UDC 676.27.274

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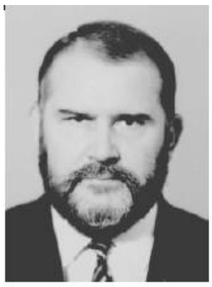


INVESTIGATION OF CATIONS INFLUENCE CONTAINED IN RIVER WATER ON SWELLING AND STOCK BEATING

The positive influence of sodium cations content in water is established. It is offered to compensate the reduction of their content resulting from flood or pouring rain by adding table salt to the water consumption system of the paper production.

Keywords: waste paper mass, paper-making properties, swelling, milling, river water, cations, sodium-potassium pump, Donnan effect, capillary-porous colloid structure of pulp fibers, cell wall membrane, zeta potential, cationic potential, electrical conductivity.

Natural waters that have a number of anomalous properties contain dissolved and suspended materials whose blend composition changes depending on the water reservoir, atmospheric precipitation and season. This has a big impact on paper and cardboard production (sizing, physical and mechanical properties, depositions, foaming behavior) [1].

The goal of our study is to analyze the temporal variations of water composition and establish the qualities that have a big impact on the technology of production of components for container board to develop measures to prevent the negative impact of these changes. As previously reported [3], there are major differences in water electrical conductivity levels in the short-circuit system of the paper machine, cationic and zeta potential of pulp connected with seasonal changes in river water composition (Table 1).

Table 1

Seasonal Changes in the Short-Circuit System of the Paper Machine

Characteristic	Characteristic value for measurement period	
	winter	summer and autumn
Electrical conductivity, µS·m/cm	700…800	800…900
Cationic potential, mEq/l	60…70	220…240
Zeta potential, mV	−5…−7	−11…−12

In 2006–2009, when seasonal changes in river water composition were studied at OAO Polotnyanyi Zavod Paper Factory (the Sukhodrev river), OOO Sukhona Pulp and Paper Mill (the Sukhona river), OAO Poligrafkarton (the Volga river), significant variations in Na^{+}, K^{+}, Ca^{+2}, Mg^{+2} content and their influence on paper and cardboard quality were identified (Table 2).

It seemed advisable in the first place to study the influence of sodium and potassium cations in natural water on pulp swelling and milling — the most important processes regulating the paper-making properties of pulp. Our hypothesis is based on the theory that describes the role of sodium and potassium in mineral metabolism in animal and plant cells [2, 5–9], i. e. in the operation of the so-called "sodium-potassium pump".

Phenomena that are observed in the capillary contribute to wetting and surface tension. It is commonly believed that osmotic pressure is the main force that ensures water movement in the fiber structure. Fiber swells intensively due to osmotic pressure that arises when cations in the solution start moving in the opposite direction (the Donnan effect named after F.G. Donnan, a British physical chemist who developed van't Hoff's theory of membrane equilibrium) [5, 8].

Membrane channels are permeation-selective only for certain substances. This selectivity depends on the pore radius and distribution of charged functional groups within them. There are channels that let pass sodium (sodium channels), potassium (potassium channels) and chloride (chloride channels) ions, etc. There is more than one channel for each ion type and these channels ensure very high transportation speeds (~10^8 ions per second).

Table 2

Seasonal Changes in River Water Composition (the Sukhodrev)

Ions	Ion content for measurement period, mg/l			
	March–April	May–June	July–August	September–October
Na^+	4.4	15.0	172.2	9.4
K^+	2.7	2.4	11.9	8.4
Ca^+	27.2	49.9	522.1	51.7
Mg^{+2}	3.1	9.1	10.1	22.2
Cl^-	10.0	10.0	16.3	17.4
SO_4^{-2}	12.9	16.0	24.5	18.5

Pulp is known to have a capillary-porous colloid structure. Spaces between micro- and macrofibrils are formed by macropores (their diameter in the cell wall equals 30.0 nm) that let pass only those ions that have an appropriate diameter. The cell wall pores and capillaries are accessible by Na^+ and K^+ ions (their radiuses are 13.3 nm and 9.8 nm, respectively), but are inaccessible by other water components (unlike sodium ions, polyvalent cations, firstly, prevent charged groups from passing through the membrane as a result of diffusion and, secondly, are not biogenic (i. e. are not among the permanent components of plant cells) [2].

The disjoining action of water caused by osmotic pressure and the sodium-potassium pump, i. e. by the ionic part of osmotic pressure within the fiber wall microstructure, facilitates the formation of unbounded hydroxyls within the wall during milling.

