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KINETICS OF THE RECYCLED PULP FIBERS SWELLING

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ABSTRACT

The aim of the work has been to verify the suitability of the method for determination of kinetics of the recycled pulp fibers swelling. In pursuance of the achieved experimental results it might be said that after certain modifications this method is appropriate for the objective quantification of the dimensional changes of the recycled pulp fibers. This can also be applied in practice, e.g. to determine the wear factor of the recycled pulp fibers.

KEYWORDS: Pulp, recycled pulp fibers, swelling kinetics.

INTRODUCTION

The swelling issue of the pulp fibers results from the theory of wood swelling and it is deeply wedded with wood and its moisture content.

Free hydroxyl groups (OH) play the main role in swelling. OH groups are able to bind water by hydrogen bonds. The content of free OH groups in wood is significantly limited by lignin-saccharide bonds. Therefore swelling of the bleached pulp fibers (where lignin is limited) is more intensive.

Fiber swelling has practical importance for the manufacture of paper. These days fiber swelling is a frequently discussed issue thanks to repeated usage of waste paper for paper production (paper recycling).

The pulp fiber recycling leads to the decrease of thickness of the fiber wall as well as to the decrease of the tensile strength. The ratio between the lumen diameter and the width of the fiber increases whereas the direct proportion between the tensile strength and the width of the fiber wall can be observed (Okayama 2001).

Kraft pulp with markedly decreased strength swells less during the process of recycling and possesses a lower bonding potential. There are also certain changes in the strength and these are connected with the morphological properties of the fiber (lumen diameter, slight ratio). The recycled fibers are less hydrophilic than the original ones. There may have been observed remarkable increase of the contact angle with water, which is related to the fiber surface inactivation. This inactivation occurs during the process of recycling and it is known as "irreversible hornification"(Okayama 2002).

Milling is one of the most important processes to retrieve the paper potential of the recycled fibers. Milling increases both the flexibility of the fiber and the swelling ability which ameliorates bonding and strength (Woodward 1996).

The fiber crystallinity index slightly varies during recycling. This effect is induced by minor increase of the crystallinity in certain amorphous part of the fiber. The recycled fiber lumen is insufficiently re-opened at the wet stage. The water content bonded in the fiber wall influences the recycled fiber ability to swell repeatedly very much. Decrease of repeated swelling corresponds with decrease of the content of water bonded in the cell wall. This might be caused by decrease of amorphous areas known as sub-morphological changes of the fiber wall (Khantayanuwong et al. 2002).

Recently (Češek et al. 2005, 2006, Češek and Milichovský 2005) have applied the method of vapor condensation kinetics on the simple recycling examination. This simple method for the determination of the recycled fibers (fibers exposed to repeated moistening, defibrillation, dewatering and drying) is significantly influenced by the porous molecule connections. During recycling the porous connections get more hydrophobic and hydrophilic parts that protect their anion-active character.

The Faculty of Wood Sciences and Technology at Technical University in Zvolen developed a simple method for monitoring the first faster pseudolinear swelling phase. This method determines wood swelling kinetics in the first seconds of its contact with water or ather polar solvents (Solár 2006).

This method was successfully used to monitor the wood dimensional changes caused by intended fungi degradation (expressed as swelling "relative velocity constants"). However, there is one disadvantage resulting from natural heterogeneity of wood. Therefore the achieved results cannot be considered as absolute.

The aim of this work has been to find out whether the method of the determination of wood swelling kinetics might also be used to determine the swelling kinetics of the recycled pulp fibers. If so, the mathematical characterization of pulp fiber swelling kinetics in recycling process has to be done.

MATERIAL AND METHODS

Material

Bleached kraft pulp made of hardwood was used to monitor the swelling kinetics of the fiber in the process of simple 8-multiple recycling.

There were prepared three 8-multiple recycled pulps (drying temperature of 80°C, 100°C and 120°C) to compare the influence of drying.

The first fiber treatment (zero recycling) consisted of the manual pulp laceration, defibering, milling on 29 °SR and drying.

The pulp was returned into the defibering, milling and drying process within 8-multiple recycling modeling. The pulp samples were removed at each recycling stage. They were used to prepare the sheets and monitore the selected physical and chemical properties of the pulp.

