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Impact of selected technological factors on free swelling of cellulose fibres

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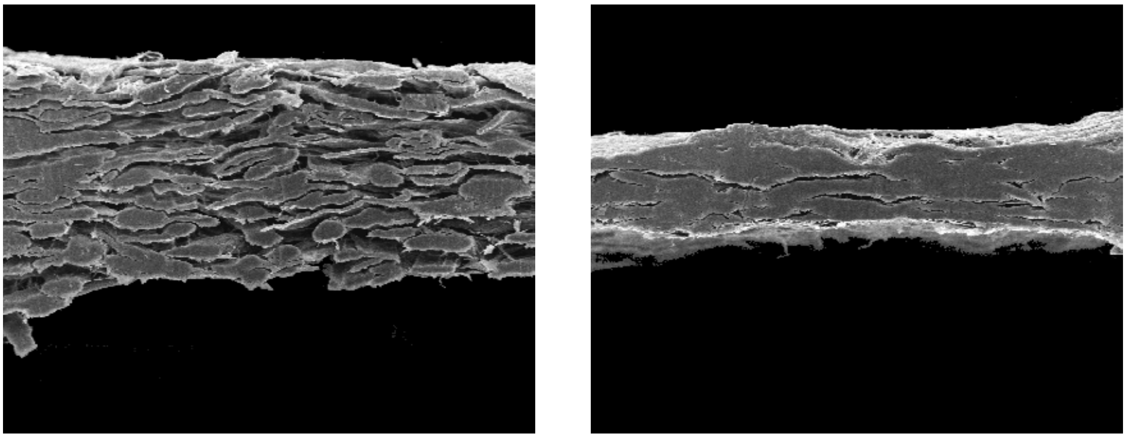
Abstract: The purpose of this work was to determine the impact of selected technological factors like: process duration, refining degree and pulp consistency on free swelling of papermaking pulp based on cellulose fibres. Free swelling is the effect of water sorption by the cellulose fibres without their simultaneous mechanical treatment (e.g. refining). Free swelling effect was measured by pulp water retention value (WRV). On the basis of the test results, it was found that the free swelling is a long-lasting process which depends on many process variables (e.g. pulp consistency, refining time). For the tested pulp of consistency 10%, the optimal time of the free swelling was 100 minutes. Pulp consistency of 25% increased optimal free swelling time to 110 minutes. Results show that the level of free swelling depends on refining time. The higher refining time, the lower increase in WRV after free swelling operation.

Keywords: papermaking, pulp, free swelling, refining, pulp consistency

INTRODUCTION

It is well known that unrefined plant-based cellulose fibres used in the paper production have a low ability to create a paper structure of high mechanical properties. This results from the fact that strength properties of a paper product depend on the surface of inter-fibre bonding. The unrefined cellulose fibres are relatively stiff, therefore paper made from such fibres will have a loose structure and low strength (Fig. 1a). Basic efforts - aimed at improving papermaking ability - have to be focused on maximal development of bound surface in paper. This effect is obtained by increasing fibres flexibility [1,2].



a) b)

Fig. 1. a) Structure of paper made from unrefined pulp, b) Structure of paper made from refined pulp (flexible fibres). SEM photography, magnification x200

To increase flexibility of cellulose fibres, it is necessary to weaken the bonds connecting their structural elements. In practice, it is done in the pulp refining process. Mechanical interactions between knives in the refining equipment damage external, impermeable layers of cellulose fibres and make internal layers available for water. Water molecules are strongly attracted by free, polar carboxyl, hydroxyl or sulfo groups [3,4]. These groups are present in chemical compounds (e.g. cellulose, hemicellulose, lignin) constituting building material of the plant fibre cell wall or are brought into the fibre structure by their treatment (pulping, bleaching) [4,5,6]. The effect of this attraction results in replacing hydrogen bonds with hydrous bridges loosening, in a consequence, each layer of a cell wall. This phenomenon is called internal fibrillation. The swelling of cellulose fibres is the result of internal fibrillation. One of the factors that allows to determine the progress in internal fibrillation is water retention value (WRV) developed by Jayme [7]. It was also proved that the increase in WRV of fibres is clearly connected with the increase in paper mechanical properties.

It is important to remember that water penetration and swelling are the processes of specific kinetics [8,9]. A certain period of time is required for water to penetrate into all available spaces. Therefore, fibre swelling occurs not only during refining operation but also (in a limited range) during free contact with water (free swelling).

At present, a thorough knowledge of kinetics in swelling process of papermaking cellulose fibres becomes particularly important. Growing capacities of technological lines connected with higher paper machines capacities make the time of specific unit operations shorter. Such a system usually does not ensure minimal time needed for the appropriate fibre swelling. The effect may involve non-optimal development of papermaking properties of a given pulp. As a result, lower paper quality could be obtained.

