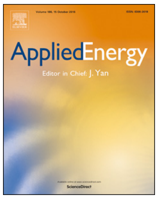
Applied Energy 231 (2018) 628–634

Contents lists available at ScienceDirect

Applied Energy

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



Fuel quality of stored wood chips – Influence of semi-permeable covering material

Erik Anerud[a,*], Raida Jirjis[b], Gunnar Larsson[b], Lars Eliasson[c]

[a] *Department of Forest Biomaterials and Technology, Swedish University of Agricultural Science, Forest Biomaterials and Technology, SE-901 83 Umeå, Sweden*
[b] *Department of Energy and Technology, Swedish University of Agricultural Science, Box 7032, SE-75007 Uppsala, Sweden*
[c] *The Forestry Research Institute of Sweden, Uppsala Science Park, SE-75183 Uppsala, Sweden*

HIGHLIGHTS

- Covering protected chips from rewetting and allowed water vapor to pass through.
- The effect of covering was greatest at the edges and top of the pile.
- The covered part of the pile had lower dry matter losses than the uncovered.
- Covering had a positive influence on net calorific value and recovered energy.
- Covered storage of residue chips provides opportunities to reduce supply chain costs for the delivered energy.

ARTICLE INFO

Keywords:
Wood chips
Storage
Fuel quality
Coverage
Dry matter losses

ABSTRACT

Storage is an important component in securing the supply chain for forest fuels, but can result in substantial dry matter and energy losses that reduce the economic value of the material. This study examined fuel quality and amount of recovered energy during storage of forest-residue chips stored in a full-scale pile and the effect of covering the pile with a water-resistant, vapour-permeable fabric.

Moisture content in the covered part declined continuously during the trial, while mean moisture content in the uncovered part did not change, due to rewetting at the surface. Average dry matter losses after seven months were 5.8% in the covered part and 7.3% in the uncovered part.

Combined changes in fuel quality and dry matter decreased the amount of assessable energy (expressed as net calorific value as-received from an initial kg of dry base) by 5.3% in the uncovered part and 0.6% in the covered part. Thus covering the pile with a semi-permeable fabric provides opportunities to store wood chips at lower cost.

1. Introduction

The share of renewable fuels in the Swedish national energy supply is steadily increasing [1], and the European Union (EU) renewable energy directive target of 49% renewables in Sweden by 2020 was achieved in 2013. One major factor in this success has been increased use of forest fuels, in particular primary forest fuels, in heat and power production. There is a great potential to further expand the use of primary forest fuels [2], i.e. forest biomass harvested for energy use, if its competitiveness relative to other fuels can be improved. This could be achieved through more efficient supply chains, involving both reduced costs for operations and improved value retention during storage of biomass, i.e. better fuel quality management.

The main source of primary forest fuels is logging residues [3], a by-product (tops and branches) from harvesting operations producing saw logs and pulpwood. Forest operations are carried out continuously during the year, and consequently logging residues is also produced year-round. However, the demand for forest fuels is seasonal, with high demand during the winter [4]. This temporal imbalance between production and demand in the supply chain creates a need for storage of biomass, either as untreated residues or as residue chips. There are two factors which determine the timing of chipping and chip transport during the year: (1) storage of logging residues results in lower dry matter losses than storage of chips [5,6] and (2) increased payload utilisation reduces the total costs of chipping and transport if the logging residues are chipped before transport [7,8].

---

[*] Corresponding author.
E-mail address: erik.anerud@slu.se (E. Anerud).

https://doi.org/10.1016/j.apenergy.2018.09.157
Received 23 June 2018; Received in revised form 14 September 2018; Accepted 17 September 2018
0306-2619/

Much work has been done to increase the efficiency in chip supply systems (e.g. [9–14]). An obvious way to reduce the supply cost is to increase the annual utilisation of chippers and chip trucks. However, this requires storage of chipped material without excessive storage costs and excessive dry matter losses. Large-scale storage of chips would also reduce the risk of disturbances in the fuel supply chain affecting heat and power production during peak demand [15].

Dry matter losses of 1–4% per month in small-scale piles have been reported in several studies [5,6,16–18]. The mechanisms of degradation are well documented [19]. Moreover, wood chips accumulate heat from microbial activity and chemical oxidation processes during storage [20,21], this could lead to economic losses due to losses of dry matter and energy. The microbes involved use glucose as their energy source and their level of activity is related to moisture content, combined with oxygen level and the surrounding temperature. Fungal activity between temperatures 20–50 °C depends on species (e.g. whether it is mesophilic or thermophilic). A moisture content between 30 and 50% is ideal for fungal growth. Thermo-chemical oxidative reactions can occur at ambient temperature but accelerate with increasing temperature, leading to exothermic reactions, which in the worst case could cause auto-ignition [20].

Different handling methods aiming at facilitating drying by increasing the net calorific value and protecting the biomass from ambient rewetting have been studied. Experiments with portable cover show lower moisture content and lower dry matter losses when chips are stored under a naturally ventilated tarpaulin cover [22]. Passive natural ventilation under piles results in drier biomass than in non-ventilated conditions, while combining natural ventilation with a cover gives a marginal improvement. Use of various fan systems that lower the moisture content has been studied for chips of different wood species [22,23], but such systems result in more complex and demanding management, leading to higher costs, a factor which has to be considered [24].

