# APPLICATION OF COMPUTER IMAGE ANALYSIS FOR CHARACTERIZATION OF VARIOUS PAPERMAKING PULPS

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Laboratory-prepared bleached kraft pulps, made from wood of different tree species, and industrial neutral sulphite semichemical (NSSC), chemithermomechanical (CTMP) and groundwood pulps were studied by the computer image analysis method. The number of fibres in a mass unit of pulp, the relative content of fines and also the morphological fibre properties were determined. The obtained results were discussed and compared.

***Keywords***: computer image analysis, papermaking pulps, pulp properties, fibre properties

## INTRODUCTION

Nowadays, some of the most important issues in papermaking include the improvement of paper properties and lowering of production costs. As reported in the literature, one of the possibilities to reach this aim is the selection of furnish for a specific type of paper.[1] For example, to improve the bulk of graphic papers, it is necessary to use pulps with stiffer fibres, [2-4] whereas, to lower the cost of these papers, an adequate solution may be added to a certain amount of CTMP fibres. Thus, from the viewpoint of a papermaker, it is very important to have the possibility of predicting the final product properties on the basis of the properties of the semimanufactured product used. As shown in the literature, a factor that facilitates this process is knowledge on the fractional composition of fibrous pulps, fibre dimensions, as well as their shape and damage degree – to mention just a few.[5-11]

For decades, the determination of such properties caused several difficulties, because it was labour- and time-consuming.[10,11] Nowadays, the development of methods based on the computer image analysis of the fibrous slurry permits a precise and quick analysis.[12-15] There are at least a few devices available operating on the basis of this technology.[16] One of them is MorFi, the apparatus designed by Techpap, describing the fractional composition of pulps, dimensions of fibres and their degree of damage and thus permitting to determine the following indices:[17,18]

- content of fibres in the mass unit of pulp;
- relative content of fine elements (fibres, other cells and cell elements) with lengths below 0.2 mm, calculated on the basis of the area of this fraction in the picture of a fibrous slurry, recorded by a digital camera, and which can be considered as a meter of fines content in the pulp;
- dimensions of fibres (length, width);
- mass of a fibre length unit (coarseness);
- percentage content of the fibres that have kinks in the pulp;
- average degree of fibre curl, calculated by the equation:

$$curl = (1 - l / L) \times 100$$

where $l$ is the highest fibre dimension and $L$ is its developed length;
- percentage share of shortened fibres in the pulp, expressing the percentage share of the fibres whose ends have an atypical shape, indicating cutting (for example, with the knives of a chipper) or disruption during technological operations.

The present paper is devoted to the determination of the above-mentioned indices for bleached kraft, unbleached NSSC and CTMP pulps, as well as groundwood, for demonstrating their diversified furnish and fibre dimensions. Thus, the properties of fibrous semimanufactured products determine their suitability for papermaking purposes.

## EXPERIMENTAL

### Pulps

Two types of pulps commonly used in papermaking were employed.

The former type included kraft pulps obtained in our laboratory through pulping of birch wood (*Betula pendula*) – B, beech wood (*Fagus silvatica*) – Bc, hornbeam wood (*Carpinus betulus*) – H, poplar wood (*Topola robusta*) – Pl, oak wood (*Quercus*) – O, acacia wood (*Robinia pseudacacia*) – A, pine wood (*Pinus silvestris*) – P, and spruce wood (*Picea abies*) – S, by the kraft pulping method (19-23% of active alkali on wood, 90 min at 165 °C, water-to-wood ratio – 4), followed by oxygen delignification (2-3% of NaOH on o.d. pulp, 100 °C, 60 min, 0.6 MPa $O_2$, pulp consistency – 8%) and bleaching with chlorine dioxide (in stages $D_0$ and $D_1$: 2-3% $ClO_2$, 75 °C, 90 min, pulp consistency – 10%; and in stage E: 1.5% NaOH on o.d. pulp, 75 °C, 90 min, pulp consistency – 10 %).

The latter type of pulps was obtained from wood by neutral sulphite semichemical (NSSC-birch) and chemithermomechanical (CTMP-spruce and CTMP-poplar pulps) methods, or by the mechanical method only (groundwood spruce pulp). All pulps from this group were of industrial origin. NSSC, CTMP and groundwood pulps were obtained from Mondi Świecie S.A. (Poland), Pulp and Board Plant in Svetlogorsk (Russia) and Myszków (Poland), respectively. However, the authors are not familiar with the details of the methods used for the production of these pulps.