Method of the monitoring the swelling of the fiber

The monitoring principle of fiber swelling (as well as in the original method) consists of recording the dimensional changes in the water-swollen experimental sheet. These changes are examined by the sensors and transformed into the electric signals. These sensors are in the vertical contact with the pulp sheet (min. size 25 x 25 mm) through distance glass inlet. The measured electric signals are processed by PC and evaluated by graphic dependence of swelling on time. Swelling is defined as the difference between the immediate and initial inlet distance (in %). The modified apparatus which was used to monitor the swelling of the fiber is presented in Fig. 1.

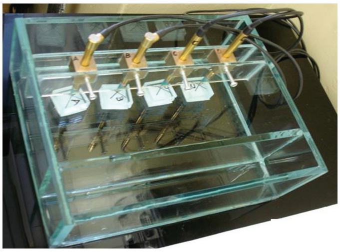


Fig. 1: The pulp fibers swelling-monitoring apparatus.

RESULTS AND DISCUSSION

The results of the measuring of the changes of the recycled pulp fibers depending on time are presented in Fig. 2a – 2c.

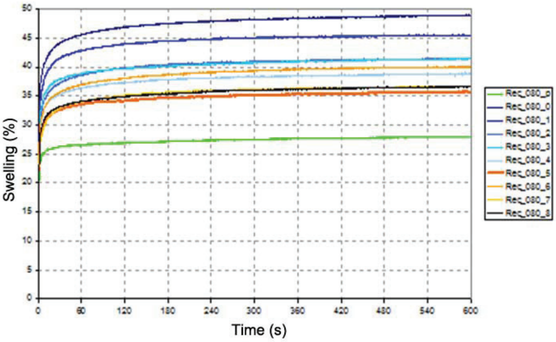


Fig. 2a: Course of pulp fibers swelling dried at temperature 80°C.

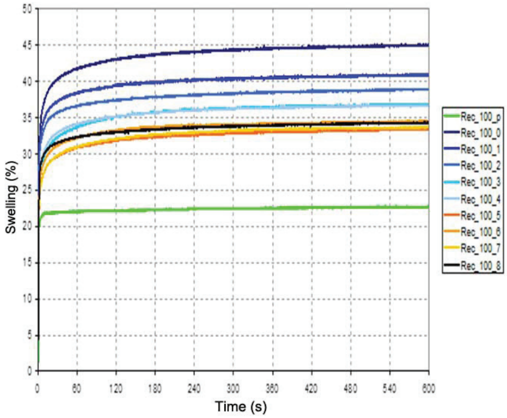


Fig. 2b: Course of pulp fibers swelling dried at temperature 100°C

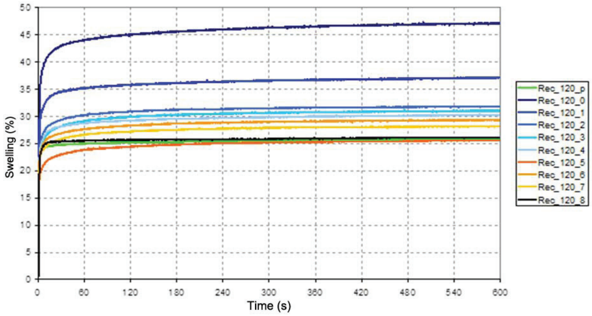


Fig. 2c: Course of pulp fibers swelling dried at temperature 120°C.

The results of our experiments are in compliance with quoted authors Woodward (1996), Okayama (2002), Khantayanuwong (2002).

The swelling ability of the fibers is positively and also negatively influenced by the changes in the pulp fibers. These are caused by drying and repeated beating during the recycling process.

The original fibers, which are not corrupted by beating, show the worst swelling ability. Beating causes the corruption of the cell wall of the original pulp fibers and the cell wall is disposed of outer layers (P, S1). The pulp fibers are fibrillated and delaminated at the same time. The released structures cause intensive swelling of the fibers in water medium. This fact is proved by maximal swelling value at 0 recycling.

