

Björkman A. Studies on finely divided wood. Part 1. Extraction of lignin with neutral solvents. *Svensk Papperstidn.* 59:477-85, 1956. [Billeruds AB, Säffle, Sweden]

After grinding wood powder dispersed in a nonswelling liquid in a vibrational ball mill 50 percent of the lignin may be extracted. The purified "milled wood lignin" is presumed to be a very useful material for lignin chemists. [The SCI® indicates that this paper has been cited in more than 295 publications, making it the most cited paper in this journal.]

Solvent Extraction of Natural Lignin

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I studied chemical engineering in Sweden, and I have earned my living in this field, both in Swedish industry and teaching in Denmark. During my studies, I took particular interest in creating lab equipment and in wood chemistry, particularly of lignin. My first teacher in the field was the pioneer Bror Holmberg. At the time, lignin could only be extracted from wood by the action of chemicals. Holmberg suggested to me in 1947 that the extracted lignin product would become more homogeneous if wood was reduced to small particles before treatment. Also, chemists always complained that samples of native lignin were unattainable, enhancing its enigmatic image.

I submerged myself in the ocean of lignin literature and was captivated by the idea of studies on finely divided wood. This eventually led to the Dr. Sci. degree (with this *Citation Classic* being one of five articles) and recognition in the realm of wood chemistry. Meanwhile, I had taken a position in the pulp and paper industry. Supported by the American-Scandinavian Foundation, I spent several months of 1950 at the Institute of Paper Chemistry in the US, initiating my work on dividing wood. I contemplated ideas like milling at low temperatures, where wood gets brittle, or exploding wood by building up within it extremely high nitrogen pressure and releasing the pressure instantaneously. Fortunately, while in the US I got hold of a set of drawings of a vibrational ball mill, to break up the wood structures in my research.

Back in Sweden, I managed, supported by Holmberg and the famous Erich Adler, to obtain a grant and also the permission of Billerud to conduct investigations on lignin extraction. The work had to be done outside office hours, i.e. evenings and weekends. Adler received one of my first samples of milled wood lignin (MWL), later also called Björkman lignin. He soon produced MWL himself and lignin chemists around the world followed him. My method (or some modification) is still being used, as evidenced in recent books.¹⁻³

Yet, it is not evident whether milling "opens up" the wood structure to allow lignin to diffuse or if lignin is set free by breaking covalent bonds. Indeed, by the use of stronger, non-lignin-selective solvents, I was able to extract lignin-carbohydrate complexes. These have been used as well by wood chemists, bringing further recognition. Incidentally, the MWL I obtained did contain a minor amount of hemicelluloses. Only recently a fully pure MWL has been produced by fractionation.⁴ (I had planned to purify my "crude" MWL in 1957, but did not find time for it.)

In my recent studies on solid wood, I have found that N-methylmorpholine-N-oxide monohydrate/dimethylsulfoxide, a mixture which dissolves even cellulose at room temperature, cannot dissolve wood, as such, to a noticeable degree (after removal of the various low-molecular extractives). Most likely, the lignin is "pointwelded" to hemicelluloses (and to cellulose?) to such a degree that this chemically loose structure (matrix), requires a reagent and/or mechanical "unzipping" to release the polymers.

The (possibly) few interpolymer bonds can hardly explain much of the mechanical and rheological properties of wood. We lack sufficient knowledge of the ultrastructure of wood—i.e., the coherence of its main constituents cellulose, hemicelluloses, and lignin—to form cell walls and wall-to-wall structures, which, together with the anatomic morphology, impart to wood its remarkable properties as a composite. This problem occupies me as professor emeritus, a gratifying undertaking if you take into account that wood science for me has been a sparetime endeavor.

1. *Ullman's encyclopedia of industrial chemistry*, 5th ed., Vol. A. 1990. 15. p. 305.
2. *Proceedings from 6th International Symposium on Wood and Pulp Chemistry*. Melbourne, Australia. April/May, 1991.
3. **Lewin M & Goldstein I S.** *Wood structure and composition*. Marcel Dekker, 1991. p. 183; 287.
4. **Lundquist K, Simonsen R & Tingsvik K.** On the composition of dioxane-water extracts of milled spruce wood: characterization of hydrophilic constituents. *Nord. Pulp Pap. Res. J.* 5(3):107, 1990. Received June 23, 1992