### Computer image analysis

The characteristics of the above-mentioned fibrous pulps were computer analyzed, in a MorFi apparatus. The method consists in the determination of pulp and fibre properties on the basis of images recorded by a high-resolution camera, during the flow of the pulp suspension against its lens.[18]

### Classical determination of fines

10 g of oven-dried pulp in 2 $dm^3$ water was disintegrated in a laboratory disintegrator for 3 min, then transferred to a laboratory distributor and diluted with water up to a total volume of 5 $dm^3$. Further on, the suspension was poured into a Büchner funnel with a wire net bottom with 75 x 75 μm openings. Then, the fraction of fibres was collected and diluted with water, again up to a total volume of 5 $dm^3$, and again filtered through the metal net. The procedure was repeated for each pulp until the water passing through the metal net was clear. For the pulps designated as B, Bc, H, Pl, O, A, P, S, NSSC-birch, CTMP-spruce, CTMP-poplar and groundwood spruce, there were carried out 5, 5, 5, 5, 6, 4, 4, 7, 7, 8, 8 and 10 such cycles, respectively. After the last cycle, the fraction of fibres was collected from the wire net of the Büchner funnel and was dried and weighed. Further on, the amount of fines was calculated from the difference between the mass of the dry pulp sample subjected to analysis and the mass of the fibre fraction collected from the metal net at the end of the analysis.

## RESULTS AND DISCUSSION

The first group of pulps, which was analyzed in the MorFi apparatus, included bleached kraft pulps obtained from wood of various tree species. The results of the assessment of pulp and fibre properties are compiled in Table 1. In addition, the fines contents in the pulps (expressed in wt%) were determined by the above-mentioned classical method.

The fundamental function of the devices operating by computer image analysis of the fibre suspension is to evaluate fibre dimensions, such as average length and width. As shown in Table 1, the fibres of softwood pulps have the highest length of all bleached wood kraft pulps (pine – 2.34 mm and spruce – 2.10 mm). It is worth noting that these values are lower than those reported several years ago[10,19] as average values for the wood of these species, which may result from the changes in fibre length produced during pulp production, and also from the fact that pulps are now produced from the wood of younger and younger trees.

Compared to softwood fibres, the average length of hardwood fibres is two to three times lower (0.73-1.09 mm). Hornbeam pulp has the longest fibres of all these pulps (almost 1.1 mm), beech, oak, birch and poplar pulps have shorter fibres (0.85-0.95 mm), while acacia pulp has the shortest ones (0.73 mm). These results agree with the data available in literature. For example, Paavilainen[2] reported fibre lengths of birch and acacia pulps of 0.9 and 0.7 mm, respectively, while the lengths reported by Mohlin and Hornatowska were of 0.85 and 0.65 mm, respectively.[20,21]

It should be observed that the differences between the values obtained by different authors may be caused not only by the origin of the raw material, but also by the type of analyser used by individual authors, as reported by Turnen *et al.*,[16] as well as by the degree to which the raw material is processed.

Computer image analysis of fibre suspension also permits the evaluation of fibre length distribution (Fig. 1).

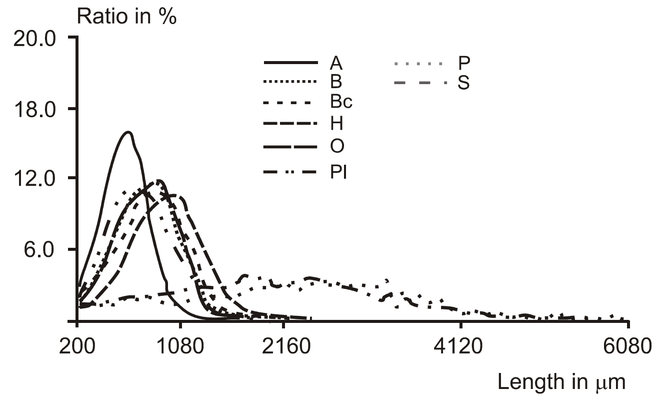


Figure 1: Fibre length distribution of acacia (A), birch (B), beech (Bc), hornbeam (H), oak (O), poplar (Pl), pine (P) and spruce (S) pulps

