Influence of pulp refining on tissue paper properties

JURAJ GIGAC AND MÁRIA FIŠEROVÁ

ABSTRACT: We investigated the influence of refining conditions (refiner tackle type and specific edge load) on bulk softness, absorbency, tensile strength, and wet tensile strength of bleached pulp. Commercial elemental chlorine free (ECF) and totally chlorine free (TCF) bleached sulfite and kraft spruce, birch, and eucalypt pulps were used in this investigation. We found that refiner tackle type and specific edge load had a significant influence on the evaluated properties. Higher specific edge load when using a universal tackle increases softness and absorbency of hardwood kraft pulps. The highest tensile index of bleached hardwood kraft and spruce sulfite pulps was achieved by fibrillation refining at low specific edge load (under 0.70 J/m). The wet tensile strength index of the tested pulps beaten to 30°SR increased 3-4 times. Pulp refining increases wet tensile index and reduces water absorbency of paper. Hardwood kraft pulps are suitable for production of tissue paper with high softness and absorbency. Spruce sulfite pulps are suitable to achieve high bulk softness and low tissue paper absorbency. Birch kraft pulp is a good choice if a higher tensile strength is required in addition to softness and absorbency. To manufacture tissue papers with deep embossing, softwood kraft pulp is required because of its high strength properties.

Application: The results of this study can help tissue mills select pulp types and refining conditions best suited to the papers they produce.

Softness, absorbency, tensile strength, and wet tensile strength are important properties of tissue paper; the order of significance depends on end use. Selection of suitable pulp grades and proper pulp processing is required to achieve the softness of the product needed for the user's comfort and still maintain the necessary strength level required in converting operations. Softness, to a certain extent, is the result of subjective feelings. At present, objective methods for evaluation of softness are not available. Two types of softness can be distinguished: so-called bulk softness and surface softness. Bulk softness is the perception of softness obtained when the sample is crumpled between the hands. Surface softness is the perception of softness obtained when the fingertips are lightly brushed over the surface of the sample [1,2]. Surface softness is a complex function of surface contours and mechanical properties of tissue paper.

Surface softness is measured by scanning the sample surface for irregularities with a pressure sensitive transducer. The most applied method of perceptual surface softness evaluation is testing one or more series of products by a group of evaluators called panel testing. A paired comparison method also can be used to evaluate surface softness [3-7].

Because bulk softness correlates well with tensional stiffness, it is used for investigations of bulk softness. Tensional stiffness is a product of elasticity module (Young's module of elasticity) and thickness. Young's module of elasticity is a ratio of tensile force and elongation in the linear portion of the tensile curve obtained on a tensile tester. Flexural rigidity is also a function of elasticity module and thickness. For this reason it is also suitable to measure flexural rigidity when investigating bulk softness.

The ability to absorb liquids is a common requirement of all creped sanitary tissue products, such as towels, facial tissue, toilet tissue, paper diapers, or hospital bed pads. Several factors contribute to high tissue absorbency, including the type of pulp, wetting agents, and machine adjustments [8]. Tensile strength is important for high bulk in tissue paper converting.

Wet tensile strength is an important property of tissue products. The required wet strength level depends on the end use. Towels must generally have the highest wet strength to maintain integrity when used in liquid absorbency tasks. Toilet tissue is generally the tissue product of lowest wet strength because the product must disintegrate rapidly when entering the sewage system. Napkins and handkerchiefs are intermediate between towels and toilet tissue with regard to wet strength [8]. Third-generation polyamidamine-epichlorhydrin resins containing minimum monomers are used to increase the wet strength of tissue papers [9], but papers with increased wet strength are difficult to repulp [10,11]. Recycling of such paper is made easier by application of slot screens (0.2 mm) after the deflaker; 20% of screenings are returned to the deflaker [12,13].

The properties of tissue paper are influenced by input raw materials and manufacturing technology [12,14]. Thickness, elongation and crepe, tensile index, and stiffness of tissue paper are influenced by the creping doctor contact angle, the operation time and service life of the creping doctor, adhesions of the paper web on the Yankee cylinder, and properties of coating on the Yankee cylinder [15]. Calendering of tissue paper improves softness, but simultaneously reduces thickness.

The objective of this work was to investigate the influence of refiner tackle type and specific edge load in refining of commercial bleached pulps on bulk softness, absorbency, tensile strength, and wet tensile strength.

EXPERIMENTAL

Pulp samples

Commercial totally chlorine free (TCF) bleached birch kraft pulp, elemental chlorine free (ECF) bleached eucalypt kraft pulp, TCF bleached spruce kraft pulp, ECF bleached spruce kraft pulp, ECF bleached spruce sulfite pulp, and TCF bleached spruce sulfite pulp were used in these experiments.

Pulp pilot refining line

We used a steep cone Jylhä 0 refiner with universal and fibrillation tackle for refining. The universal refiner tackle has a shorter bar length per second of 13.5 km/s and a small bar angle of 14°. The fibrillation tackle has a high bar length per second of 20.4 km/s, a large bar angle of 52°, and narrower knifes and grooves on the rotor.

Pulp refining procedures

The commercial pulps were repulped at 4% consistency and refined in a steep cone refiner at 3.5% consistency. Softwood and hardwood pulps were refined with a universal tackle at a specific load of 0.67-2.40 J/m. The fibrillation tackle was used only for refining of hardwood pulp at a specific edge load of 0.54-1.91 J/m. Spruce sulfite pulps were refined with the same fibrillation tackle at a specific edge load of 0.54-1.37 J/m. The flow of pulp through the refiner was controlled by an ultrasound flow meter. Samples of refined pulp were collected in the range of 20°SR to 50°SR.

