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Investigating gas emissions and dry matter loss from stored biomass residues

Xiao He [a], Anthony K. Lau [a,*], Shahab Sokhansanj [a,b], C. Jim Lim [a], Xiaotao T. Bi [a], Staffan Melin [a,c]

[a] Department of Chemical and Biological Engineering, University of British Columbia, 2360 East Mall, Vancouver, BC V6T 1Z3, Canada
[b] Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
[c] Delta Research Corporation, 501 Centennial Parkway, Delta, BC V4L 2L5, Canada

HIGHLIGHTS

- Gas emissions from stored forest residues under various conditions were measured.
- The effect of temperature on CO_2 emissions differed for different materials.
- Total gas emissions from aerobic reactors were higher than non-aerobic reactors.
- Percent dry matter loss of the materials was positively correlated to gas emission.
- Microbial analysis results are compatible with the CO_2 emission results.

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ABSTRACT

Biomass is considered a renewable and eco-friendly source for conversion into bioenergy. The objective of this paper is to investigate the gas emissions and dry matter loss during storage for better management and handling of biomass. Experiments were conducted using Douglas fir residues for a range of temperatures under non-aerobic and aerobic conditions. Results showed that the CO_2 emission from the mixed chips and greens was an order of magnitude greater than the wood chips. CO_2 emissions from the aerobic reactors exhibited similar trends as the non-aerobic reactors with respect to the effect of temperature. Similar types of volatile organic compounds were detected from the chips and the mixed materials. Total gas emissions from the aerobic reactors were higher than the non-aerobic reactors. Dry matter loss and gas emissions was found to be positively correlated, reaffirming that gas emission is an important factor leading to dry matter loss of stored biomass residues.

1. Introduction

Bioenergy produced from a variety of biomass feedstocks is categorized as renewable energy source, along with direct solar energy, geothermal energy, hydropower, ocean energy and wind energy [1]. In a study of life cycle emissions, the production of electricity from biomass are generally considered to be eco-friendly due to the lower greenhouse gas (GHG) emissions and some of the criteria air pollutant emissions as compared to fossil fuels [2]. Spatially and temporally explicit life cycle inventory of non-GHG air pollutants (including the criteria air pollutants and volatile organic compounds) from ethanol derived from corn grain or corn stover versus gasoline have also been described [3].

Douglas fir (*Pseudotsuga menziesii*) is a softwood species that grows on the west coast of North America, extending from northern British Columbia to northern Mexico. It makes up some 25% of the tree species in coastal British Columbia. After logging and other process operations, the forest residues which mainly include wood chips, bark, needles and leaves are usually piled in the forest or on site for a period of time, in order to ensure continuous availability for bioenergy production during the growing season and winter months [3,4].

The problems induced during the storage of high-moisture biomass residues with moisture contents that exceed 40% (wet basis) include gas emissions and dry matter loss due to degradation [5]. It is well known that all biomass gradually decomposes over time, both chemically and biologically. Microbial activity in stored biomass, especially the growth of molds, is a major cause of decomposition of the materials leading to heat buildup and potentially high

* Corresponding author. Tel.: +1 604 822 3476; fax: +1 604 822 6003.
E-mail address: aklau@chbe.ubc.ca (A.K. Lau).

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temperatures in the pile. During the period of fast decomposition, there exist the risks of emissions, energy losses, and fires [6,7].

The common gas emissions from stored biomass were identified to be mainly CO_2, CO, CH_4 and non-methane volatile organic compounds (NMVOCs) [8]. The generation of CO_2 can result from thermal oxidation, aerobic biodegradation or anaerobic biodegradation. Svedberg et al. [9] and Arshadi and Gref [10] postulated that CO is formed from the auto-oxidative degradation of lipids and fatty acids present in wood, and storage temperature is one of the critical factors. NMVOCs can result from the breakdown of wood hemicellulose; wood extractives which include a variety of low molecular weight organic compounds (such as fatty acid, resin acids, terpenes) have also been realized as one source of NMVOCs [11].

The gas emissions from stored biomass are affected by several factors such as temperature, the age of the materials and the oxygen content. Kuang et al. [12] concluded from their lab-scale study that peak emissions of the gases were associated with higher temperature and relative humidity in the headspace of the reactors with stored wood pellets. Wihersaari [6] found that the greenhouse gas emissions were almost three times higher for fresh versus dried forest residues. In a study of wood chip piles in a terminal storage, Rupar and Sanati [13] observed an increase in air emission due to the increased temperature directly above the pile. When logs and wood chips are stored in confined spaces, the gas emissions such as CO, CO2 and hydrocarbons (VOCs) could accumulate to toxic levels along with oxygen depletion [14].

