EFFECT OF MAGNETIC FIELD ON CELLULOSE
REFINING PROCESS AND STRENGTH PROPERTIES

Dimitrina Todorova¹, Kiril Dimitrov²

¹University of Chemical Technology and Metallurgy
Department of Pulp, Paper and Printing Arts
8 Kliment Ohridski, 1756 Sofia, Bulgaria
E-mail: toodorova.dimitrina@uctm.edu
²University of Applied Technical Science Wildau, Germany
E-mail: dimitrov@th-wildau.de

ABSTRACT

This study presents the results from the investigation of the effect of constant magnetic field over the refining process of soft and hardwood pulp suspensions and an evaluation of its white waters and paper samples strength properties. In our experiment were used two types of kraft pulp - 100 % of softwood (pine and spruce) and 100 % of hardwood (acacia). The refining degree and dewatering time for 700 ml filtrate were determined by the Schopper Riegler Value ºSR, according to ISO 5267-1/AC: 2004. The magnetic treatment of pulp suspensions was performed by using magnetic stator device with field intensity of 0,1 T. Aqueous stream (the paper furnish) was passed vertically downwards through the pole gap space with linear speed 0,6 - 0,8 m s⁻¹ at quintuple and octuple crossing of the fluid. Of each pulp type were produced sheet samples 70 g/m² without and with quintuple and octuple magnetic treatment. Tensile index, N m/g of papers was determined on a tensile testing machine Zwick/Roell, (ISO 1924-2:1985), Burst index, kPa m²/g (ISO 2759:2014) and Tear index, mNm²/g (ISO 1974:2012). The results show positive effect of the magnetic treatment over the cellulose refining time, cellulose suspensions dewatering effect and paper samples strength properties. For both investigated types of cellulose with a view of complete evaluation of the parameters studied out the quintuple magnetic treatment is optimal.

Keywords: magnetic treatment, cellulose, refining, dewatering, turbidity, conductivity, strength.

INTRODUCTION

The magnetic treatment (MT) of water and aqueous suspensions is an old method, which has remained a controversial process practically used mainly for industrial and domestic water purification for over 50 years [1]. The first patent was registered in 1945 by Belgian Engineer Vermeiren, who used a variation of the method for water softening, without the use of any chemicals [2]. The main advantage of this type of treatment is the possibility of reducing the usage of chemical additives to prevent lime scale deposition and corrosion of facilities, which are in most cases expensive, can be harmful to human life and are environmentally disruptive. Scientific experiments in this area date back to the 1960s [3].

Many scientists investigate the effect of MT on water and conclude that the effect on water bears a complex and multifactorial character and explanation might be found in the changes of ion distributions and ion hydrations in the nearness of dispersed particle surfaces [1, 4 - 6]. Cai et al. used magnetic field (MF) to investigate the effect over the water molecular hydrogen bonds. The stationary MF changes the physicochemical properties of water at 0.5 T in a flowing-circulated system. The MT brought down the surface tension of purified water while promoted the viscosity at 298 K. It was suggested that the water intramolecular energy decreased and activation energy increased over the magnetic treatment time. The rotational motions of water molecules got slowdown and more hydrogen bonds were formed and
Many researchers claimed that magnetic fields change the scale formation and corrosion [8 - 12]. Kobe et al. report that the MF influence the formation of aragonite rather than calcite. They proved the existence, and preferential growth, of the crystal form which does not cause scaling, or at least not to such an extent as calcite [11]. Otsuka and Ozeki examined some properties and functions of water treated under magnetic field. No change in properties of pure water distilled from ultrapure water in vacuum was observed. However, when the same magnetic treatment was carried out after the distilled water was exposed to O\textsubscript{2}, water properties such as vibration modes and electrolytic potential were changed. They conclude that the usage of magnetic treated water in industrial and agricultural processing could improve the properties in the foods, cosmetics and sanitation, etc. [12]. Mosin and Ignatov demonstrated that the effect of the magnetic field on water is a complex multifactorial phenomenon resulted in changes of the structure of hydrated ions as well as the physico-chemical properties and behavior of dissolved inorganic salts, changes in the rate of electrochemical coagulation and aggregate stability (clumping and consolidation), formation of multiple nucleation sites on the particles of fine dispersed precipitate consisting of crystals of substantially uniform size [13].
Y. Podcernjaev and V. Filipov explain this result by reducing the hydration of the ions found on the surface of the fibers. Y. Podcernjaev and N.Z. Banelle apply magnetic treatment in a water purification system both in laboratory and paper mill. The results show that the rate of separation of the particles from the water at a voltage in the 100 kA/m field and a flow velocity of 0.6 m/s is increased 2 times. The cleaning performance increases with 30% [16].

