Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 56 (2015) 970–981

ADVANCES IN SPACE RESEARCH
(a COSPAR publication)

www.elsevier.com/locate/asr

Low temperature ozone oxidation of solid waste surrogates

James A. Nabity [a,1,*], Jeffrey M. Lee [b,2]

[a] *University of Colorado, Boulder, CO 80309, United States*
[b] *NASA Ames Research Center, Moffett Field, CA 95032, United States*

Received 1 January 2015; received in revised form 15 May 2015; accepted 16 May 2015
Available online 23 May 2015

Abstract

Solid waste management presents a significant challenge to human spaceflight and especially, long-term missions beyond Earth orbit. A six-month mission will generate over 300 kg of solid wastes per crewmember that must be dealt with to eliminate the need for storage and prevent it from becoming a biological hazard to the crew. There are several methods for the treatment of wastes that include oxidation via ozone, incineration, microbial oxidation or pyrolysis and physical methods such as microwave drying and compaction. In recent years, a low temperature oxidation process using ozonated water has been developed for the chemical conversion of organic wastes to CO_2 and H_2O. Experiments were conducted to evaluate the rate and effectiveness with which ozone oxidized several different waste materials. Increasing the surface area by chopping or shredding the solids into small pieces more than doubled the rate of oxidation. A greater flow of ozone and agitation of the ozonated water system also increased processing rates. Of the materials investigated, plastics have proven the most difficult to oxidize. The processing of plastics above the glass transition temperatures caused the plastics to clump together which reduced the exposed surface area, while processing at lower temperatures reduced surface reaction kinetics.

Keywords: Ozone oxidation; Waste treatment; Solid wastes; Mixed wastes; Plastics; Sterilization

1. Introduction

A critical need for long term space missions is an effective method to control solid wastes. The current estimates of solid waste generation rates are about 1.69 kg/CM-d (kilograms per crew member per day) for long duration space missions and 1.39 kg/CM-d for short term missions (Hanford, 2004). If one assumes a 180 day mission for a crew of six, then a total of 1825 kg of waste will be generated. Without processing and using the highest densities that have been achieved to date of 64 kg/m^3, a space of approximately 28.5 m^3 would be required to contain this waste (Pace and Fisher, 2004). Alternatively, a waste treatment system would need to process the waste at the rate at which it is produced (423 g/h).

In addition to occupying valuable space, leaving the waste untreated could cause the crew to be exposed to odors and biohazards, which would be a serious threat to their health and morale. Moreover, the waste provide a haven for organisms that if released could interfere with our ability to detect life beyond Earth. The United Nations Treaties and Principles on Outer Space (2002) states that "…Parties to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination [forward contamination] and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter [back contamination]…" NASA policies (NPI 8020.7 and NPD 8020.7G) use this as the basis to establish principles and guidelines for human missions to Mars. Hogan et al.

---

* Corresponding author.
E-mail address: james.nabity@colorado.edu (J.A. Nabity).
[1] Associate Professor, Department of Aerospace Engineering Sciences.
[2] Chemical Engineer, Bioengineering Branch.

http://dx.doi.org/10.1016/j.asr.2015.05.026
0273-1177/

(2005) describe the potential impact that compliance with this doctrine imposes on waste management; particularly, since it will be desirable to leave waste behind in order to control back contamination. Finally, if the waste is not processed, neither the oxygen nor the water contained in the waste will be recovered. For these reasons, it is important that waste treatment methods destroy biological contaminants, and reclaim valuable resources from the waste or be able to repurpose the waste for reuse.

1.1. Waste treatment by compaction, pyrolysis, incineration and microbial processes

Waste treatment methods have received considerable attention due to storage needs and the hazards that the waste streams pose to the crew onboard the International Space Station. Compaction, pyrolysis, incineration, and microbial and ozone oxidation have been investigated because of their promise for safening wastes, reducing volume, recovering water and producing useful commodities such as methane, carbon dioxide and water. For example, NASA Ames Research Center has investigated the heat melt compaction of wet and dry wastes to reduce volume by ten-fold and recover water (Pace et al. 2011; Jones et al. 2013). Hard tiles will be produced if the waste stream contains a sufficient amount of plastics (approximately 20% or greater) to bind and enclose the other wastes. Ewert and Broyan (2013) describe the potential to reuse these compacted waste tiles as radiation shielding.

