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Compression drying of energy wood

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ABSTRACT

This study investigated the compression drying of energy wood in the form of sawdust. The test was carried out on freshly-felled Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and Downy birch (*Betula pubescens*) in Finland. The compression pressure (6–38 MPa) and time (0–60 s) were adjusted in the experiments; it was found that pressure had more of a pronounced effect on dewatering than pressing time. When the compression holding time was zero, the highest drying rate reached for spruce was 25 percentage units and the second highest was 24 percentage units for pine using 38 MPa. The use of a holding time increased the drying effect by 1.0–2.3 percentage units. The lowest moisture content from all the tests, 30% (wet basis), was achieved for birch by continuous pressing using 38 MPa and with a pressing time of 30 s. The result was 7 percentage units above the fiber saturation point (23% wet basis) of birch. Increasing the maximum compression pressure in the tests improved dewatering, but the improvement lessened with higher pressures. The energy consumption of compression drying is only a fraction of the energy required to vaporize water in thermal drying. The energy consumption for Scots pine and Norway spruce was almost the same, but the downy birch, due to its denser and stronger wood, required more energy than the softwoods.

1. Introduction

Energy produced from energy wood can be increased by improving the quality of the wood fuel. The most important quality factor of energy wood is the moisture content of the wood. The lower the moisture content the better the energy wood quality. The heating value of dry wood is 5.3 MWh/ton, which is significantly higher than that of fresh wood 2.2 MWh/ton [1–3]. The drying of wood fuel can be done either by using artificial drying (thermal drying) or by using natural conditions (solar energy and wind); the latter ones being preferred. However, the disadvantage of natural drying is the slowness of the drying process and the dryness achieved. The moisture content range, in Finland, of freshly-felled small-sized Scots pine and Norway spruce trees is 50–60%, and for birch trees 40–50% [4]. According to Laurila and Lauhanen [5] the average moisture content of energy wood in Finland was about 43% after an average roadside drying period of 11 months. The survey of Nurmi and Hillebrand [6] showed that moisture content of small-sized whole trees, at a good roadside storage site after one summer, was about 40%. Thus a cheap, fast, simple and innovative drying method is needed.

Water is in the wood in two forms: part of it is bound to the cell walls and part is (so called) free water in cell lumens. Wood has a cellular structure [7], mostly formed of dead cells, which have rigid cell walls and a void inner cavity called the lumen. In a living tree water is transported from the roots to the leaves or needles through these hollow lumens, and in freshly cut trees the lumens are often filled with water.

The chemical constituents of wood contain hydroxyl groups, which can form strong intermolecular hydrogen bonds with water molecules [8]. Water can therefore bind tightly to the chemical components of the cell wall. The free water in lumens can be removed by compressing the wood until the cellular structure of the wood collapses and squeezes the water out of the wood.

When wood dries, for example in thermal drying, the free water in the lumen leaves first. The moisture content at which the lumen is free of water, but the cell walls are still fully saturated, is called the fiber saturation point [8]. The fiber saturation point differs between tree species and usually it ranges from 20% to 25% (wet basis) [8,9]. In theory wood can be dried by compression to the fiber saturation point, although in practice a small amount of free water will probably always remain in the wood structure.

The idea of drying energy wood by compressing has been tested in a few previous studies. The first tests were conducted by Haygreen [10, 11] in the beginning of the 1980s. Haygreen tested compression drying of single blocks of wood [10], and blocks of wood as well as wood chip mats [11]. Liu and Haygreen continued the tests, and determined optimum pressure and compression times for a variety of North American tree species [12].

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After these studies not much work was carried out until Yoshida et al. [13] introduced a roller compression dryer; this consists of two drying stages, each stage contains two rollers that are positioned closely together leaving a narrow gap. Wood chips are fed into the gap, and the compression of the rollers removes the water. The lowest moisture content obtained was 46% (wet basis).

The previous studies of compression drying are encouraging, but the method has not yet entered into industrial use. There was still a need to evaluate this drying method by determining if the fiber saturation point could be reached, and to use tree species that are commonly used for forest energy production in Nordic countries.

The first aim of this study was to clarify the effect of the pressing force and time on wood moisture content. The second aim was to determine if compression drying could reduce the moisture content of wood to its fiber saturation point level (ca. 20–25% wet basis). The laboratory tests were carried out on three commercially important tree species: Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and Downy birch (*Betula pubescens*).

