Chapter 4
Biodebarking

4.1 Introduction

Bark is the outermost layer of tree trunks and branches (Fig. 4.1). It protects the tree from its environment. It is distinct and separable from wood. Bark refers to all the tissues outside of the vascular cambium. It overlays the wood and consists of the inner bark and the outer bark. The inner bark, which in older stems is living tissue, includes the innermost area of the periderm. The outer bark in older stems includes the dead tissue on the surface of the stems, along with parts of the innermost periderm and all the tissues on the outer side of the periderm. The outer bark on trees is also called the rhytidome.

The border between wood and bark is cambium (Fig. 4.1), which comprises only one layer of cells. This living cell layer produces xylem cells toward the inside of the stem and phloem cells toward the outside. The cambial cells divide continuously and have a lower mechanical strength than that of other wood cells. Cambium characteristics include high pectin and protein content and the absence or low concentration of lignin (Simson and Timell 1978; Thornber and Northcote 1961; Kato 1981; Fu and Timell 1972). The cambial tissue consists of intracellular material and primary cell walls. According to a model presented for the primary cell wall of dicotyledonous plants, the following carbohydrate polymers are present: cellulose, pectin, xyloglucan, arabinogalactan, and hydroxyproline-rich glycoprotein. The pectins in primary cell walls of dicotyledons are heteropolymers. In addition to galacturonic acid units, they also contain rhamnose linked to galacturonic acid units in interior chains, whereas galactose and arabinose are present as side chain structures (Aspinall 1980; Dey and Brinson 1984). The primary cell wall structure in coniferous trees has not been studied as closely as that of dicotyledons. The content of pectin compounds in the cambial cells varies between the wood species studied.

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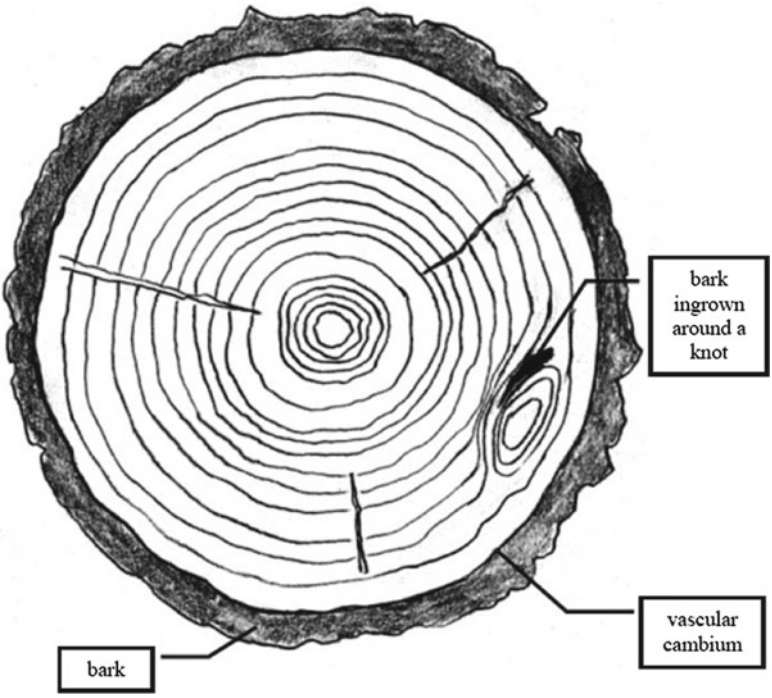

Fig. 4.1 Cross-sectional line drawing of wood

In Betula platyphylla (birch), Fraxinus elatior (ash), Pinusponderosa (pine), and Acer pseudoplatanus (sycamore), the contents of pectic substances in the cambium are 18, 6.6, 8.5, and 15%, debarking respectively (Thornber and Northcote 1961). The cambium of Pinus silvestris (pine) consists mainly of pectic material (partially esterified polygalacturonic acid, arabinan, galactan) (Fu and Timell 1972). In addition, cellulose, glucomannan, and glucurono-araboxylan are present (Meier and Wilkie 1959). In Pinus silvestris, 59% of the galacturonic acid units extracted from cambium were methylated. The cambial tissue of Populus tremuloides (quaking aspen) contains 40% pectins in addition to smaller amounts of arabinogalactan, xyloglucan, xylan, glucomannan, cellulose, and protein (Simson and Timell 1978).

