Waste Management 33 (2013) 2267–2276

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Decomposition of forest products buried in landfills

Xiaoming Wang [a,*], Jennifer M. Padgett [a,1], John S. Powell [b,2], Morton A. Barlaz [a]

[a] Department of Civil, Construction, and Environmental Engineering, Campus Box 7908, North Carolina State University, Raleigh, NC 27695-7908, United States
[b] Department of Chemical and Biomolecular Engineering, Campus Box 7905, North Carolina State University, Raleigh, NC 27695-7905, United States

ARTICLE INFO

Article history:
Received 29 November 2012
Accepted 4 July 2013
Available online 12 August 2013

Keywords:
Landfills
Municipal solid waste
Forest products
Anaerobic decomposition
Biogenic carbon storage

ABSTRACT

The objective of this study was to investigate the decomposition of selected wood and paper products in landfills. The decomposition of these products under anaerobic landfill conditions results in the generation of biogenic carbon dioxide and methane, while the un-decomposed portion represents a biogenic carbon sink. Information on the decomposition of these municipal waste components is used to estimate national methane emissions inventories, for attribution of carbon storage credits, and to assess the life-cycle greenhouse gas impacts of wood and paper products. Hardwood (HW), softwood (SW), plywood (PW), oriented strand board (OSB), particleboard (PB), medium-density fiberboard (MDF), newsprint (NP), corrugated container (CC) and copy paper (CP) were buried in landfills operated with leachate recirculation, and were excavated after approximately 1.5 and 2.5 yr. Samples were analyzed for cellulose (C), hemicellulose (H), lignin (L), volatile solids (VS), and organic carbon (OC). A holocellulose decomposition index (HOD) and carbon storage factor (CSF) were calculated to evaluate the extent of solids decomposition and carbon storage. Samples of OSB made from HW exhibited cellulose plus hemicellulose (C + H) loss of up to 38%, while loss for the other wood types was 0–10% in most samples. The C + H loss was up to 81%, 95% and 96% for NP, CP and CC, respectively. The CSFs for wood and paper samples ranged from 0.34 to 0.47 and 0.02 to 0.27 g OC g^{-1} dry material, respectively. These results, in general, correlated well with an earlier laboratory-scale study, though NP and CC decomposition measured in this study were higher than previously reported.

1. Introduction

Approximately 24.3 million Mg (1 Mg = 1000 kg) of paper and paperboard, and 12.3 million Mg of wood were discarded in the U.S. municipal solid waste (MSW) stream in 2010, and most of these materials were managed in landfills (U.S. EPA, 2011). In addition, construction and demolition (C&D) waste is often disposed in MSW landfills, and contains as much as 40% wood (Staley and Barlaz, 2009). The disposal of large quantities of these forest products in landfills also occurs in other countries that rely on landfills as a disposal option for municipal waste. For example, it was reported that approximately 2.3 million Mg of wood products and 2.0 million Mg of paper products are disposed in Australian landfills annually (Ximenes et al., 2008).

The decomposition of forest products under anaerobic conditions in landfills results in the generation of approximately equal volumes of biogenic carbon dioxide and methane (Barlaz, 2006). Some of the methane is released as a fugitive emission due to incomplete landfill gas capture and incomplete oxidation in landfill cover soils. However, a significant portion of biogenic carbon in wood and some paper products (e.g., newsprint) does not decompose, and therefore represents a biogenic carbon sink. Wang et al. (2011) estimated that approximately 10 million Mg of carbon are sequestered in U.S. landfills annually due to wood discards, while Skog and Nicholson (1998) estimated approximately 61 million Mg of annual carbon storage attributable to wood and paper discards in U.S. landfills. Documentation of carbon storage in landfills is important, as recent analyses have shown it to be a significant factor in an overall landfill life-cycle analysis, accounting for offsets of 141–261 kg CO_2 equivalent (CO_2-e) per Mg of waste disposed in a landfill (Christensen et al., 2009).

Cellulose (C), hemicellulose (H) and lignin (L), closely associated with each other as lignocellulose, are the major polymeric components that comprise forest products. Cellulose and hemicellulose are microbially converted to methane and carbon dioxide under anaerobic conditions (Micales and Skog, 1997; Barlaz, 2006), while lignin is considered to be recalcitrant (Colberg, 1988). As such, the complete conversion of cellulose and hemicellulose in landfills would not be expected due to the presence of lignin that reduces holocellulose (cellulose and hemicellulose) bioavailability. Lignin acts as both a physical and chemical barrier to microbial

* Corresponding author. Tel.: +1 919 513 4421; fax: +1 919 515 7908.
E-mail address: xwang25@ncsu.edu (X. Wang).
[1] Geosyntec Consultants, 10220 Old Columbia Rd, Suite A, Columbia, MD 21046, United States.
[2] Carolina Brewery, 120 Lowes Drive, Suite 100, Pittsboro, NC 27312, United States.

0956-053X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.wasman.2013.07.009

degradation of holocellulose (Colberg, 1988; Tong et al., 1990; Stinson and Ham, 1995).

The ultimate biodegradability of selected wood and paper products under laboratory-scale landfill conditions has been reported (Eleazer et al., 1997; Wang et al., 2011). Size-reduced and homogenized substrates were incubated under optimal conditions (moisture, pH, nutrients, and temperature) to maximize both the rate and extent of decomposition. In contrast to the laboratory, field-scale studies have the advantage of examining decomposition under real-world conditions. However, they have associated difficulties including heterogeneous particle size, low moisture content, poor mixing, sample contamination, a lack of baseline values, and difficulty in sample recovery (Baldwin et al., 1998; Ximenes et al., 2008).

