.33
White Bread	15.38	Tape	6.22
Cream Spinach	7.69	Plastic	50.67
Turkey Ham	7.69		
Fruit Punch	15.38		
Celery	7.69		
Pitted Prunes	7.69		
Crackers	7.69		
Oranges	11.54		

For all periods, the composting materials were manually chopped into a 2.5 cm square pieces, adjusted to 55 % - 65 % initial moisture content with distilled water, and loaded into the SOB. After an initial 1 hour mixing period, the composter rotated for 4 min every 6 hours. During the entire composting process, compost temperature (°C), room temperature (°C), and CO_2 production, % (in line CO_2-sensor, GMP221 Probe, Vaisala Inc., Helsinki, Finlandia) were monitored at 5 min intervals, and averaged by the hour. Total mass reduction (%), calculated by difference between the initial and final compost mass weight, and final pH was determined at the end of each composting period.

In period 1, a simulated long-term mission space-related solid, 55-FBD: 45-SBD (w/w) proportions, was loaded into the SOB (± 4 kg) for 7 days. On day two, 15 g of soil (rear surface soil obtained from the Happy Hammock area of KSC) were added to the SOB as microbial inoculum. A second period *in-vessel* composting was conducted utilizing 45 % of the solid wastes composted in period 1, 55 % food wastes (total 4.2 kg), and 70 g of soil. The use of styrofoam as a bulking agent (to increase air flow through the pile) on the composting process was evaluated in period 3. The *In-vessel* composting unit was loaded for eleven days with 75% of pre-composted solid wastes (2 kg), 25% food wastes (1 kg), and 70 g of styrofoam. On day four, 0.58 kg of FBD components were added to the SOB. Using biodegradable plastic instead of regular plastic on the composting characteristics of SRSW was evaluated in period 4. The *In-vessel* composting unit was loaded for eleven days with 55% FBD (1.65 kg) and 45% SBD (1.29 kg) components. On day one, 50 g of styrofoam, and 300 g of previously composted SRWS were added as bulking agent and microbial inoculum. After 3 and 6 days of composting, 1 and 1.8 kg of FBD components were added to the composter, respectively. Period five evaluated the use of ceramic

(2.8 kg) as a bulking agent and the relationship between initial FBD mass (kg) and heat production on the composting of SRSW. The SOB was loaded for five days with a 55 % FBD (4.4 kg): 45% SBD (3.6 kg) mixture. Biodegradable plastic was utilized within the SBD components and 300 g of soil were added as microbial inoculum at the beginning of the composting process.

RESULTS AND DISCUSSION

Figure 2 shows the CO_2 production, compost temperature, and room temperature during the entire composting process. For each period, table 2 shows the compost components, final pH, total mass reduction, average CO_2 production, room temperature (RT), compost temperature (CT) and the difference between CT and RT. In period 1, composting SRWS resulted in an acid fermentation, with a minor increase in compost temperature, low CO_2 production, and only minor mass reduction. Similar to period 1, the period 2 reuse of SBD components in the compost mass did not increase the pH, CO_2 production, or compost temperature during the composting process. Total mass reduction was higher in period 2 than in period 1, but this difference in carbon loss may be due to the length of the composting process rather than the compost components (7 and 11 days for period 1 and 2, respectively). The acid pH observed in periods 1 and 2 could be an indicator of lack of oxygen in the compost mass, as a result of the presence of SBD components, especially plastic. The sticky properties of regular plastic might avoid the oxygen infiltration into the compost mass creating anaerobic conditions. Under anaerobic fermentation, the production of lactic acid and short chain volatile fatty acids by anaerobic or facultative microorganisms decrease the pH, affecting the metabolic activity and proliferation of heat producing microorganisms. These results show that it is not possible to use components with SBD as bulking agent during the composting process of SRSW. In both phases, an increase in CO_2 production, an indicator of microbial metabolic activity, was observed when adding soil as a microbial inoculum. This increase in food wastes degradation when added the microbial source may also indicate the beneficial effects of the addition of microbial starter for the composting process.