Trees have a cambium layer between the bark and the wood. It is the cambium layer that is the living and continuously growing part of the tree. The cells in this layer divide continuously, which is why they tend to have a lower mechanical strength than cells elsewhere in the tree. In debarking, the aim is to remove the bark together with the cambium layer. Characteristically, the cambium comprises high pectin content. Pectin polymers consist of galacturonic acid, ramnose, arabinose, and galactose. As well, the cambium comprises hemicellulose, cellulose, and protein.

Debarking using conventional commercial procedures usually does not remove all of the barks from logs. It is recognized that up to approximately 3% of bark from

coniferous wood and approximately 10% of bark from nonconiferous wood may remain after debarking. Bark has complex anatomy and chemistry. It is a contaminant in the wood supply used for making pulp, decreasing the quality of pulp in proportion to its level. There is very little usable fiber in bark, mostly because bark fibers are very small; and bark consumes chemicals during the pulping and bleaching stages (Smook 1992). Furthermore, it causes dark specks in the final paper product. Some types of bark (e.g., western red cedar and aspen) contain significant quantities of fiber and can be tolerated to an extent in an alkaline pulping system. The relatively high level of nonprocess elements (impurities), such as silica and calcium, interfere with chemical recovery process. For the pulp industry, typical bark tolerances in wood chips are 0.3–0.5%, although the kraft process is more tolerant than the other pulping processes. Bark removed from wood is usually burned as a fuel. Whole-tree chopping in the forest (a practice some argue will become important in the future as it gives a higher yield of wood chips) requires that the chips be cleaned before pulping to remove bark, dust, needles or leaves, twigs, etc.

A significant disadvantage of current mechanical debarking methods and equipment is that in order to achieve a desired degree of debarking it is necessary to continue the debarking process well beyond the time it takes to remove substantially all the bark, in order that pieces which hold steadfastly to the logs can be removed. This results in significant wood loss especially in the trunk areas already completely debarked. Moreover, it leads to increased debarking times and greater energy consumption. Enzymes specific for the hydrolysis of the cambium and phloem layers have been found to facilitate bark removal (Bajpai 1997, 2006, 2009; Viikari et al. 1989, 1991a, b; Wong and Saddler 1992; Ratto et al. 1993; Grant 1992, 1993, 1994; Hakala and Pursula 2007; Ma and Jiang 2002). Enzymes actually weaken the bonds between the bark and wood and break down polymers present in the cells of the cambium layer. The logs may be subjected to enzyme treatment prior to debarking by known methods. If desirable, the enzyme treatment may also be effected after debarking, i.e., part of the bark is first removed, possibly after enzyme treatment, whereupon the logs are subjected to an enzyme treatment designed to weaken the bonds between the wood and the remaining portions of the bark. This allows the remaining bark portions to be removed during a second debarking procedure which may consist of mechanical or some other kind of treatment. The enzyme treatment may also be implemented in other ways in conjunction with the debarking.The enzyme treatment may be implemented by immersing the logs in the treatment solution, or by flushing and/or spraying the logs with the treatment solution. The enzyme treatment has the effect of reducing the detaching resistance of the bark, i.e., it tends to make the bark loosen. This facilitates mechanical debarking and significantly increases the speed thereof. The fact that the bark is more easily removed reduces the amount of energy needed for the debarking. A higher and more constant degree of debarking is achieved. Moreover, enzyme treatment helps reduce wood losses that occur in traditional mechanical debarking as a result of differences in the barking resistance between different trunks or logs. Enzymatic method shows great potential for saving both energy and raw material (Viikari et al. 1989; Ratto et al. 1993).