In contrast with beating, the consecutive drying process causes the collapse of the fibers, decrease of hydrophility and inter-fiber bonding surface due to the decrease of free OH group content. This results in the decreased swelling ability. The negative influence of drying and temperature proves progressive decrease of the swelling fiber ability with the ascending drying temperature and increasing recycling count. Temporary increase of the swelling ability observed at 6th recycling is probably caused by delamination of the cell wall of the fiber.

From dependence profile in Fig. 2 it might be concluded that:

- maximal velocity of pulp fiber swelling is achieved during the first seconds of the contact of the sheet with the used medium - water. Then swelling velocity decreases progressively until zero value.
- swelling ability of the pulp fibers reduces dependence on the recycling number
- pulp fibers always achieve maximal swelling after zero recycling (after first milling)

Swelling kinetics was evaluated by the regression analysis. Swelling of the recycled pulp fibers counts with the existence of two qualitatively different and independent factors (physical action):

- The first factor was evaluated by regression function:

$$y_1 = A * (1 - e^{-k*t}) \qquad (1)$$

where: parameter A - maximal swelling induced by the first factor,
constant k - determines the achieved velocity of limiting (maximal) value A.

- The second factor was evaluated by regression function:

$$y_2 = (2*B) / \pi * arctg\,(q * t^{n}) \qquad (2)$$

where: value B - maximal swelling induced by the second factor,
constants q, n determine the profile and achieved velocity of limiting (maximal) value B.

Taking the first derivative of both regression functions, we obtained swelling velocities induced by these two components - kinetics of both actions in differential mode:

$$y\acute{}_1 = k*A*e^{-k*t} = k*(A - y_1) \qquad (3)$$

$$y\acute{}_2 = [(2*B*n*q) / (\pi * q^{2})] * t^{n-1} / (1/q^{2} + t^{2*n}) = Q * t^{n-1} / (R + t^{2*n}) \qquad (4)$$

Totally 30 regression dependences were deduced based on experimental data achieved under 3 temperature (80°C, 100°C, 120°C) after 10 treatments (non-milled, milled, after 1st, 2nd, ..., 8th recycling), in 41 times and at 4 repetition:

$$y = A * (1 - e^{-k*t}) + 2*B / \pi * arctg\,(q * t^{n}) \qquad (5)$$

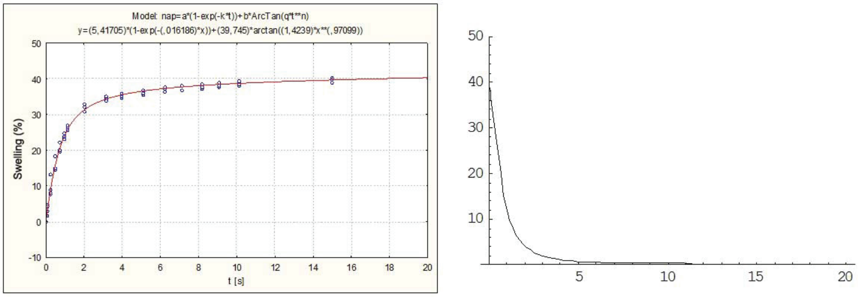
regression dependences parameters are presented in Tab. 1. The limiting value of first swelling components A is more than 7 %. This maximal value of A component is significantly lower than the limiting value of second component B which achieves value more 40 % after zero recycling and 80°C. Parameter n in the second component is in two cases lower than 1. This fact physically indicates unlimited swelling velocity at the first moment. In other cases the swelling velocity increases until definite value, then culminates and finally decreases to zero (Fig. 3).

Tab. 1: Parameters of the obtained regression dependencies.