Table 1
Properties of bleached kraft pulps and of their fibres, determined by the MorFi apparatus and conventionally determined contents of fines

| Pulp / Index, unit | B | Bc | H | Pl | O | A | P | S |
|---|---|---|---|---|---|---|---|---|
| Length-weighed fibre length, mm | 0.92 | 0.95 | 1.09 | 0.85 | 0.90 | 0.73 | 2.34 | 2.10 |
| Width, μm | 21.3 | 22.3 | 22.6 | 21.1 | 21.0 | 17.2 | 30.9 | 28.7 |
| Coarseness, mg/m | 0.117 | 0.138 | 0.127 | 0.105 | 0.140 | 0.076 | 0.192 | 0.178 |
| Number of fibres, $\times 10^6$/g of pulp | 11.07 | 9.15 | 9.09 | 13.60 | 9.50 | 20.17 | 3.84 | 4.29 |
| Fine elements, % | 6.3 | 11.5 | 8.4 | 6.8 | 8.1 | 9.5 | 4.3 | 3.8 |
| *Fines, wt%*[1)] | *2.7* | *8.5* | *6.5* | *3.4* | *5.4* | *8.7* | *2.2* | *1.7* |
| Kinked fibres, % | 53.4 | 32.3 | 29.2 | 53.9 | 67.9 | 48.6 | 56.5 | 64.0 |
| Curl, % | 11.0 | 8.4 | 8.1 | 11.6 | 15.8 | 11.4 | 15.3 | 14.9 |
| Broken ends, % | 18.7 | 25.4 | 20.4 | 22.6 | 27.1 | 15.0 | 31.4 | 31.9 |

[1)] determined by the classical method

As shown in Figure 1, the fibre length distributions of the pulps produced from different wood species are characterised by two main features. First, the fibre length distributions of softwood pulps have highly different fibre lengths, compared to those of hardwood pulps. Secondly, the lower the average fibre length, the sharper is the fibre length distribution curve.

Besides fibre length, an important fibre dimension is width. Fibre width and lumen width affect the susceptibility of the fibres to transverse deformation. As shown in Table 1, softwood fibres have the highest average fibre width (29-31 μm), whereas hardwood fibres record considerably lower values (17.2-22.6 μm). From the latter, beech and hornbeam fibres have somewhat higher width (22.3 and 22.6 μm, respectively). The width of birch, poplar and oak fibres is similar, ranging between 21.0 and 21.3 μm, while acacia fibres have the lowest width (17.2 μm).

A special fibre feature, which determines the number of fibres in paper with a specific basis weight, and also the ability of fibres to form fibre-to-fibre bonds, is the mass of the length unit of statistical fibre, namely coarseness. The value of this index is influenced by two fibre properties: fibre width and fibre wall thickness.

As evidenced in Table 1, pine and spruce pulps have the highest value of this index among all bleached kraft pulps (0.192 mg/m and 0.178 mg/m, respectively). Of all hardwood pulps, the oak and beech ones have the highest values of coarseness (0.140 and 0.138 mg/m, respectively). The value of coarseness of hornbeam, birch and poplar pulp fibres is lower, *i.e.* 0.127 mg/m, 0.117 and 0.105 mg/m, respectively, and the lowest in the case of acacia pulp fibres (0.076 mg/m). Similarly with fibre length, it can be stated that the results on the coarseness of the fibres of selected pulps are generally compatible with those obtained by the authors who used optical analysers,[2,20] as well as by those who determined coarseness using the classical method.[10,22]

The discussed fibre properties affect another important feature of the pulps, namely the number of fibres in a mass unit of pulp – an important index affecting the optical properties. According to Table 1, acacia pulp has the highest number of fibres per 1 gram of all hardwood pulps ($20.17 \times 10^6$). The number is lower for poplar and birch pulps (13.6 and $11.07 \times 10^6$, respectively), and the lowest for beech, hornbeam and oak pulps ($9.09$-$9.50 \times 10^6$). Softwood pine and spruce pulps contain a considerably lower number of fibres – the former only $3.84 \times 10^6$/g, and the latter – $4.29 \times 10^6$/g of pulp.

The second property of the pulps, determined by computer image analysis, was the relative content of fine elements (particles shorter than 0.2 mm), expressed as percentage of the area of all elements recorded during measurements. This index can be considered as the meter of fines content in pulps. As shown in Table 1, beech and acacia pulps have the highest amount of fine elements measured in this way (11.5 and 9.5%, respectively), hornbeam and oak pulps have a lower content of such elements (8.4 and 8.1%, respectively), birch and poplar pulps – even lower (6.3 and 6.8%, respectively), whereas pine and spruce pulps – the lowest (4.3 and 3.8%, respectively).