4.2 Enzymes Used for Debarking

Pectin breaking enzymes, hemicellulases, cellulases and/or proteases, and other enzymes capable of weakening the bonds between wood and bark and/or breaking down polymers present in the cambium have been used. Many commercial preparations of these enzymes are available.

4.3 Application of Enzymes for Debarking

Finnish researchers (Ratto et al. 1993; Viikari et al. 1989, 1991a, b) used debarking enzymes, specific for the hydrolysis of the cambium and phloem layer, from *Aspergillus niger*. A clear dependence was observed between the polygalacturonase activity in the enzyme preparation and reduced energy consumption in debarking. In addition to polygalacturonase, the enzyme mixture produced by *A. niger* also contained other pectolytic and hemicellulolytic activities. The amount of energy needed for the removal of bark was found to decrease to 20% of the reference value (Table 4.1). In this experiment, wood disks were soaked in the enzyme solution and the enzyme was diffused mainly tangentially to the border between wood and bark.

Ratto et al. (1993) studied the effect of enzymatic pretreatment on the energy consumption of wood debarking on the laboratory scale, using enzymes to degrade the cambium layer. Three different pectinases and xylanases were used – a commercial preparation Pectinex Ultra SPL (NOVO) and two preparations produced at VTT biotechnical laboratory: polygalacturonase produced by *A. niger* and a partially purified polygalacturonase obtained from *A. niger* (Bailey and Ojamo 1990; Bailey and Pessa 1990). Xylanase was a commercial preparation, Pentosonase (MKC). The pectinases were dosed (185 nkat/mL) according to their polygalacturonase activity, and the hemicellulase (100 nkat/mL) was dosed according to its xylanase activity. All the enzymes were found to reduce the energy consumption to some extent (Table 4.2). The best result – a 50% decrease in energy consumption, was obtained with Pectinex Ultra SPL. Of the three pectinases, this preparation showed the widest spectrum of the activities of enzymes that hydrolyze the various cambial components. In addition to polygalacturonase, pectin lyase, xylanase, and endoglucanase activities were also detected. The partially purified polygalacturonase with the lowest xylanase and endoglucanase activities was the least efficient

Table 4.1 Effect of pretreatment with polygalacturonase enzyme on energy consumption during debarking of spruce

Polygalacturonase activity (nkat/mL)	Relative energy consumption (%)
0	100
37	75
185	45
195	20

Based on data from Ratto et al. (1993)

Table 4.2 Effect of enzyme treatment on energy consumption during debarking of spruce

	Enzyme dose (nkat/mL)				
Enzyme	Polygalacturonase	Polymethoxyl-galacturonide lyase	Xylanase	Endoglucanase	Energy consumption as % of control
Crude polygalacturonase	185	<0.1	1.1	1.6	77
Partially purified polygalacturonase	185	<0.1	0.2	<0.1	87
Pectin ex ultra SPL	185	0.6	2.0	5.5	50
Pentosanase	0.2	<0.1	100	1.6	82

Based on data from Ratto et al. (1993)

Table 4.3 Effect of enzyme treatment time on energy consumption during debarking of spruce

Treatment time (hour)	Relative energy consumption (%)
0	100
2	98.0
12	62.0
24	50.0

Based on data from Ratto et al. (1993)

Table 4.4 Stability of enzyme in the debarking water

Incubation time (days)	Residual activity (%)
o	100
3	100
8	84.0
10	78.1
15	76.2

Based on data from Ratto et al. (1993)

of the three pectinases. About 18% decrease in energy consumption was obtained with the xylanase preparation.

For Pectinase Ultra SPL, the effects of enzyme dosage and treatment time were studied (Ratto et al. 1993). As much as 80% decrease in energy consumption was obtained with a polygalacturonase dosage of 900 nkat/mL in a 24-h treatment. A moderate effect, a 25% decrease in energy consumption was obtained when only 4% of this activity (40 nkat/mL) was used. For a 50% decrease in energy consumption, a polygalacturonase dosage of 185 nkat/mL was needed. With this dosage, a 40% decrease was obtained in 12 h, whereas only a slight effect was observed after 4 h of treatment (Table 4.3).