Provision of a cover can protect biomass from ambient rewetting [6,16,25–28]. However, a compact covering material will not decrease the average moisture content of the pile but only redistribute it, due to condensation, leading to increased moisture content at the surface. This could cause high dry matter losses unless water vapour can pass through the cover. Methods of covering that prevent precipitation reaching the stored chips and at the same time allow water vapour to be released are needed. This means using an effective method to ventilate the water vapour caught underneath the cover, or using a semi-permeable covering material.

Studies on covering small-scale piles (100–200 m^3 with height less than 5 m) have shown that use of a non-woven textile leads to lower moisture content and lower dry matter losses than in non-covered piles [16,17,26,29]. However, height and size of the pile affect the permeability [5], which in turn affects the distribution of moisture and heat. Evaluating the usefulness of such methods for large-scale storage based on values obtained from small-scale studies is therefore difficult. The objective of the present study was thus to evaluate the effects of using a semi-permeable covering material on large-scale storage of logging residues. The focus was on fuel quality aspects relevant for the economic value of the material, i.e. moisture content, energy content and fuel value.

2. Materials and methods

2.1. Woody material and storage location

Logging residue chips were stored in a partly covered pile on a paved surface at Vagersta, Sweden (59°48′N; 16°31′E), from June 2013 until January 2014. When choosing this storage terminal, prevailing wind direction and maximum sun exposure were considered.

The residues, i.e. branches and tops, used to produce the chips were harvested in the area surrounding Skinnskatteberg in central Sweden during 2012, and thereafter stored in covered windrows. The material was dominated by Norway spruce (*Picea abies* (L.) H. Karst) residues, mixed with a small amount of Scots pine (Pinus sylvestris) and birch (Betula spp.) residues. The windrows were covered with paperboard, which is common practice in Sweden to protect the biomass from precipitation, i.e. rewetting.

The residues were chipped at landings, using a Bruks 805 chipper, in June 2013, immediately prior to the experiment. After homogenisation at the terminal, the particle size distribution of the chips, determined according to standard methods [30], was dominated by chips in the range 8–45 mm (84%) and they were thus classified as P45 fuel chips according to European standards [29].

2.2. Meteorological data at the storage site

Throughout the storage period, a mobile weather station (WS-GP1®) was positioned close to the pile for collection of weather data, including temperature and precipitation. Historical data (30-year averages) on local weather conditions, based on values for Sala (15 km from Vagersta), were obtained from the Swedish Meteorological and Hydrological Institute (SMHI). These data were used for comparison with measured data during the experiments, allowing the results to be set in a historical context.

The ambient temperature during chipping, homogenisation and pile construction was 16 °C, which was only marginally different from the average long-term value according to data from SMHI. Cumulative precipitation during the first three months of storage (July–September) was 140 mm, which was low compared with the 30-year average (252.0 mm), and increased to 325.8 mm by the end of the seven-month storage period. There were some severe rain events (15–30 mm) in July and September. Cumulative precipitation during the period October-December was 144.8 mm, which was similar to the average value of 152.5 mm. All precipitation during the experiment consisted of rain.

The prevailing wind direction was from south to north, especially at wind speeds above 2 $m\,s^{-1}$. The average wind speed increased from 1.8 $m\,s^{-1}$ during June-mid September to 2.8 $m\,s^{-1}$ during mid-September to January. In the corresponding periods, the average humidity increased from 73.7% to 87.6%.

2.3. Field trial structure and sampling

The experimental pile was a single full-scale chip pile with the following dimensions: base 15 m, length 35 m and height 6.5 m, with the main axis east-left (Fig. 1). The estimated volume of the pile was 1450 m^3, corresponding to about 250 Mg oven-dry chips. During the experiment, one half of the pile (coloured grey in Fig. 1) was covered with a semi-permeable material, Toptex®, with a specific weight of 200 $g\,m^{-2}$, and the other half was left uncovered as a control (white in Fig. 1). Within each half, two vertical zones (labelled A–D in Fig. 1), each with nine sampling points (see Fig. 2), were established for determination of dry matter losses and other parameters. In conjunction with pile construction, 10 samples per sampling point were collected. Half the sampled material was saved for further analysis of initial characteristics of the wood chips, while the other half was divided into net bags (3.0 mm mesh), weighed and placed back in the pile. Each zone contained 90 samples in total, evenly distributed between the nine points, as shown in Fig. 2.

Experimental set-up and initial sampling were performed in June 2013. Samples were recovered in September 2013 and in January 2014. Temperature development, particularly in zones B and C, was measured with two logging systems, Tinytag® and FireWorm®. In these zones, six Tinytag sensors for each zone were placed at the sample heights, with three at 1.5 m, two at 3.0 m and one at 4.5 m (Fig. 2). In addition, FireWorm cables with a temperature sensor distance of 1.0 m were placed horizontally underneath the pile and at a height of 1.5 m. Moreover, one vertical sensor cable was placed in each of zones B and