As already mentioned, apart from the evaluation of the fines content performed by the computer image analysis method, Table 1 also presents results on the assessment of the fines contents obtained by the classical method, expressed in wt%. As these data show, these values were lower than those obtained using computer image analysis method (expressed as % in area). However, it should be noted that both methods reflect in the same way the differences in fines contents among pulps.

Apart from fibre dimensions, the degree of fibre damage can be also determined by computer image analysis, by the calculation of kinked fibres, curl and broken ends indices.

As shown in Table 1, the highest degree of fibre deformation was determined for pine and spruce pulps, being lower for birch, poplar, acacia and oak pulps, while the lowest value was recorded for beech and hornbeam pulps. Thus, it seems that both higher fibre length and lower coarseness favour fibre deformations. An exception is oak pulp, whose fibres, although characterized by higher coarseness, show large changes in shape, *i.e.* high values of kinked fibres and curl indices. Possibly, the reason is the high number of large diameter pits in the oak fibre walls, distinctly visible in the microscopic image of oak fibres, compared to the fibres of other pulps.

The same properties as those discussed for kraft pulp fibres were also determined for unbleached NSSC-birch, CTMP-poplar and CTMP-spruce pulps, as well as for groundwood. The results are presented in Table 2.

As for the average fibre length of these pulps, the data presented in Table 2 show that, in the case of NSSC-birch and CTMP-poplar pulps, it is close to that of bleached kraft birch and poplar pulps. In comparison with spruce kraft pulp, the length of CTMP-spruce pulp fibres was significantly lower (1.31 mm), which indicates greater susceptibility of the long fibres to shortening, *versus* that of short fibres, *i.e.* for CTMP-poplar pulp. The data presented in Table 2 also show that, in comparison with the other pulps, groundwood is characterized by definitely the lowest average fibre length (0.61 mm).

Fibre length distributions of NSSC, CTMP and groundwood are plotted in Figure 2. It shows that NSSC-birch and CTMP-poplar pulps are characterized by the closest fibre length distribution value to that of birch pulp. However, in comparison with birch pulp, they contain a distinctly lower number of longer fibres and a higher number of shortened fibres/fibre elements (0.2-0.4 mm).

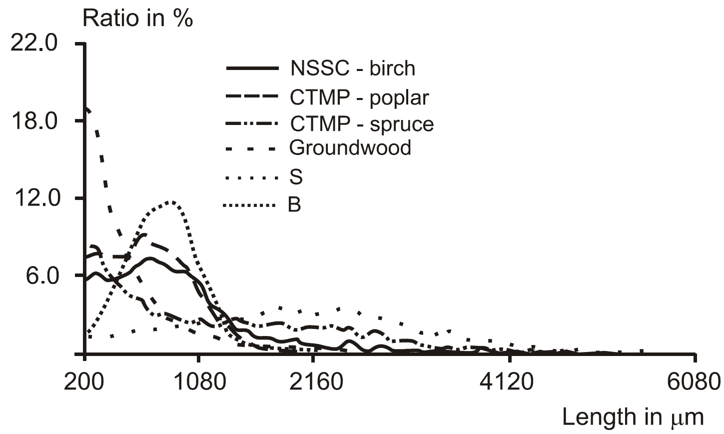


Figure 2: Fibre length distribution of NSSC, CTMP pulps and groundwood against fibre length distribution of birch and spruce bleached kraft pulps

Table 2
Properties of NSSC, CTMP pulps and groundwood and of their fibres, determined by the computer image analysis method, and the contents of fines determined by the classical method

| Type of pulp / Index, unit | NSSC-birch | CTMP-spruce | CTMP-poplar | Groundwood spruce |
|---|---|---|---|---|
| Length-weighed fibre length, mm | 1.04 | 1.31 | 0.81 | 0.61 |
| Width, μm | 33.3 | 33.3 | 29.8 | 31.7 |
| Coarseness, mg/m | 0.318 | 0.264 | 0.217 | 0.212 |
| Number of fibres, $\times 10^6$/g | 4.39 | 4.99 | 7.38 | 9.75 |
| Fine elements, % | 13.7 | 13.1 | 19.2 | 21.7 |
| *Fines*, *wt%*[1)] | *11.2* | *14.9* | *16.2* | *25.2* |
| Kinked fibres, % | 20.3 | 20.1 | 18.5 | 18.2 |
| Curl, % | 7.3 | 8.1 | 6.6 | 8.6 |
| Broken ends, % | 42.1 | 42.7 | 37.1 | 46.4 |