Cell walls are membranes that separate solutions with different concentrations. Thus, the fiber swelling degree may change. There are mainly potassium ions inside the cell, while the intercellular space contains mainly sodium ions. One would think that the situation should be just the opposite. As a sodium ion is about 1.5 times smaller than a potassium ion, it should be easier for it to penetrate the membrane and, consequently, there should be more sodium ions inside the cell as compared to larger potassium ions. However, sodium ions attract water molecules forming a water envelope that prevents them from passing through the membrane. The difference in the number of potassium ions inside and sodium ions outside the cell causes an electric potential difference that facilitates the transfer of ions and different substances from intercellular space into the cell and back.

MS5B (GOST 10700) wastepaper was the object of this study. Before defibering the wastepaper in a laboratory pulper, it was prehydrated in artesian water at 20 °C for 0.6–4.0 hours.

The pulp that had been deflaked for 3 minutes (just like in real plant environment) was milled using the laboratory mill until the freeness value was 25 and 35 °SR. The water yield, water retention, weighted average length of fiber were measured; pulp sheets weighing 100 g per 1 m^2 were made to measure strength characteristics.

The experimental part of the study comprised three stages. At the first stage, it was expected that the influence of duration of fiber swelling that preceded defibering in the pulper on the paper-making properties of the pulp would be studied. To do so, constant-composition artesian water was used as the multiple publications dedicated to the dynamics of the paper-making properties of pulp when the swelling duration is increased lack data on the recording of water composition and sodium and potassium cations.

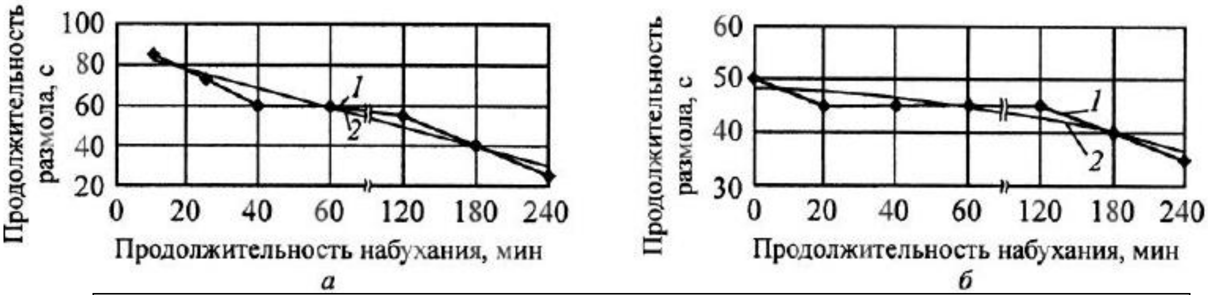


Рисунок	
Продолжительность размола, с	Milling duration, s
Продолжительность набухания, мин	Swelling duration, min

Fig. 1. The impact of duration of pulp swelling that preceded its defibering on the duration of its milling until the freeness value was 25 (*a*) and 35 °SR (*b*): 1 – practical data; 2 – approximation straight line (R^2 = 0.937)

At the second stage where the swelling duration before defibering was 0.5 and 1.0 hours, 9 g/l of table salt was added to artesian water. The material was further treated in the same way as at the first stage save that it was milled using the laboratory mill until the freeness of 25, 35 and 45 °SR was achieved.

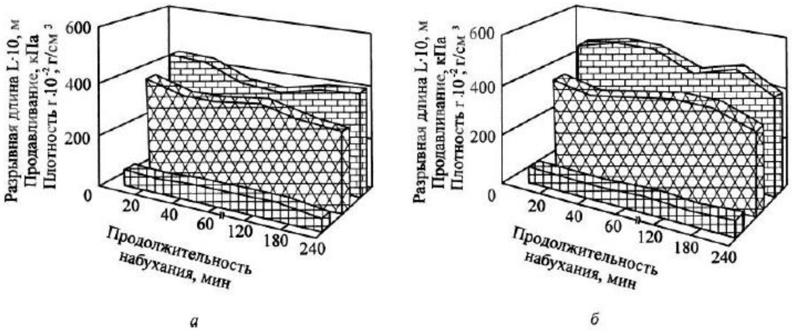
The dynamics of swelling and milling in distilled water without additives as well as with sodium and potassium cations was studied at the third stage.