In pulp and paper industry, magnetic fluid processing is suitable for optimizing different technological processes. The possible effects and areas of application are: Improving mass exchange - for example when precipitating, filtering, refining, fillers and dyes retention, etc.; Improvement of heat exchange processes - for example, drying, evaporation and some positive side effects as energy savings from reduced hydrodynamic resistance in fluid transport, inhibition of corrosion of metal parts and surfaces and improving the water clarity. The efficiency of magnetic processing depends on the MF strength and gradient, the linear flow rate, the liquid phase composition, and the magnetic flux utilization ratio.

As a result of the survey, scientific publications over the last ten years, in the field of paper production, were not detected.

The purpose of the present study was to investigate the effect of constant magnetic field over the refining process of soft and hardwood pulp suspensions, evaluation of its white waters and paper samples strength properties.

In accordance with worldwide trend for using less chemical additives in the papemaking process, especially those used in the paper slurry, at the expense of increased consumption of surface finishing, the current study can be used as an example for sustainable expediency.

**EXPERIMENTAL**

**Materials**

The softwood pulp was delivered by SCA, Sweden and is bleached sulphate kraft cellulose from pine and spruce trees. The properties include: breaking length of 3300 m, (ISO 1924/2), Tensile index of 26 N.m/g, (ISO 1924-2), Burst index of 1.5 kPa m²/g, (ISO 2758), Tear index of 18.8 mN.m²/g, (ISO 1974) and 87 % brightness (ISO 3088).

The hardwood pulp was delivered by Svilosa AD, Bulgaria and is bleached hardwood kraft pulp from acacia trees. The kraft pulp is placed on the market under the registered trade mark SVILOCELL®. The properties include: breaking length of 1800 m, (ISO 1924/2), Tensile index of 17 N m/g (ISO 1924-2), Burst index of 0.70 kPa m²/g (ISO 2758), Tear index of 2.1 mN.m²/g (ISO 1974) and 88 % brightness (ISO 3088).

**Methods**

In our experiment were used two types of kraft pulp - softwood and hardwood, which were refined by laboratory Jokro mill method with six refining units, (ISO 5264-3:21979). The refining concentration in each unit was 6 % (16 g o.d.f in 267 ml water). Two pulp suspension were prepared - with 100 % of softwood (pine and spruce) and 100 % of hardwood (acacia) and were refined separately. The refining degree was determined by the Schopper Riegler Value ºSR, (ISO 5267-1/AC: 2004). The dewatering time was determined by Shopper Riegler apparatus (Germany). The measuring conditions are the same as for determination of beating degree in Shopper Riegler, according ISO 5267-1/AC: 2004, but the central vertical out-pipe is closed. The concentration is 0.2 % (2 g o.d.f in 1000 ml water). The apparatus provides the possibility of measuring the dewatering ratio of different pulp and paper suspensions by measuring the time (in seconds) for obtaining from 200, 300, 400… to 700 ml filtrate. In the current experiments the dewatering time was measured for 700 ml filtrate. Four parallel samples were made for each pulp suspension without and with magnetic treatment.

The magnetic treatment of pulp suspensions was performed by using magnetic stator device, (Fig.1) which is...
a stator of permanent ferromagnets branded MagStator [17] and its field intensity is 0.1 T. Aqueous stream (the paper furnish) was passed vertically downwards through the pole gap space with linear speed 0.6 - 0.8 m s⁻¹ at quintuple and octuple crossing of the fluid.

The papermaking process was simulated by using laboratory paper-sheet machine. All samples were prepared on paper laboratory machine (Rapid-Kothen, Germany) according to ISO 5269-2:2005, with a grammage of 70 g/m², with drying conditions of 96°C and duration of 7 minutes. Of each pulp type were produced sheet samples without and with quintuple and octuple magnetic treatment.