[1)] determined by the classical method

CTMP-spruce pulp and groundwood, both made of spruce wood, have different fibre length distribution. As shown in Figure 2, the CTMP pulp shows the most favourable distribution of these two pulps (closer to softwood kraft pulps) although, in this pulp, one may also observe a lower content of longer fibres and a higher number of short fibres/elements (0.2-0.4 mm) than in spruce kraft pulp. Groundwood has the most unfavourable fibre length distribution, in which very short (0.2-0.5 mm) and short (0.5-1.0 mm) fibres or fibre elements dominate.

In comparison with kraft pulps, the values of mean width of NSSC, CTMP and groundwood pulps are higher. For example, compared to birch and poplar pulps, there is a difference of more than 50%. A tendency similar to that observed for CTMP pulp was also reported by Karlsson *et al.*[15] The coarseness values of the NSSC, CTMP and groundwood pulps are also higher than those of kraft pulps (0.212-0.318 mg/m). The high coarseness values of the NSSC and CTMP pulps made of hardwood influenced the number of fibres in the mass unit of these pulps, which amounted to 4.39 and 7.38 × $10^6$, respectively. Therefore, it was approximately twice lower than that of birch and poplar kraft pulps.

While, in the case of CTMP-spruce pulp, the number of fibres was close to that of spruce kraft pulp, in the case of groundwood it was considerably higher, which proves that a considerably higher number of fibres are broken during groundwood production.

In comparison with kraft pulps, NSSC, CTMP and groundwood pulps have higher contents of fine elements. As shown in Table 2, in the case of NSSC-birch, CTMP-spruce, CTMP-poplar and groundwood pulps, the contents of these elements were approximately 2, 3, 3 and 6 times higher than those of the corresponding kraft pulps (Table 1).

As in the case of kraft pulps, the contents of fines in NSSC and CTMP pulps, as well as in groundwood, were also determined by the classical method (Table 2). The values thus determined differ from the values obtained by the computer analysis method with about 1.8-3.5%. However, it is difficult to say why these classically determined contents of fines were higher than those determined with a MorFi apparatus, in the case of groundwood and CTMP-spruce pulp, and lower in the case of NSSC-birch and CTMP-poplar, *i.e.*, as in the case of kraft pulps. Apart from this, one can state that the general tendency in the fines content, determined by both old and modern methods, is the same, *i.e.* the highest content of fines was noticed in groundwood, being lower in CTMP poplar pulp and the lowest in CTMP-spruce and NSSC-birch pulps.

The analysis of the indices describing the shape of fibres shows that, in the case of NSSC, CTMP and groundwood pulps, there were obtained lower values of kinked fibres and curl indices than those of the corresponding kraft pulps. The fibres of kraft pulps, nearly void of lignin, are thus more susceptible to deformation than the NSSC, CTMP and groudwood pulp fibres. However, in comparison with kraft pulps, the broken ends index of NSSC, CTMP and groundwood pulps was higher.

## CONCLUSIONS

The evaluation of different papermaking wood pulps, carried out by computer image analysis, showed many differences in fibre dimensions, which can have a substantial effect on the properties of the products made from these fibres. For instance, fibre length ranged from 0.6 mm for groundwood to 2.4 mm for pine pulp. Substantial differences were observed in the remaining fibre properties, such as fibre width and coarseness.

Fibre length distribution of bleached kraft pulps shows that the sharper is the curve of distribution, the lower the value of the average fibre length of a given pulp. Out of the wood pulps made by neutral sulphite semichemical, chemithermomechanical or mechanical treatment, the fibre length distribution of NSSC-birch and CTMP-poplar pulps, as well as that of CTMP-spruce pulp, was the most similar to the fibre length distribution of the corresponding kraft pulps, while the fibre length distribution of groundwood pulp was the least similar.

An important attribute of the fractional composition of NSSC and CTMP pulps, and especially of that of groundwood, is an increased amount of the 0.2-0.4 mm fibre fraction. The number of fibres in the mass unit of pulp was the highest in the case of acacia pulp ($20.17 \times 10^6$), considerably lower for poplar and birch pulps ($13.60 \times 10^6$ and $11.07 \times 10^6$, respectively) and the lowest in the case of beech, hornbeam and oak pulps ($9.09\text{-}9.50 \times 10^6$). The number of fibres in the mass unit of NSSC and CTMP pulps ranged from 4.39 to $7.38 \times 10^6$, being therefore higher than in softwood pulps and lower than in hardwood pulps.