Serio et al. (2005) investigated the pyrolysis of solid wastes augmented by catalytic oxidation. Microwave pyrolysis was used to convert biomass (wheat straw and feces) into ethylene, methane, and hydrogen gases (Serio et al., 2013). Conversion rates reached 60 g/h for wheat straw and 200 g/h for feces at operating temperatures of 850–1000 °C. Torrefaction (a mild pyrolysis process at conditions of about 300 °C) was investigated to sterilize and convert feces and biomass wastes into CO_2, CO, and CH_4 (Serio et al., 2014). The dry char residue has potential use as feed material for the production of activated carbon and a nutrient-rich substrate for plant growth among other uses. Mixed waste streams containing plastics and metals will likely pose a challenge.

The wastes must usually be dried before incineration in order to ensure nearly complete combustion at temperatures of up to 800 °C. Because of the high temperature, it is challenging to continually feed the solids into the incinerator while supporting the flame. Gaseous off-products include NO_x and SO_2 which would quickly build to toxic levels in a spacecraft if left untreated. Fisher et al. (1998) report a waste incineration system that incorporated a fluidized bed combustor and a catalytic flue gas clean up system to remove NO_x and SO_2 pollutants. With further optimization the process can produce activated carbon.

Microbial processes, such as composting, use aerobic bacteria to oxidize wastes. Whitaker and Alleman (2006) developed a solids thermophilic aerobic reactor (STAR) to process biodegradable solid waste into feedstock for plants and animals, which was optimized for solids loading and pH and then Whitaker and Alleman (2007) integrated STAR into a regenerable closed-loop life support system for food production and treatment of water, air and waste. Drawbacks of the STAR system are low solids loading (<8%), the sensitivity to pH and the relatively slow rates of conversion compared to other processes. Whitaker et al. (2004) report a period of 11 days to process a 46 L mixture with 3% solids loading.

1.2. Waste treatment with ozone

Low temperature oxidation with ozone (O_3) has great potential to convert organic wastes to CO_2 and H_2O, while disinfecting any inorganic residuals Wickham et al. (2007). Ozone has a strong oxidizing potential, so the oxidation reactions go to completion even at low temperatures from 100 to 125 °C. Because the reactions go to completion, the process is not likely to produce toxic partial oxidation compounds, and because of the relatively low operating temperature compared to incineration it is not likely to produce NO_X. Nabity et al. (2008) recycled unused ozone back to the reactor to improve the efficiency and increase the waste oxidation rates of the system developed by Wickham.

Nabity et al. (2009, 2010) next report a pilot-scale system to demonstrate its ability to treat a waste stream made up of mixed solids. The mass and volume of the system were 140 kg and 1.0 m^3, respectively. The packaging density of this prototype was poor, only 140 kg/m^3, and thus it was projected that the volume could be reduced by a factor of 10. Nominal operating conditions of 125 °C and 4.3 atm (65 psia) were established during experiments to optimize the oxidation rate of waste streams. Average rates for mixed solids and feces were 8.5 and 15.9 g/h, respectively. The principle products of the reaction were H_2O and CO_2. The total organic carbon (TOC) measured in the recovered water was less than 100 ppm. The measured concentrations of CO and NO_x in the exhaust gas stream were less than 1000 ppm CO and 2 ppm NO_x, respectively. Assuming an available volume of 14 m^3 for the waste treatment system (half that needed for storage during a 180 day mission), an ozone oxidation system has potential to oxidize up to 1190 g/h if operated continuously.

1.3. Motivation for the present study

Nabity et al. (2010) observed in these ozone oxidation experiments that the plastics within the waste stream clumped together, most likely because the reactor temperature was within the range of melt points for the plastics (between 105 and 130 °C for polyethylene plastics), and their rates of oxidation were much slower than the other waste components. Nabity et al. (2009) observed an approximately 6.5% reduction in the oxidation rate of a surrogate feces when the reactor temperature was lowered from 125 to