The first attempt to quantify the decomposition of specific waste components in landfills was reported by Baldwin et al. (1998). Selected lignocellulosic materials were buried and retrieved periodically over 6 yr from three U.S. landfills. Materials were selected to cover a range of biodegradabilities, including filter paper, pasta and lima beans (readily degradable); broccoli and peanuts (moderately degradable); and newspaper and sunflower seeds (slowly degradable). Newspapers (~25% lignin) exhibited 13–31% holocellulose loss at three sites over the monitoring period. In contrast, no filter paper (negligible lignin content in fresh materials) was recovered, which might suggest its complete biodegradation. These results show that more lignified materials exhibit less anaerobic biodegradation.

The decomposition of wood products in three Australian landfills was determined by comparing the composition of excavated samples with their fresh controls (Ximenes et al., 2008). Limited decomposition of wood products was observed after 19 and 29 yr, respectively. However, up to 18% loss of the organic carbon (OC) in hardwoods and softwoods was measured in waste buried for 46 yr, although some aerobic decomposition may have been occurred in these samples.

The objective of this study was to measure the extent of decomposition of various wood and paper products buried in full-scale landfills. Samples were buried in landfill areas operated with leachate recirculation and excavated after approximately 1.5 and 2.5 yr. Results are compared to decomposition measured in laboratory reactors designed to measure the ultimate rate and extent of decomposition (Eleazer et al., 1997; Wang et al., 2011).

2. Materials and methods

The field experiment involved burial of selected wood and paper samples at two commercial landfills, Uwharrie Environmental Landfill in Troy, North Carolina, U.S. (Uwharrie LF) and Maplewood Landfill in Amelia, Virginia, U.S. (Maplewood LF). Samples were buried in landfill areas operated with leachate circulation, so that these samples were exposed to leachate from mixed refuse.

2.1. Materials

Wood products selected included hardwood (HW), softwood (SW), and four engineered woods: plywood (PW), oriented strand board (OSB), particleboard (PB) and medium-density fiberboard (MDF). Paper products included newsprint (NP), corrugated container (CC) and copy paper (CP). These materials were chosen to represent major types of wood and paper products present in U.S. MSW. All the woods were obtained from a commercial lumberyard. NP was obtained from the Raleigh News and Observer; CC was purchased at a local store; and CP was collected from a recycle bin at North Carolina State University. Wood samples were cut to a length of ~30 cm. The width and thickness of each wood type depended on the original dimensions of collected lumbers, which ranged from 10 to 15 cm wide by 1 to 5 cm thick. The NPs and CPs were not subjected to any size reduction, while the CCs were cut to sheets that were about 30 cm length by 15 cm width.

Materials buried in Uwharrie LF included a hardwood (HW-White Oak), a softwood (SW-Pine), PW, OSB made from hardwood (OSB-HW), PB, MDF, NP, CC and CP. The samples were wrapped in polypropylene mesh bags (McMaster Carr 9883T65, Robbinsville, NJ, U.S.) to facilitate moisture infiltration and sample retrieval. All woods were loaded into one bag while three additional bags were used for NP, CC and CP, respectively. These four bags were tied together with a polypropylene rope to comprise a sample set.

Materials buried in Maplewood LF were a hardwood (HW-Red Oak), a softwood (SW-Spruce), PW, OSB-HW, PB, MDF, CP, NP and CC. Based on the experience with the polypropylene bags, metal cages were used to facilitate moisture infiltration and sample recovery. The cages were made from angle iron and included multiple compartments to separately store each material (Fig. 1).

2.2. Site description and sample placement

The sample sets described above were buried in Uwharrie and Maplewood LFs in June 2007 and May 2009, respectively. These sites were selected based on the opportunity to access samples several years after burial, and the use of leachate recirculation to accelerate solids decomposition.

At Uwharrie LF, trench excavation and sample burial took place on June 4 and 5, 2007. Samples were buried in a landfill section that was operated to accelerate refuse decomposition through leachate recirculation. Three sub-trenches (C, D, and E) were excavated to place sample sets at various distances between two leachate injection trenches (A and B) (Fig. 2). Four, 8 and 12 sample sets were placed in trenches C, D and E, respectively, with the intention that samples would be excavated over time. The depths of sample burial ranged from 3.5 to 5.5 m, and the distances of trenches C, D, and E away from the leachate injection point in trench A ranged from 4.0 to 19.0 m. The sample burial area was backfilled with excavated refuse and a layer of soil. Leachate injection was initiated 2 days after sample burial.

Sample placement varied slightly at Maplewood LF. Samples were buried in four boreholes on May 14, 2009 at various distances between leachate injection trenches. Duplicate sample cages were buried in 3-m deep boreholes, and excavated refuse was placed back over the sample cages and re-compacted. The location of each borehole was surveyed, and steel cables were laid over the top of each sample cage to mark its position. The sample burial area was covered with soil and seeded with grass after the burial.

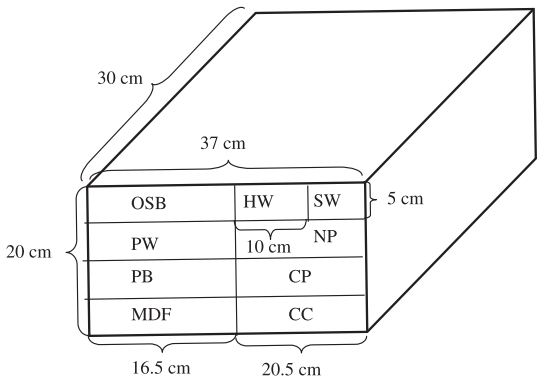

Fig. 1. Schematic of sample cage buried in Maplewood LF (not to scale). Selected wood and paper samples were stored separately in each compartment as illustrated.