Previous studies have also been conducted on dry matter changes over 6–12 months of in-field storage for a variety of woody biomass including logging residues, bundles, loose slash and woodchips [6,15–18]. Factors such as the physical characteristics of biomass feedstocks, weather conditions, and the method (covered versus uncovered) and duration of storage were found to influence the extent of dry matter loss. The reported average dry matter loss ranged from 0.7% to 1.5% per month for biomass having initial moisture content of 40–55% in these studies. Since dry matter produces energy in thermal processes such as combustion, it is desirable to minimize dry matter loss during biomass storage in order to keep up the calorific value and the potential revenue.

Gas emissions could lead to considerable dry matter loss from stored biomass. Literature review indicates that few studies reported dry matter loss along with gas emissions. Besides, the emission from stored Douglas fir residues including CO_2, CO, CH_4 and total VOCs have not been studied. Hence, the objectives of this paper were to investigate the gas emissions from the stored fresh Douglas fir residues under different temperatures, while at the same time measure the percent change in dry matter during the storage period. The findings from this study are important to the biomass supply chains from the field to the biorefinery, during which the net energy may decrease due to the gas emissions and hence dry matter loss.

2. Materials and methods

2.1. Materials

The materials used in this study were Douglas fir (*P. menziesii*) wood chips and greens. Douglas fir (DF) chips were obtained from Fibreco Export Inc., North Vancouver, BC. They originate from suppliers in British Columbia, and are produced from sawmill operations' residual chips and through whole log chipping. The wood chips contain no more than 1% bark. Fresh DF greens (needles) were obtained from the trimmings and cut branches of DF trees in the Vancouver area.

All materials were stored in a cold room at 4°C to minimize any degradation before the experiment. The size of chips as measured by Gilson Testing Screen (TS-1 & TS-2, Serial No. 2920, Gilson Company, Worthington, OH) had a range of 5–30 mm. The moisture content of the samples was determined in triplicate in a forced-air convection oven at 103 °C for 24 h to obtain the bone dry biomass according to CEN Standard EN14774-1 [19]. Initial moisture contents of the DF chips and greens were, on average, 48% and 54% (wet basis) respectively. A number of glass containers (2 L) were fitted with valves and sampling ports and assembled as reactors for the experiment. Each container was loaded with 170 g (dry mass) materials.

2.2. Experimental setup

Two series of tests were conducted in this study. In Test Series #1, reactors were only filled with DF chips. Test Series #2 involved chips and greens that were mixed in the ratio of 1:1 on dry mass basis. The green parts of the residues are expected to be more readily biodegradable as compared to the woody parts due to the presence of more nutrients. For each test series, eight reactors were divided into two groups to simulate the storage situation, one group under aerobic and the other group under non-aerobic conditions. The actual storage environment of the forest residues in the field would be in between these two conditions in terms of oxygen content.

After the reactors were loaded with the materials, they were sealed and placed either in a cooler at 5 °C, or in ovens with temperature maintained at 20, 35 and 50 °C. The range of temperature adopted for the test represents cool to hot climate conditions in different geographic locations, and involving seasonal variations. Group 1 reactors are "non-aerobic reactors", which were sealed at all times to study gas emission under airtight conditions. After the daily gas sampling event, air was pumped into an aerobic reactor via a metal tube inserted into the bottom of the reactor in order to replenish and maintain high oxygen level (aerobic condition) in the reactor. Two replicates were performed for each test. The results shown in this paper are the average values of the two replicates. In all cases, the experiment was run for two months.

2.3. Gas emission measurements

During each sampling event, 3 ml gas sample was drawn from each reactor to measure the CO_2, CO, CH_4 and O_2 gas concentrations. The concentrations of these gases were analyzed by gas chromatography (Model SRI 8610C, Mandel, USA). The GC was calibrated regularly with the corresponding standard gases. Gas sampling occurred daily for the aerobic reactors. Gas emissions from the non-aerobic reactors were measured daily at the beginning of the test, and then every few days in the later stage of the experiment in order to ensure the sufficient volumes of gas remaining in the non-aerobic reactors. 250 μL gas sample was drawn from each reactor to analyze the NMVOC composition. A GC/MS analyzer (Model 5975B/6890N, Agilent Technologies, USA) was used for qualitative analysis of the NMVOCs.

For the aerobic reactors, the total concentration of NMVOCs (TVOC) was measured by a portable VOC monitor (Model PGM, RAE Systems, San Jose, CA) on a daily basis. However, for the reactors under non-aerobic conditions, the same procedure cannot be applied since this would cause a larger amount of gases to be released from the reactor, thus affecting the accuracy of gas analysis for the remaining test (storage) period. Hence, TVOC for non-aerobic containers was only measured at the end of the test period.

2.4. Microbial analysis

At the end of all tests, samples were taken from each reactor and sent to a microbiology laboratory (I.G. MicroMed Environmental, Vancouver, BC) for cultivation and microbial analysis. The

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