The purpose of the project was to determine the impact of selected technological factors like free swelling duration time, degree of refining and pulp consistency on the free swelling of selected cellulose pulp.

MATERIALS AND METHODS

Unbleached kraft pine pulp was used in the experiments. All refinings were done in PFI mill according to TAPPI T 248 standard method. Water retention value (WRV) of fibres was tested according to SCAN-C 102 XE (8 measurements per sample were done). It was assumed that, after centrifuging of tested pulp sample, free swelling was finished.

RESULTS

From practical point of view, the time of pulp swelling in the technological line is a function of total capacity of the line before the paper machine. Increased residence time can be obtained only by increased capacity of the technological line (e.g. by construction of the additional chest). Therefore, in order to reduce costs, it is necessary to determine optimal swelling time. In presented tests, the boundary time of the free swelling was defined as the time after which the increases in swelling degrees were less than 5% of total WRV increase (obtained in given conditions for a given pulp). Figure 2 shows the changes in this value determined for the different times of the free swelling accomplished for two different consistencies of tested pulp: 10 and 25%. It was found that shapes of curves which show the kinetics of free swelling process can be described by exponential formula (1):

$$WRV = WRV_0 + a * e^{b*ts} \quad [2]$$

where:

- ts - free swelling time, min
- WRV_0 - initial WRV value, %
- a, b - individual coefficients for given pulp and its properties

Further experiments proved that the general shape of the curve does not depend on consistency nor refining time. On the other hand, experiments shown that higher pulp consistency resulted in lower, final level of WRV factor. On the basis of previously given definition of the limit swelling time, it was found that the required time (T_S) for tested pulp was also pulp consistency dependent. For pulp consistency of 10% optimal free swelling time

T_S was approx. 100 minutes while for pulp consistency of 25% time T_S was about 110 minutes (fig. 3). This fact clearly points, that for obtaining optimal pulp swelling (i.e. proper paper mechanical properties) both parameters: time of swelling and consistency are vital.

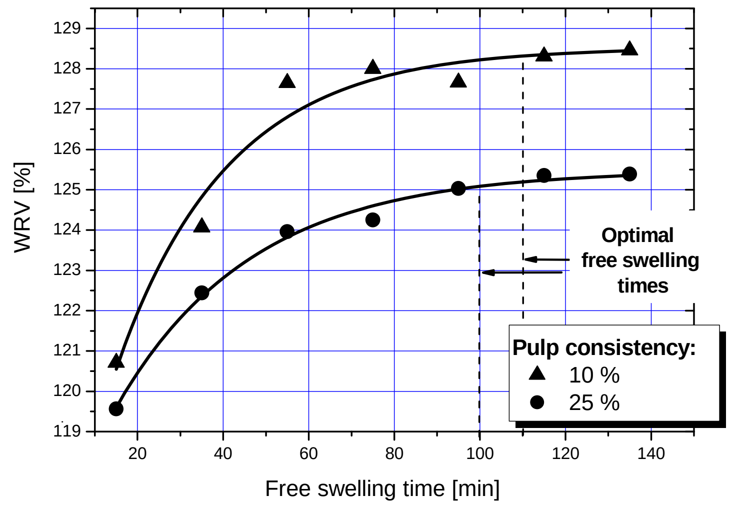


Fig. 2. Example of changes of water retention value (WRV) during free swelling of unbleached Kraft pine pulp previously refined in laboratory PFI mill (time of refining - 1 minute)

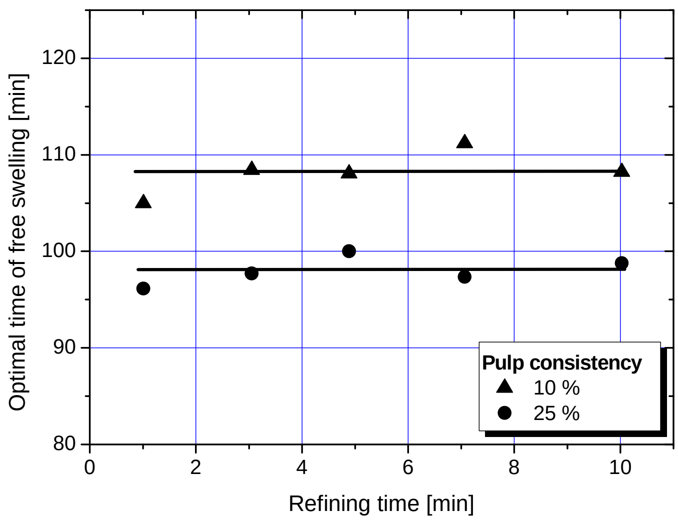


Fig. 3. Determination of optimum duration of free swelling for tested pulp refined under different refining conditions (time of refining)

