MICROSCOPIC ANALYSIS OF FIBER MATERIALS FOR PAPER PRODUCTION AND THEIR SHEET-FORMING PROPERTIES

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Abstract

The fibrous materials used in paper production are obtained by chemical processing of wood or straw. In most cases, fibrous materials of plant origin are used for paper production. These are the different types of cellulose, high yield cellulose, semi-cellulose, different types of wood pulp and secondary fibrous material. The microscopic method is used in paper production to study the structure and size of the source fibres, to control the grinding process and to determine the fibre composition of the paper. In order to use numerous types of paper, different fibrous materials are used in a certain ratio. When choosing them, the sheet-forming properties of fibrous materials are taken into account, which together determine their ability to provide the necessary properties of the paper. The aim of the present work is to present a microscopic analysis of the condition of the fibrous materials, some peculiarities in the composition and structure, as well as their connections with leaf-forming properties in the formation of a paper sheet. Studying and knowing these properties makes it possible to obtain paper with certain qualities.

Keywords: *paper, fibrous materials, cellulose, microscopic analysis*

1. INTRODUCTION

When obtaining new types of paper and to improve the quality of the existing range of papers, it is necessary to know the sheet-forming properties. The initial sheet-forming properties of the fibres from which papers are obtained vary considerably depending on the technological mode of their use. This noticeable change in the properties of the resulting paper can be realized at any stage of the paper production process. When obtaining paper with predetermined properties, not only the properties of the source fibres determined by the chemical composition and morphology must be taken into account, but also the possible change of these properties in the technological process of paper production.

In the production of different types of paper, fibrous materials are used in different proportions. Basically, the paper is obtained from one, two, three or more types of fibrous materials, forming a composition according to the type of fibres, prepared accordingly. Often, when changing the technological mode for processing semi-finished products, paper with the same properties can be obtained using other semi-finished products. Each type of paper is made from the cheapest fibrous semi-finished products, which ensure high quality products with the least complex technological operations during their processing. When choosing fibrous materials should take into account the sheet-forming properties of the complex, which ensure the required quality of the finished product [1].

The paper is an elastoplastic, capillary porous sheet material obtained from plant fibres, processed in a certain way and firmly connected to each other in a thin sheet. It manifests both elastic and plastic properties, which largely determine the leaf-forming properties of fibrous materials.

To establish the relationship between the different properties of the paper, the geometric properties of the paper structure must be related, which determine the mechanical and optical properties with the bonding forces between the fibres and the conditions of paper formation.

Influence of the properties of the output fibres on the properties of the paper

The leaf-forming properties of plant fibres are largely determined by the structure of the cell of which they consist, schematically shown in *Fig.1*.

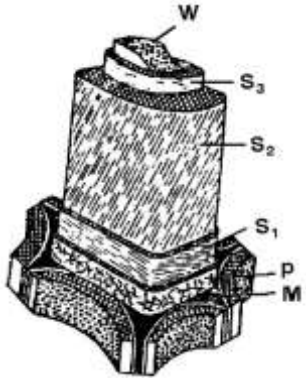


Fig. 1. Schematic representation of the structure of the plant cell

Legend: M - middle lamella, p - primary wall, S_1, S_2, S_3 - secondary cell wall layers, W - warty layer lining the cell lumen

Source: Daniel, G 2009, 'Wood and Fibre Morphology', in M Ek, G Gellerstedt, G Henriksson (eds.), *Pulp and Paper Chemistry and Technology* (Vol. 1), Walter de Gruyter GmbH & Co. KG, Berlin, p. 61.

The cell wall of the plant fibre consists of two layers: a primary (cambial) wall, denoted by P and a secondary wall, which is divided into three sublayers – S_1 - external, S_2 - middle, S_3 - internal [2]. The primary wall P of the fibre is completely destroyed by boiling and bleaching the pulp. The outer layer of the secondary wall is preserved in unbleached cellulose and partially destroyed in bleached cellulose. It is this layer that complicates the process of grinding and fibrillation of the fibres. Upon swelling and grinding, this layer having the same structure, but different chemical composition in coniferous and deciduous wood species is removed, after which the cell wall of the middle layer is fibrillated without difficulty. The inner layer S3 is difficult to separate from the other layers of the plant cell. The more the fibres are fibrillated and the outer surface is deployed, the greater the possibilities for contacts between the fibres and the possibilities for the formation of hydrogen bonds, van der Waals forces and friction forces. It is important not to shorten the fibres during fibrillation. The strongest fibre connections in the paper are obtained when the fibres are connected by the fibrils of the layer S_2, less strong between P and S_1 [3-5].