Grammage was determined in accordance with the ISO 536 standard, 10 samples of each paper were cut into size 10 x 10 cm and weighed. Strength properties - tensile index, burst index and tear index were analysed in the standard atmosphere at 23°C of temperature and 50 % of relative humidity. Tensile index, N/m²/g of papers were determined on a tensile testing machine Zwick/ Roell, according to ISO 1924-2:1985. Ten probes for each sample was tested. Burst index, kPa m²/g was determined according to the standard method ISO 2759:2014. For each paper, ten samples were tested. Tear index, mNm²/g was determined according to the standard ISO 1974:2012, where two samples of each paper were tested with the Elmendorf method.

RESULTS AND DISCUSSION
Investigation of the influence of magnetic treatment on the coniferous and deciduous cellulose refining kinetics

The change in the refining degree of the two types of pulp over time is shown in Fig. 2. The expected result for faster beating process of the hardwood pulp was justified. Obtaining of 30 °SR refining degree without magnetic treatment for acacia pulp was achieved for about 9 minutes while for the pine pulp was for about 23 minutes. The course of the curves is similar to other studied coniferous and deciduous cellulosic species but for the used acacia pulp the course is more steepen. This seems likely due to the specific characteristics of this type of cellulose - a lower alpha cellulose content, a higher hemicellulose content, and weaker strength.

As a principle, the process of pulp refining of coniferous cellulose is always more susceptible and more energy intensive than that of deciduous cellulosic types.

Coniferous species are longer fibrous and homogeneous in morphological composition, with higher levels of lignin content and fewer hemicelluloses, which is a prerequisite for difficult and slow refining. Fig. 3 shows the variation of the degree of refining for softwood cellulose without and in the presence of magnetic treatment. The course of all three curves is similar and is typical of the refining process of coniferous cellulose.

Refining of the coniferous cellulose from pine wood (Fig. 3) after the magnetic treatment was improved and beating degree of 30 °SR was gained with about 4 min faster when the cellulose suspension passes the magnetic field eight times. As early as the tenth minute of refining process, the beating degree increased by 5 units. Beneficial effect of the magnetic treatment over
the beating degree of the softwood pulp was observed during the 10th to 20th minute of the refining process and at octuple passage the beating degree was improved with 6 °SR compared to non-magnetic treatment.

The effect of the quintuple magnetic treatment of the pine cellulose suspension over the refining process was sufficient. The total time for pulping of the cellulose was shortened by 3 minutes. The course of the curve is closer to that of cellulose without magnetic treatment. This indicates that the quintuple magnetic treatment does not cause significant changes in the character and behaviour of the medium and the pulp itself but supports the processes of hydration and fibrillation of the cellulose fibres. Probably it is due to the better alignment and pre-orientation of the water dipoles and of the metal cations contained in the slurry. Hydration of the cellulosic fibers is likely to occur only after the initial moment of refining, namely after 5 - 10 minutes of the refining.

Twice as low as coniferous cellulose was the refining time to achieve 30 °SR beating degree of the hardwood cellulose (Fig. 4). Higher effect of the magnetic treatment was observed at quintuple passage of the slurry through the magnetic field. The course of the curves for the three investigated pulp suspensions is similar. Obviously, the octuple passage of the cellulose suspension from acacia wood through the magnetic field is inappropriate. This is probably due to the characteristics of the acacia wood and to the fact that each type of pulp has a different magnetic receptivity. The time to reach beating degree of 30 °SR in both cellulosics was shortened by about 4 min. The overall refining time of the acacia pulp was 7 minutes and for the pine pulp 22 minutes.

**Investigation of the effect of magnetic treatment on the drainage ability of cellulosic suspensions**

Fig. 5 shows the drainage ability of cellulosic suspensions. Magnetic treated cellulose slurry was drained more rapidly. Even with quintuple magnetic treatment, the dewatering time of 700 ml from the apparatus decreased with about 5 s for acacia cellulose and 3 s for pine. The overall effect on this indicator was better for softwood cellulose than for hardwood. This effect is probably due to the higher purity of the pine cellulose system and its greater magnetic susceptibility. Longer fibres are arranged evenly and form a mesh on the apparatus sieve with larger passages for water passage. In addition, deciduous cellulose contains more hemicelluloses that lower drainage capacity. The presence of fine short fibres causes a dense and closed cellulose suspension structure on the screen of the apparatus, which also reduces the drainage capacity.