The highest relative content of fine elements in pulp, known as having a negative effect on dewatering and pressing, was observed in the case of groundwood (21.7% of the area of fibres/elements), followed by CTMP-poplar pulp (19.2%), NSSC-birch and CTMP-spruce pulps (13-14%) and beech pulp (11.5%) while, for other kraft pulps, it was below 10% – especially low for softwood pulps (3.8-4.3%). The values of fine elements contents for various papermaking pulps obtained by computer image analysis were generally higher than those determined by the classical method. Nevertheless, both methods reflected in the same way the differences in fines contents between pulps.

The determination of the indices describing the pulps with regard to their content of kinked fibres and curl showed that the higher fibre length and the lower fibre coarseness are the higher values these indices assume. The highest values of these indices were recorded for fibres of pine and spruce kraft pulps, followed by poplar, birch and acacia pulps, whereas the lowest ones were recorded for fibres of beech and hornbeam pulps. The indices discussed for NSSC, CTMP and groundwood were lower than those of kraft pulps, which indicates that the pulp fibres obtained by the chemimechanical and mechanical treatment of the wood maintain their shape better than the fibres made of kraft pulps. The broken ends index was the highest in the case of NSSC and CTMP pulps, and groundwood, and the lowest in the case of chemical pulps composed of short fibres (*e.g.* acacia pulp).

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**REFERENCES**

[1] U.-B. Mohlin, *Procs. 6th International Conference on New Available Technologies*, Stockholm, Sweden, June 1-4, 1999, p. 343.
[2] L. Paavilainen, *Pap. Puu*, **82**, 156 (2000).
[3] D. Danielewicz and B. Surma-Ślusarska, *Cellulose Chem. Technol.*, **41**, 149 (2007)
[4] D. Danielewicz and B. Surma-Ślusarska, *Fibres Text. East. Eur.*, **12**, 73 (2004).
[5] R. A. Horn, www.fpl.fs.fed.us/documnts /fplrp/fplrp312.pdf.
[6] B. D. Jordan and N. G. Nguyen, *Pap. Puu*, **78**, 313 (1986).
[7] A. Heikkurinen, J.-E. Levin and H. Paulapuro, *Pap. Puu*, **73**, 411 (1991).
[8] E. Retulainen, *Pap. Puu*, **78**, 187 (1996).
[9] E. Retulainen, *Pap. Puu*, **78**, 305 (1996).
[10] B. Surma-Ślusarska and W. Surewicz, *Cellulose Chem. Technol.*, **15**, 77 (1981).
[11] B. Surma-Ślusarska, *Procs. VIIIth International Symposium on Wood Technology*, Polish Academy of Sciences, Warsaw, October 8-12, 1990.
[12] J. A. Olson, A. G. Robertson, T. D. Finnigan and R. R. H. Turner, *J. Pulp Pap. Sci.*, **21**, 367 (1995).
[13] R. J. Trepanier, *Tappi J.*, **81**, 152 (1998).
[14] G. Robertson, J. Olson, P. Allen, B. Chan and R. Seth, *Tappi J.*, **82**, 93 (1999).
[15] H. Karlsson, P.-I. Fransson and U.-B. Mohlin, *Procs. 6th International Conference on New Available Technologies*, Stockholm, Sweden, June 1-4, 1999, p. 367.
[16] M. Turnen, C. Le Ny, T. Tienvieri and J. Niinimäki, *Appita J.*, **58**, 28 (2005)
[17] G. E. P. Tourtollet and A. Cochaux, *Procs. XIVth International Papermaking Conference PROGRESS'02*, Gdańsk, September 24-27, 2002, p. II-7-1.
[18] Owner's Manual of MorFi LB01, Techpap.
[19] F. Potůček and J. Miklik, *Chem. Pap.*, **64**, 147 (2010).
[20] U.-B. Mohlin, *Nordic Pulp Pap. Res. J.*, **16**, 235 (2001).
[21] U.-B. Mohlin, J. Hornatowska, *Appita J.*, **59**, 225 (2006).
[22] L. Paavilainen, *Pap. Puu*, **75**, 343 (1993).