On the basis of the determined free swelling times, the impact of refining progress on subsequent pulp free swelling was investigated. Figure 4 shows the increase of pulp WRV after refinings performed with different length (time). Obtained results shown that higer refining time resulted in lower increase of WRV after free swelling. It means that for longer refined pulps, free swelling has lower impact on overall pulp swelling (and simultaneously on development of final paper properties). Additionally, pulp refined in higher consistency was characterized by significantly lower DWRV than low consistency pulp refined under similar conditions. Detailed analysis proved that kinetics of this process can be described by the general, exponential formula (2):

$$\Delta WRV = WRV_0 + a * e^{\frac{-t_R}{b}} \quad [2]$$

where:

t_R - refining time in PFI mill, min
WRV_0 - initial WRV value, %
a, b - individual coefficients for given pulp

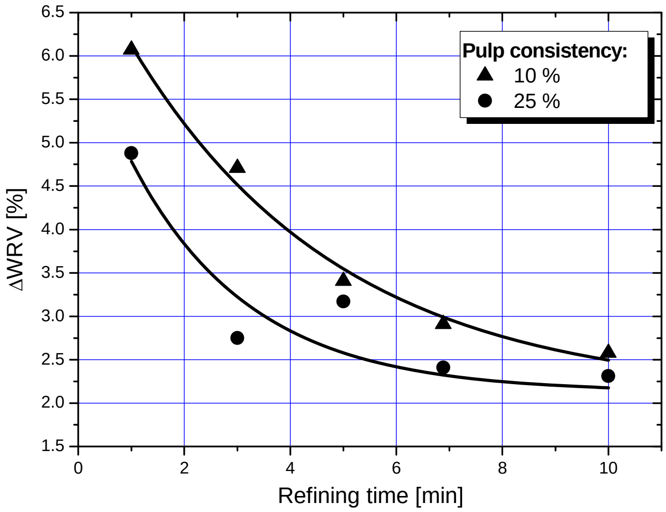


Fig. 4. Change of refined pulp WRV for different refining conditions

Equation (2) enables to calculate theoretical growth of WRV after free swelling operation for given pulp refined in PFI mill in t_R time.

SUMMARY

On the basis of the test results it was found that the free swelling is a long-lasting process which additionally depends on many process variables (e.g. pulp consistency, refining time). For the tested pulp of consistency 10%, the optimal time of the free swelling was 100 minutes. Optimal free swelling time was increased to 110 minutes for pulp consistency of 25%. Results show that the level of free swelling depends on refining time. It was also found that the higher refining time, the lower increase in WRV after free swelling operation.
It can be concluded that optimal utilization of free swelling phenomenon can be obtained for low consistency pulps refined with low intensity.

ACKNOWLEDGEMENT

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Streszczenie: *Wpływ zjawiska swobodnego pęcznienia włókien celulozowych na właściwości papieru.* Celem niniejszej pracy było określenie wpływu wybranych czynników technologicznych, takich jak czas prowadzenia procesu mielenia i stężenie masy papierniczej na zjawisko swobodnego pęcznienia masy papierniczej. Mianem swobodnego pęcznienia określono tutaj efekt zmiany ilości wchłoniętej wody przez cząstki włókniste masy papierniczej w trakcie jej przebywania w środowisku wodnym, bez dodatkowej stymulacji np. poprzez jej mielenie. Ilość wchłoniętej wody określano za pomocą wskaźnika WRV. Wpływ mielenia był badany w ten sposób, że zmieloną masę przenoszono do odpowiedniego zbiornika i pozostawiano ją tam na określony, wyznaczony odcinek czasu, a następnie określano zmianę jej stopnia spęcznienia porównując wartość WRV uzyskaną zaraz po mieleniu z wartością WRV otrzymaną po określonym czasie swobodnego pęcznienia (przebywania w zbiorniku). Na bazie wykonanych badań stwierdzono, że proces swobodnego pęcznienia jest zjawiskiem długotrwałym uzależnionym zarówno od stopnia zmienia masy papierniczej, jak i jej stężenia. Dla masy o stężeniu 10% optymany czas pęcznienia swobodnego (czas, po którym masa uzyskiwała 95% możliwego przyrostu wskaźnika WRV) wynosił ok. 100 minut, zaś dla tej samej masy o stężeniu 25%, optymalny czas pęcznienia swobodnego wzrastał do ok. 110 minut. Czas ten nie zależał od stopnia zmielenia masy. Proces mielenia wpływał natomiast na różnicę przyrostu wskaźnika WRV na skutek swobodnego pęcznienia. Stwierdzono, że im dłuższy był czas mielenia, tym zmiany wskaźnika WRV na skutek swobodnego pęcznienia były mniejsze. Analiza matematyczna uzyskanych wyników pozoliła na wyznaczenie empirycznych równań opisujących kinetykę zmian wskaźnika WRV w czasie swobodnego pęcznienia oraz kinetykę zmian przyrostu wskaźnika WRV w zależności od stopnia zmielenia masy papierniczej.

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