Influence of the chemical composition on the leaf-forming properties

Technical cellulose contains cellulose chains of different lengths, considering the contained celluloses, hemicelluloses and lignin. The cellulose content is judged by the content of α-cellulose, which is insoluble in 17.5% sodium hydroxide solution and consists of long chains of more than 200 glucose residues. The high content of α-cellulose provides the fibrous material with increased indicators of mechanical strength, chemical and thermal stability, as well as durability and stability of whiteness. The products of destruction of long cellulose molecules during chemical treatment and dissolved in 17.5% sodium hydroxide solution. γ-cellulose is the lowest molecular weight part of technical cellulose. It consists of hemicellulose chains and low molecular weight residues formed in the process of destruction of cellulose molecules. Hemicelluloses are a group of polysaccharides, macromolecules that are composed of hexose, pentose and uronic acid residues. In paper, hemicelluloses plasticize the fibres, facilitate fibrillation and help increase the strength of the bonds between the fibres.

The content of lignin in terms of leaf-forming properties of plant fibres is an unfavourable element in technical cellulose. It prevents the plasticization of the fibres, reduces swelling, makes it difficult to grind and fibrillate. Lignin causes yellowing and aging of the paper during long-term storage [6-9].

2. MATERIALS AND METHODS

2.1. Materials

Coniferous and deciduous wood of fir, spruce, pine, oak, beech, ash, poplar from which microscope preparations were prepared was studied [11].

Different types of softwood pulps produced in Sweden and Russia have been studied; pulp from deciduous wood produced in Svilocell EOD; straw pulp from KCH Misia and waste paper, delivered by Nova Knizhna Fabrika AD.

2.2. Methods

Microscopic analysis

The test fibres, pre-dispersed mechanically, are placed in a tube of water and shaken to obtain a homogeneous suspension with a concentration of about 0.05%. A few drops of the fibrous suspension are applied to a glass slide. Excess water is removed with the help of filter paper. With a sharp needle (pin) carefully distribute the fibres in the drop and dry at a temperature of about 60 °C per lamp. After cooling the slide, a drop of the staining solution is applied to the fibres and covered with a cover glass. Stained preparations with Herzberg's reagent (ISO 9184-3: 1990) were observed under a microscope. The 'Cl-Zn-I' reagent colours the plant fibres in different colours depending on their lignin content: cellulose – from blue to violet colour (sulphite cellulose is intense blue, and sulphate - paler and darker, with a brownish tinge); wood pulp and semi-cellulose – from light yellow to yellow-brown colour depending on the yield [10].

3. RESULTS AND DISCUSSION

Types of fibrous materials used in the pulp and paper industry

The main raw materials for the production of fibrous materials used in the pulp and paper industry are coniferous wood, deciduous wood and stems of annual plants (straw, bagasse).

Coniferous wood and cellulose from it

The cellulose fibres obtained from coniferous wood are long ribbon-like cells (over 90%) - tracheids. The spring tracheid are wider, their walls are thin, the canal is wide, the edges are slightly rounded. They have the characteristic courtyard pores, which are seen as two concentric circles. Autumn tracheids are narrower, their walls are very thick, the canal is narrow, the edges are pointed, the pores are small and less common. The length of the fibres is 2.5-4.4 mm, and the width is on average 0.03-0.04 mm. The presence of longer fibres in softwood pulp gives the paper a higher tensile strength resistance. The specific coniferous species is determined primarily by the number and size of pores in the places connecting the tracheids with the core rays [11]. The latter consist of small parenchymal cells and are not preserved during the digestion of the wood, but along the cellulose fibre pores remain at the site of the connections.