Addition of styrofoam as bulking agent (period 3) improved the composting characteristics of SRSW as evidenced by higher pH, CO2 production, compost temperature, and total mass reduction. The difference between compost temperature and room temperature was also higher in SRWS composted with styrofoam than in SRSW composted without the bulking agent. The presence of styrofoam may increase the aerobic conditions in the compost resulting in a shift in microbial populations in the compost mass. This change in microbial community maybe responsible by the lower acidity and greater heat production observed during this composting period. However, composting SRSW with stryfoam as a bulking agent did not reach 50-55°C/3 d, temperature necessary to destroy pathogen microorganisms.

Using biodegradable plastic on the *in vessel* composting of SRSW shows a slightly improvement in the compost characteristics as compared to the initial three periods. During the entire experiment, the highest compost temperature and average CO2 production were observed when biodegradable plastic was included in the compost mass. However, using biodegradable plastic did not increase the compost temperature to thermophillic conditions, and had similar total mass reduction and final pH relative to the SRSW composted without the biodegradable plastic. In this experiment, no attempt to calculate the percentage of bioplastic degrade during the composting process was made. However, the similar mass reduction observed in periods 3 and 4 might indicate that the effect of inclusion of biodegradable plastic on the composting characteristics of SRSW was more related to the particle size rather than its degradable properties.