2. Material and methods

2.1. Wood samples

The wood samples were taken from freshly-felled: Scots pine (*P. silvestris*), Norway spruce (*P. abies*) and Downy birch (*B. pubescens*) in western Finland in March 2012. The samples consisted of chain-saw sawdust which was collected in a plastic box underneath the running chain-saw. In total about 5000 g of sawdust was collected and the samples were collected without bark. The samples were put into airproof plastic bags immediately after collection and stored in a freezer before compression drying tests. For each compression drying test about 14 g of fresh wood was used.

In the laboratory the particle size and moisture content analysis of the sawdust was carried out separately for each tree species. Particle size was determined by screening and the moisture content analysis was based on international Standard (ISO 589:2003) "Hard coal — Determination of total moisture" [14]. The drying temperature was 105 °C and a drying time of 24 h was used. The moisture content (wet basis) of the freshly-felled wood was calculated using Eq. (1) [3]. The moisture content of freshly-felled: Scots pine sawdust was 60%, Norway spruce sawdust was 63% and Downy birch sawdust was 45%. The moisture content after compression drying was calculated based on the fresh wood's weight loss which was obtained by weighing the samples before and after compression. The sawdust particle size distribution varied from 0.5 mm to 4.0 mm for all 3 tree species.

$$MC = \frac{\left(m_g - m_o\right)}{m_g} \times 100\% \qquad (1)$$

where:

MC moisture content (wet basis)
m_g the mass of the sample before drying
m_0 the mass of the sample after drying.

2.2. Pressing apparatus

A Lloyds EZ 50 material testing machine with a cylinder and piston was used in this study (Fig. 1). The material testing machine was used to generate the compression force, as well as record force and position of the piston. Force and distance traveled by the piston were used to calculate the work required in the compression drying. The pressing range of the machine was 0–50 kN with the accuracy of 0.5%. The inner diameter of the steel cylinder was 20 mm and the height of the cylinder was 118 mm. The steel piston fitted the cylinder precisely. There were four holes (diameter of 5 mm) near the bottom of the cylinder for the water to run-off. Also there was a non-waterproof joint between the bottom plate and the cylinder.

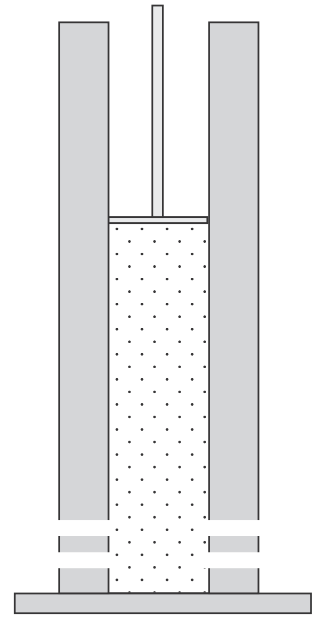

Fig. 1. The drying cylinder and the piston. Water escapes mainly through the four small holes at the bottom of the cylinder.

2.3. Pressing force and time

This study included both momentary and continuous press wood drying tests. The 6 pressing forces in the momentary pressing tests were 2000 N (6 MPa), 4000 N (13 MPa), 6000 N (19 MPa), 8000 N (26 MPa), 10,000 N (32 MPa) and 12,000 N (38 MPa). A force of 1000 N was equivalent to a pressure of 3.2 MPa in a cylinder with a diameter of 20 mm. In the continuous pressing tests: a force of 4000 N (13 MPa) was used with holding times of 30 and 60 s as well as a force of 12,000 N (38 MPa) with a holding time of 30 s. All 9 compression tests were made three times for each tree species. Thus 27 compression tests per tree species were made. In total, 81 compression drying tests were carried out.

3. Results and discussion

3.1. Drying using momentary pressing

In the first test series a method was used in which the pressure was relieved when the maximum force was reached. Fig. 2 shows the force-distance graph for Scots pine and Downy birch. With this method the lowest moisture content of 33% was achieved for birch at 38 MPa (Fig. 3). A pressure of 19 MPa was enough to reduce the moisture content of birch by about 10 percentage units from its initial moisture content (45%). However, the drying rate of softwood was higher than hardwood in this study. The highest drying rate of 25 percentage units was obtained for spruce and the second highest of 24 percentage units for pine at 38 MPa. The moisture content of pine (36%) and spruce (37%) were at the same level as each other at 38 MPa. Even 19 MPa was enough to reduce the moisture content of pine and spruce by about 20 percentage units, which was double that of birch at the same pressure. Obviously, the initial moisture content of wood and tree species had a direct effect on the drying rate of the wood.

Fig. 3 shows the effect of maximum compression pressure on the moisture content of the wood. Three parameter exponential decay