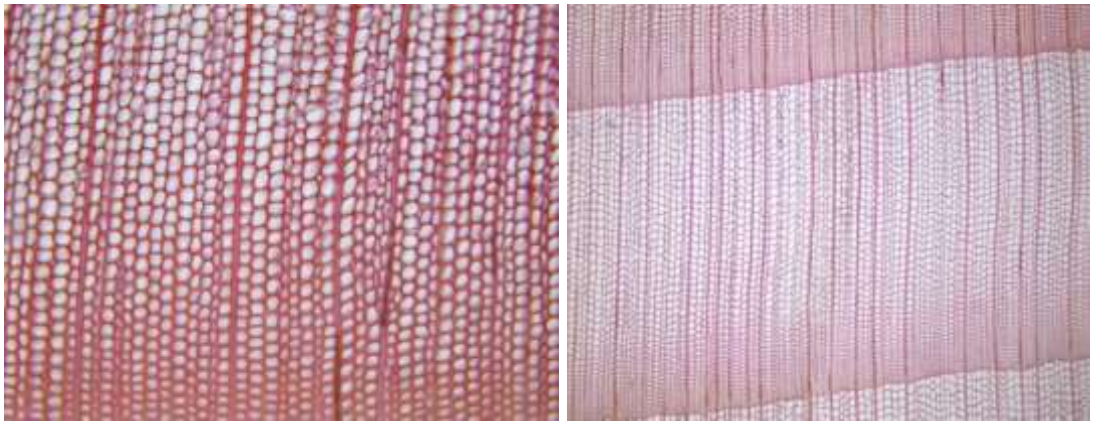


Fig. 2. Cross section of fir wood (100x)

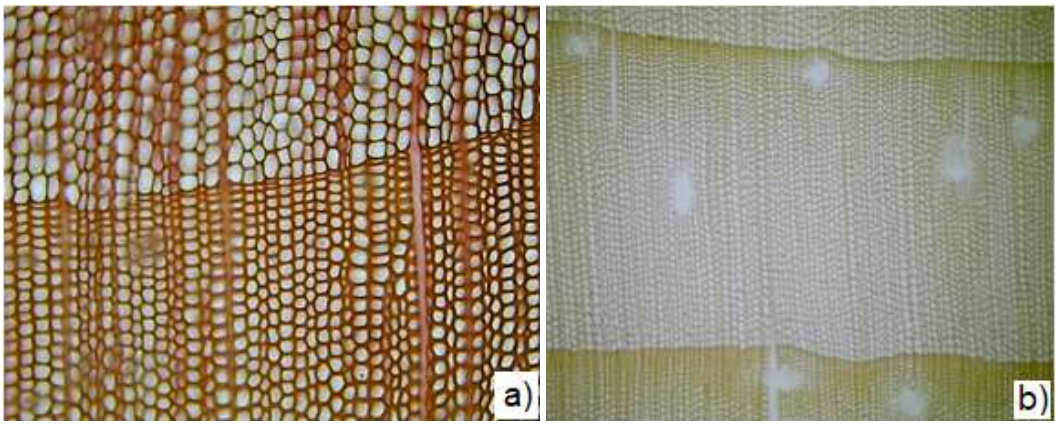


Fig. 3. a) Cross section of pine wood (100x); b) Cross section of spruce wood (100x)

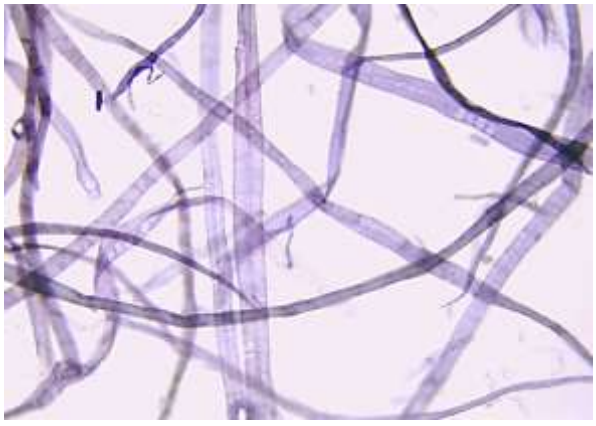


Fig. 4. Microphotograph of a bleached cellulose from mixed softwood (pine and spruce)

Deciduous wood and pulp from it

The main part of the pulp of deciduous wood are the cells of mechanical tissue (libriform). They are relatively short (0.7-1.5 mm), about 0.025 mm wide, thick-walled with needle-like pointed edges. Their general shape is spindle-shaped. The pores are very small, narrow, located at an angle to the axis of the fibre.