Ratto et al. (1993) also studied the stability of the enzyme in process waters containing various components dissolved from wood and bark, to evaluate the possibilities for enzyme recycling. Ultra SPL was incubated in process water from an industrial-scale debarker used for debarking spruce and the residual activity was measured. The polygalacturonase activity was relatively stable, showing more than 70% residual activity after 15 days at 50°C (Table 4.4). Thus, it appears possible to decrease the costs of the enzymatic pretreatment by repeated use of the same enzyme solution.

The efficiencies of the enzymes in the hydrolysis of isolated cambial tissue were also compared. Cambial tissue was isolated from spruce felled during the spring. The polysaccharides in isolated cambium were partially degraded during the isolation, as indicated by the high content of reducing sugars (51% of dry weight) in the reference sample. This effect was probably caused by the endogenous enzymes. However, galacturonic acid was not detected in the reference samples. When the substrate was hydrolyzed with the three pectinases dosed to the same polygalacturonase activity, the most efficient hydrolysis of cambial pectin to galacturonic acid was obtained with Pectinex Ultra SPL (Table 4.5). The amounts of galacturonic acid

Table 4.5 Effects of various pectinases on hydrolysis of isolated cambium

	Hydrolysis products, % of substrate	
Enzyme	Reducing sugars	Galacturonic acid
Pectinex ultra SPL	42	12.3
Crude polygalacturonase	38	3.9
Partially purified polygalacturonase	38	5.4
Pentosonase	35	0.8
Reference		0.4

Based on data from Ratto et al. (1993)

released by crude polygalacturonase and partially purified polygalacturonase were less than half of that released by Pectinex Ultra SPL. In addition to polygalacturonase, Pectinex Ultra SPL contained the highest pectin lyase activity.

Due to chemical complexity at the cambiurn interface and its variation among tree species, research to identify suitable enzymes was conducted. Metra-Serla and Kone Wood have jointly conducted pilot-scale tests (Grant 1992, 1993, 1994).

4.4 Advantages of Biodebarking

Enzymatic method is an attractive approach for debarking. Enzymatic treatments cause significant decreases in energy consumption during debarking. The energy consumed in debarking is decreased as much as 80% after pretreatment with pectinolytic enzymes. The enzymatic treatment also leads to substantial savings in raw material. Enzymes may be able not only to increase existing debarking capacity, thus saving capital investment but also to act as an aid to be used when debarking is difficult. The enzyme treatment may be implemented by immersing the logs in the treatment solution, or by flushing and/or spraying the logs with the treatment solution. The enzyme treatment has the effect of reducing the detaching resistance of the bark, i.e., it tends to make the bark loosen. This facilitates mechanical debarking and significantly increases the speed thereof. The fact that the bark is more easily removed reduces the amount of energy needed for the debarking. A higher and more constant degree of debarking is achieved. Moreover, enzyme treatment helps reduce wood losses that occur in traditional mechanical debarking as a result of differences in the barking resistance between different trunks or logs.

4.5 Limitations and Future Prospects

In logs, the bark forms an effective barrier to the enzyme and may exclude enzyme diffusion. This barrier could be overcome in practice by applying the enzymatic treatment to poorly debarked logs selected after preliminary mechanical debarking. In the case of poorly debarked wood, the major portion of the bark would already be

removed and diffusion of the enzyme would therefore be facilitated. In a mill, it might be advantageous to spray poorly debarked logs with enzyme solution before repeating the mechanical debarking. A substantial disadvantage of the current mechanical debarking methods is that the process has to be continued well beyond the time required to remove most of the bark in order to remove few pieces of bark that hold tenaciously to the logs. The enzymatic treatment applied after preliminary debarking could reduce the wood losses that normally occur. Thus, the enzymatic treatment could lead to substantial savings in raw material in addition to the savings in energy. The studies conducted so far have used enzyme preparations with polygalacturonase or xylanase as the main activity. In addition to these, other enzymes that act on the various components of the cambium may also have an effect. There is a need to study the role of each enzyme and the optimal composition of the enzyme mixture for debarking.

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