Fig. 6 shows the drainage ability of cellulosic suspensions of varying concentrations with quintuple magnetic treatment. It is seen from the figure that the effect of increasing the concentration of the suspensions to be magnetized is not the same for the investigated pulps. For the pine cellulose, increasing the concentration did not conducive to better drainage and drainage ability is correspondent to the increased concentration.
At acacia cellulose, maximum drainage was observed at 4% concentration but at 6% the drainage was significantly improved and even better than at 2% concentration. These results could be explained by the type and morphology of individual cellulosics. Long fibre pulp is drained and the increased concentration makes the system worse structured, and magnetic processing is not able to influence enough for re-ordering. On the other hand, it makes the long fibres more flexible and elastic, and drainage becomes more difficult. In the present experiment deciduous cellulose was from acacia wood, and it has a high content of short fibres and increasing the concentration had a positive effect in the presence of magnetic treatment. Obviously, for better drainage it is necessary to magnetise the fibres closer together to achieve a uniformly arranged and recharged of the system.

**Investigation of the influence of magnetic treatment on the strength properties of paper samples**

Fig. 7, Fig. 8 and Fig. 9 represent the strength results of the laboratory obtained paper sheets from the examined acacia and pine cellulosics.

In the current experiment for the both types of cellulose even at quintuple magnetic treatment the tensile index increased but the effect for the coniferous pine cellulose was more pronounced - 6 N/m (Fig. 7). Obviously, improving the structure of the paper sheet, fibre straightening and reordering as a result of the magnetic treatment is the main reason for the improvement of this parameter. On the other hand, the magnetic processing is the reason for magnetizing the individual components of the cellulose suspension. As the fibres are shorter, their magnetic susceptibility is smaller, and the different substances have different ability to keep this magnitude over time. Therefore, for the acacia pulp the effect is smaller. For both pulps, the octaple magnetic treatment did not cause a subsequent increase in the tensile index, but the index remained higher than the one without magnetic treatment.

Burst (Fig. 8) and tear (Fig. 9) index of paper depend primarily on the strength of the fibres themselves and less on the inter-fibre bonding forces. For both types of
cellulose, the quintuple magnetic treatment was sufficient to achieve a positive effect. The octuple magnetic processing was superfluous.

Magnetic treatment increases the fibre elasticity and in the refining process they become better fibrillated, which is the reason for the increase in fibre bonding forces. In general, magnetic treatment primarily affects the ability to form more fibre bonding than on the strength of the fibres themselves. But the increased flexibility and elasticity compensates for this effect. For this reason, magnetic treatment had a greater effect on coniferous cellulose than on deciduous. For the magnetic treatment of the various cellulosic suspensions, their chemical homogeneity and purity are important. As the system is cleaner and more homogeneous, it is more magneto-responsive and after the end of the magnetic treatment magnetization lasts longer.

CONCLUSIONS

From the research carried out it was found out that:

Magnetic treatment of cellulosic suspensions of pine and acacia cellulose before refining is appropriate and causes acceleration of refining time to achieve a beating degree of 30 °SR with 4 minutes for the pine cellulose and 3 minutes for the acacia cellulose.

Magnetic treatment of softwood cellulose effects the accelerated refining process at octuple passage of the suspension through the magnetic field and occurs the refining time is 22 min.

For hardwood cellulose the octuple passage of the suspension is inexpedient as the desired degree of refining is achieved by quintuple passage of the suspension for 7 minutes.

Magnetic treatment of cellulosic suspensions prior to refining improves the structure of the paper sheet, causes fibres’ rearrangement, resulting in enhanced strength of the obtained paper samples. For both pulp types quintuple passage though the magnetic treatment is sufficient of reaching optimum strength.

Magnetic treatment of cellulosic suspensions improves the dewatering time. Even at quintuple magnetic treatment, the dewatering time for 700 ml filtrate from the apparatus decreases with 5 s for hardwood cellulose and 3 s for softwood.

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