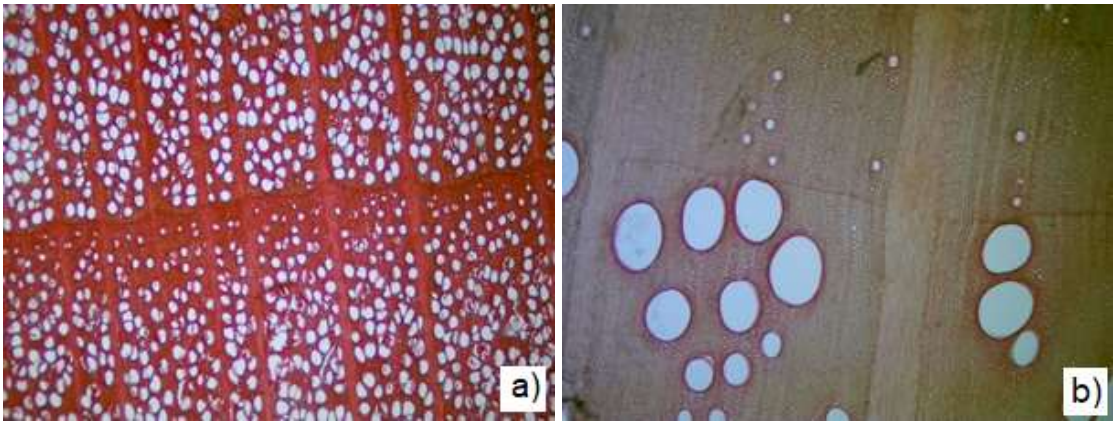


Fig. 5. a) Cross section of beech wood; b) Cross section of oak wood

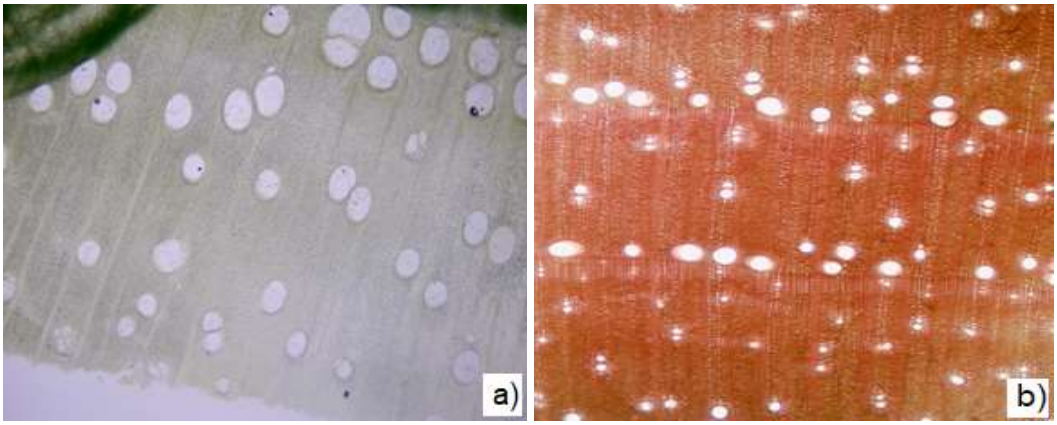


Fig. 6. a) Cross section of acacia wood; b) Cross section of wood from ash

Pulp from hardwood

A characteristic feature of vascular cells is that they are short, thin-walled, wide tubes (length 0.3-0.7 mm, width 0.05-0.6 mm). Their walls are densely covered with simple round or elongated pores in the form of network. The specific deciduous species is determined mainly by the type of vascular cells [11]. The addition of deciduous wood pulp to the composition of writing and printing papers improves the uniformity and visibility of the paper and, accordingly, the printing properties.