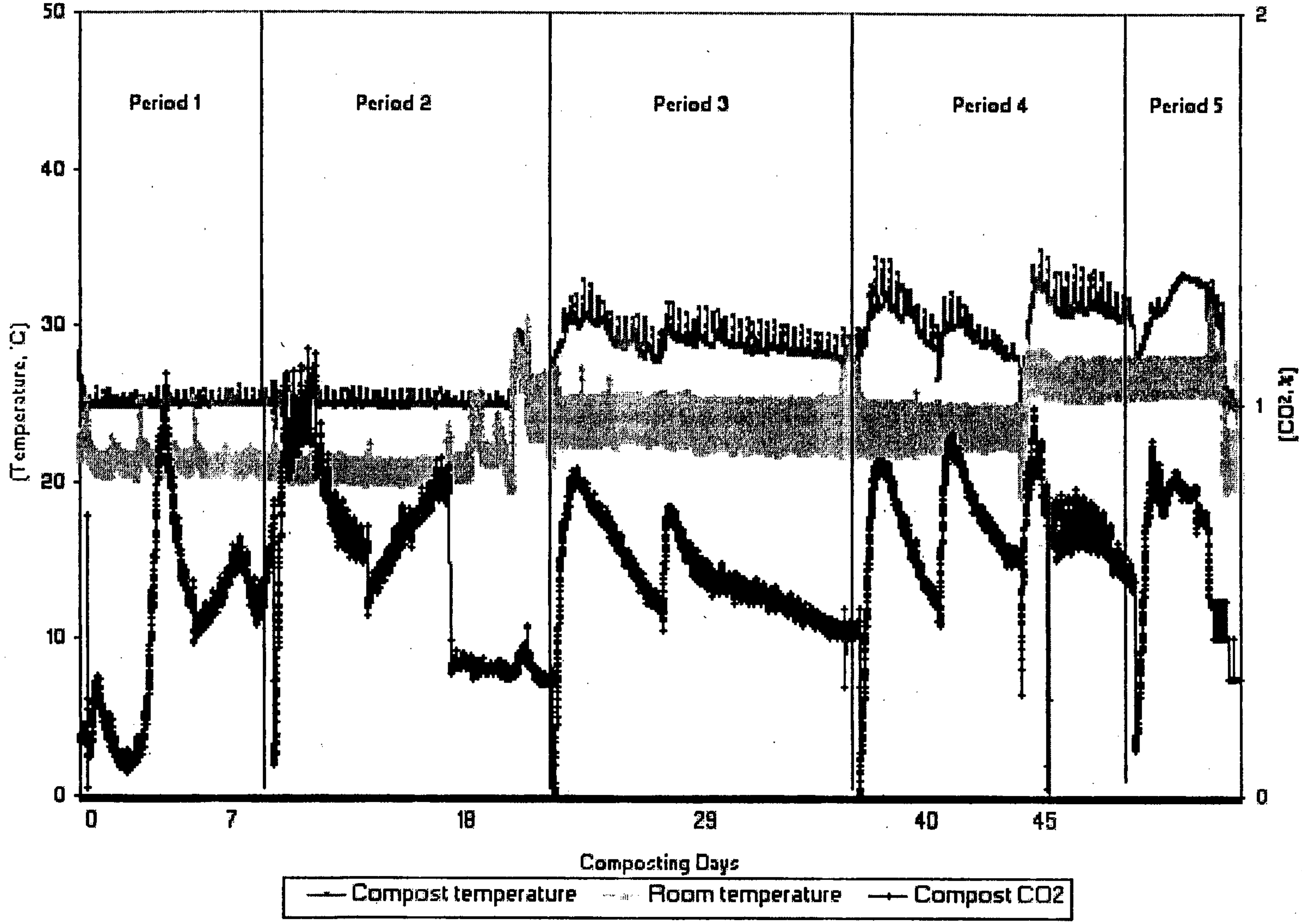

Figure 2. CO2 production and compost temperature of simulated long-term mission space-related solid wastes using the SOB

Table 2. Composting characteristics of simulated long-term mission space-related solid wastes using the SOB

Period/Components	Composting days	Average				Final	
		CO2 (%)	CT (°C)[a]	RT (°C)[b]	CT-RT	Mass Reduction (%)	pH
1 55% FBD[c]: 45% SBD[d] Initial Mix = 4 kg 17 g Soil	7	0.42	24.9	21.5	3.4	8.2	4.40
2 55% FBD; 45% Pre-composted SRSW[e] Initial Mix = 4.2 kg 73 g Soil	11	0.66	25.3	21.8	3.7	15.8	4.59
3 75% Pre-composted SRSW; 25% FBD Initial Mix = 3 kg Added FBD;.58 kg on day 4 70 g Styrofoam	11	0.64	29.0	24.0	5.0	22.2	6.29
4 55% FBD; 45% SBD (22% Bio-plastic) Initial Mix = 3 kg Added FBD, 1 kg/d-3; 1.8kg/d-6 50 g Styrofoam 300 g pre-composted SRSW	11	0.73	30.1	24.7	5.5	17.7	6.20
5 55% FBD;45% SBD (22% Bio-plastic) Total Mix = 1k g Ceramic 300 g Soil	7	0.66	30.56	26.7	4.2	12.1	6.18

[a] Compost Temperature; [b] Room Temperature; [c] Fast biodegradability ;[d] Slow biodegradability; [e] Simulated long-term mission space-related solid wastes

A slight correlation between initial FBD components and heat production was observed in periods 1 to 4, however, in period 5 increasing the initial FBD mass to 4.4 kg did not result in better compost as compared to SRSW composted in previous periods. These results might indicate that higher amount of fast biodegradable components could be necessary to increase the compost temperature to thermophillic conditions during the composting of SRSW. Final pH, an indicator of aerobic conditions, was similar in SRSW composted with ceramic and styrofoam as a bulking agents. Therefore, these results indicate that ceramic represent a promising alternative to create and maintain aerobic conditions during the composting of SRSW.

Although a moderate thermophillic temperature was not obtained during the composting process in this experiment, composting still represents a potential biological processing technology for the reduction and stabilization of long-term and short-term mission space-related solid wastes. Future research should be undertaken because of the present and future requirements to reduce and stabilize SRSW. Experiments to determine the physical characteristics such as porosity, shape, structure, texture, and consistency of individual SBD components and their influence on the aeration process need to be performed. The optimum particle size of each SBD components and their effect on the composting process needs to be investigated. Biological alternatives to improve the composting process also need to be evaluated. Although solid wastes from space-related missions contain forms of inoculum from human sources, the development and evaluation of microbial products containing cellulose degrading (fungi, actinomycetes) and heat producing microbes on the composting process of SRSW should be studied. The determination of the optimum rate of microbial inoculation on the composting process would also be helpful.

CONCLUSIONS

On the basis of this study we concluded that the Space Operation Bioconverter (SOB) is a potential biological processing technology for the reduction and stabilization of simulated long-term mission space-related solid wastes. However, the success of the *in-vessel* composting process may depend on the physical, chemical, and biological characteristics (particle size, porosity, composition, structure, texture) of the SBD components. Additional work would be require to evaluate the necessary pre-processing steps, and their associated cost, to generate a suitable feed stock for composting in the SOB.

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