Fig. 1 shows the dynamics of the reduction of pulp milling duration up to the freeness of 25 and 35 °SR where the duration of pulp swelling that preceded its defibering was changed.

Fiber swelling occurs when water penetrates intermicellary spaces and is bonded to hydroxyl groups on micelle surfaces. Water does not get inside micelles. Swelling contributes to the growth of developed specific surface area of fibers increasing paper sheet strength.

Slower milling (Fig. 1, *b*) can be attributed to the fact that, in most cases, the development of the specific surface area (fibrillation) of fibers occurs at the stage when freeness makes 25 °SR and any further increase in freeness is achieved due to fiber splitting and shortening.

Excessive (exceeding 3 hours) swelling in the main part of fiber reduces its strength (Fig. 2).



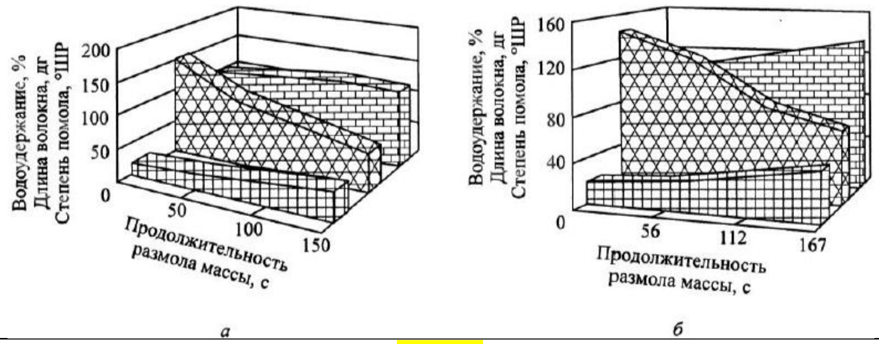


Рисунок	
Продолжительность размола массы, с	Pulp milling duration, s
Продолжительность набухания, мин	Swelling duration, min
Разрывная длина L·10, м	Breaking length L·10, m
Продавливание, кПа	Burst, kPa
Плотность r .10^{-2}, г/см^3	Density r .10^{-2}, g/cm^3
Водоудержание, %	Water retention, %
Длина волокна, дг	Fiber length, dg
Степень помола, °ШР	Freeness, °SR

Fig. 3. The dynamics of properties of samples taken from pulp milled after the stock had been swelling for 30 (*a*) and 60 minutes (*b*): ■ — freeness; ■ — fiber length; ■ — water retention

The duration of prehydration (swelling) of stock that precedes defibering can obviously be restricted to one hour, but in doing so it is important that the content of sodium and potassium in water be controlled.

The optimal duration of preliminary swelling of the stock that preceded defibering and milling was assessed at the second stage of the study. Experimental findings are shown in Fig. 3, 4.

Swelling that runs for one hour is the most preferable one in terms of water retention growth and preservation of fiber length. It is noteworthy that the duration of milling up to the freeness of 25 °SR reduced 1.5 times suggesting that water has a stronger disjoining effect caused by osmotic pressure within the cell wall infrastructure in the presence of sodium cations.

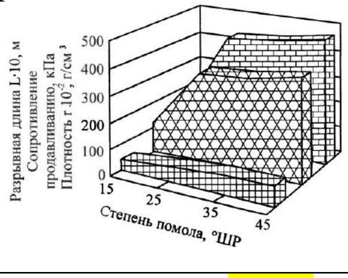


Рисунок	
Разрывная длина L·10, м	Breaking length L·10, m
Сопротивление продавливанию, кПа	Burst strength, kPa
Плотность r .10^{-2}, г/см^3	Density r .10^{-2}, g/cm^3
Степень помола, °ШР	Freeness, °SR

Fig. 4 shows changes in samples obtained from pulp that had been milled after one-hour swelling of stock in artesian water containing 3,528 mg Na^{+}/l.

The density of samples where the freeness is 35 and 45 °SR greatly exceeds the density of samples obtained from pulp that was defibered and milled in artesian water without adding sodium cations. This fact suggests a more efficient internal fiber fibrillation caused by osmotic pressure in the presence of sodium cations. Thus, the results of this study confirm the positive effect of sodium and potassium ions in pulp swelling and milling.

Fig. 4. The dynamics of properties of samples obtained from pulp milled after 60-minute stock swelling in artesian water containing sodium cations (see the marks on fig. 2)

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Received 12/4/2009

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