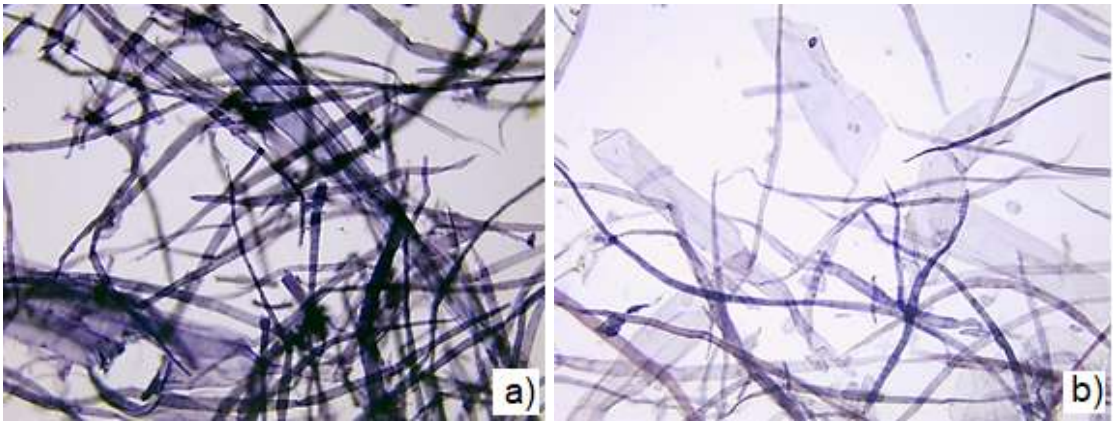


Fig. 7. a) Bleached birch pulp; b) Bleached poplar pulp

Straw pulp

Straw pulp is characterized by a wide variety of cells: facial, parenchymal, vascular, spiral, annular. The main ones are the facial ones (length 0.5-1.5 mm, width 0.01-0.02 mm) - long, thin, ribbon-shaped, with pointed edges, similar to the libriform cells of broad-leaved cellulose, but narrower. They have curves, knees, narrow channel and deep pores. The parenchymal cells are broad, thin-walled, with rounded edges, of various sizes. A characteristic feature are small cells of the cover layer (epidermis) with a sawtooth (toothed) shape. There are also annular and spiral cells, very thin. The vessels are tubular, elongated, with small pores on the walls.



Fig. 8. Microscopic analysis of a straw pulp

When choosing a fibrous material in the composition of the paper, the behaviour of the fibrous materials in the technological processes is taken into account. When both softwood and hardwood or straw pulp are used in the composition of the paper, separate grinding is required, optimal for each type of pulp.

It is recommended to use cellulose containing a sufficient amount of hemicelluloses when preparing oil-resistant and thick and strong papers.

Low-hemicellulose pulps should be used as filter paper when producing fluffy, moisture-absorbing papers. The fibres are poorly fibrillated, easily cut in the transverse direction, which ensures the production of paper with good absorbency.

High-yielding fibrous materials are used in the composition of newsprint and in the composition of sanitary paper. Unlike cellulose fibres, they are hard due to the high content of lignin, have an irregular shape and shorter length. When introduced into the composition of the paper usually reduce the strength, degree of whiteness, smoothness and durability.

High yielding fibrous materials

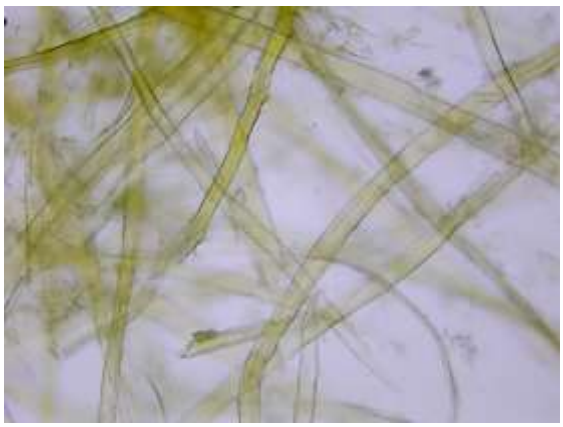


Fig. 9. Microscopic analysis of Chemical Thermomechanical pulp (CTMP)

Waste Paper

The use of waste paper as a secondary fibrous material is growing worldwide. In the production of papers from secondary fibrous material, a decrease in the physical and mechanical parameters is observed, which is due to a decrease in the length of the fibres and the interfibrous forces.



Fig. 10. Microscopic analysis of waste paper

After repeated processing of the waste paper, the length and volume of the cellulose fibres decrease and the performance of the new paper decreases. In the secondary fibrous material, a decrease in the interfibrous bonding forces is observed.

4. CONCLUSIONS

The properties of the obtained paper are determined by the properties of the fibrous materials and by the technological mode of processing. The study of the chemical composition, morphological and anatomical structure of the main fibrous materials in the pulp and paper production and the connection with the sheet-forming properties significantly determine the properties of the obtained paper. Softwood pulp provides the long-fibre fraction in the composition of the paper and gives strength to the resulting paper sheet. Broad-leaved cellulose in the composition of the paper gives opacity, porosity, fluff. The combination of these celluloses in the composition of the paper makes it possible to achieve the necessary properties for a particular type of paper. Waste paper is a valuable source of secondary fibrous material in the production of some types of paper. Paper is biodegradable, recyclable and its use is of great importance for the development of society.

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