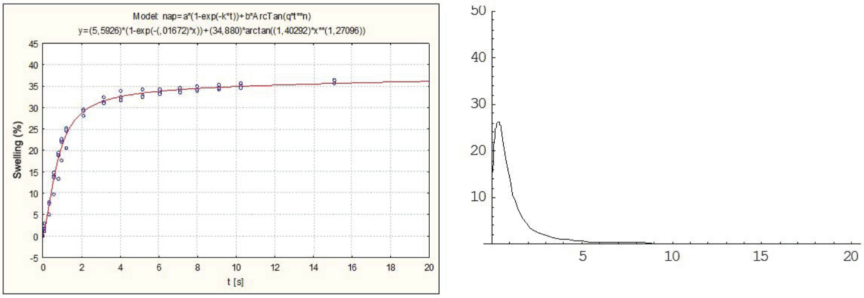
Rec.	Temperature °C	A	k	B	q	n	y_{max}
-1	80	2.427	0.01165	25.270	1.896	1.804	27.697
-1	100	1.110	0.01408	21.397	1.985	2.907	22.508
-1	120	1.561	0.01662	24.002	1.117	2.475	25.563
0	80	6.864	0.01492	**41.541**	1.274	1.237	48.405
0	100	**7.419**	0.01744	**36.984**	1.180	1.336	44.404

0	120	5.802	0.01317	**40.790**	0.969	1.428	46.592
1	80	5.418	0.01619	39.745	1.424	**0.971**	45.162
1	100	5.592	0.01672	34.880	1.403	1.271	40.473
1	120	4.465	0.02074	32.084	1.280	1.637	36.550
2	80	5.530	0.01430	35.624	1.687	**0.954**	41.154
2	100	4.683	0.01579	33.781	1.872	1.109	38.464
2	120	4.463	0.02269	26.987	1.777	1.419	31.449
3	80	5,274	0.01653	35.600	1.587	1.286	40.874
3	100	7.285	0.01665	29.117	1.467	1.381	36.401
3	120	5.373	0.02326	25.208	1.749	1.606	30.581
4	80	5.134	0.01524	33.323	1.919	1.150	38.457
4	100	6.555	0.02031	29.620	1.601	1.338	36.175
4	120	3.141	0.01602	26.794	1.497	1.383	29.935
5	80	4.176	0.01462	31.078	1.514	1.124	35.253
5	100	5.924	0.01742	27.007	1.543	1.440	32.931
5	120	4.440	0.01958	20.765	2.548	1.442	25.205
6	80	6.363	0.01450	33.203	1.688	1.261	39.565
6	100	5,689	0.01988	28.369	2.025	1.275	34.057
6	120	3,552	0.01435	25.555	1.527	1.406	29.107
7	80	6,782	0.02144	29.314	1.683	1.404	36.095
7	100	6,409	0.01778	26.802	1.881	1.317	33.211
7	120	3.876	0.01842	23.996	1.884	1.570	27.871
8	80	4.779	0.01275	31.441	1.612	1.314	36.221
8	100	3,660	0.01234	30.342	1.307	1.420	34.002
8	120	2,210	0.09180	23.494	1.049	2.493	25.704

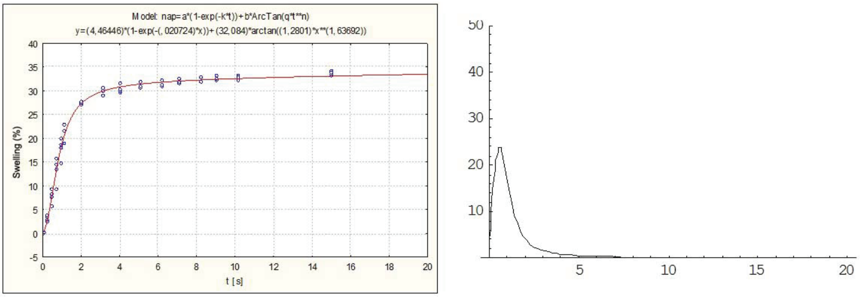
Fig. 3 a-c show typical swelling dependences y and swelling velocities y´ of pulp fibers after first recycling at 80°C (n < 1) and at temperatures 100°C, 120°C (n > 1).



a) after first recycling at temperature 80°C (n < 1)



b) after first recycling at temperature 100°C



c) after first recycling at temperature 120°C (n > 1)
Fig. 3 a–c: Typical swelling dependences y and swelling velocities y´ of pulp fibers.

CONCLUSIONS

These experiments have confirmed our expectations. Once this method, originally developed to determine wood swelling kinetics, is subjected to certain modifications, it might be applied to determine the pulp fiber deterioration degree. To ensure more precise measurement within the first seconds - during the most intensive swelling, it is necessary to implement more sensitive sensors to record the dimensional changes of the tested pulp sheets.

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