Testing methods

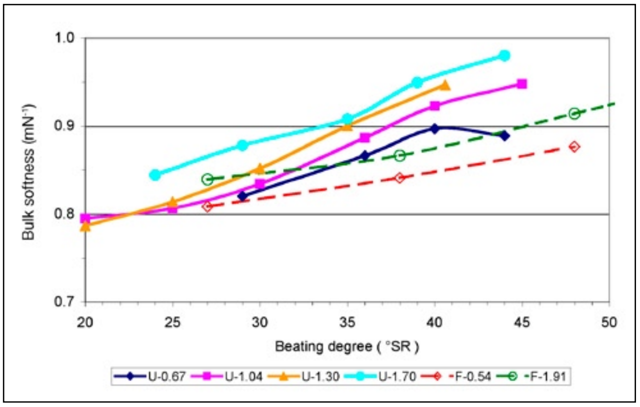
The following physical and mechanical properties of pulps and test sheets from pilot refined pulps were determined: beating degree, tensile index (according to ISO 1924), and absorbency (according to EN 12623-3). Bulk softness was measured as flexural rigidity; the lower the value of flexural rigidity, the higher the bulk softness. We determined flexural rigidity as bending resistance using TAPPI method T 556 pm-95, at 80 g/m^2 basis weight, 15° bending angle, and 10 mm distance between clamp and blade. Fiber strength was determined on a Pulmac Zero-Span 3000 tester according to ISO standard 15361.

RESULTS AND DISCUSSION

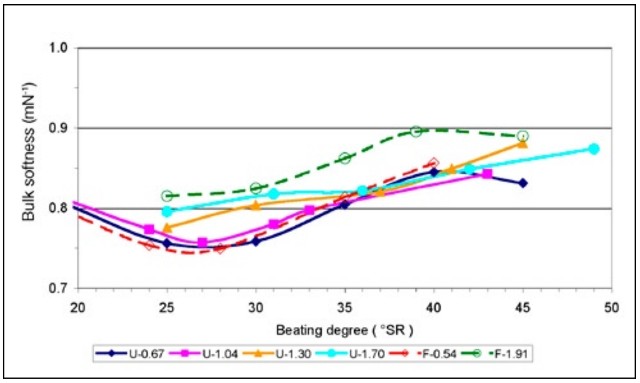
Bulk softness

Birch kraft pulp, which has long and thin fibers, had the highest bulk softness of all tested pulps. Bulk softness increases with refining (**Fig. 1**); the increase is more marked at higher specific edge loads. The same trend of bulk softness increase with increasing specific edge load was observed with both refiner tackles, although the increase with fibrillation tackle, even at high specific loading, was lower than with universal tackle.

Figure 2 shows the effects of beating degree on bulk softness of eucalypt kraft pulp. With increasing beating degree,



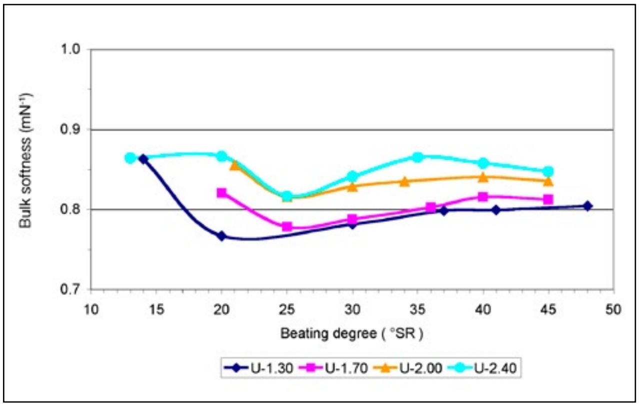
1. Influence of refiner tackle type and specific edge load on bulk softness of TCF bleached birch kraft pulp (refining conditions: universal refiner tackle [U] – specific edge load 0.67, 1.04, 1.30, and 1.70 J/m; fibrillation refiner tackle [F] – specific edge load 0.54 and 1.91 J/m).



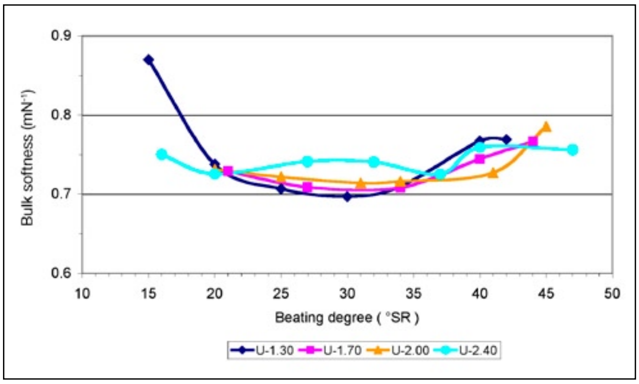
2. Influence of refiner tackle type and specific edge load on bulk softness of ECF bleached eucalypt kraft pulp (refining conditions: universal refiner tackle [U] – specific edge load 0.67, 1.04, 1.30, and 1.70 J/m; fibrillation refiner tackle [F] – specific edge load 0.54 and 1.91 J/m).

bulk softness decreases to 25°-27°SR, depending on the refiner tackle type and specific edge load, then slowly increases. For manufacturing tissue paper with maximal bulk softness, universal refiner tackle at higher specific edge load is suitable for refining birch kraft pulp. From a bulk softness standpoint, eucalypt kraft pulp is less suitable because it has lower bulk softness; and by refining, bulk softness even decreases to about 27°SR. This pulp should be refined at higher specific edge load to at least 35°SR. Best results (that is, highest bulk softness) were achieved at higher beating degree and by applying a high specific edge load.

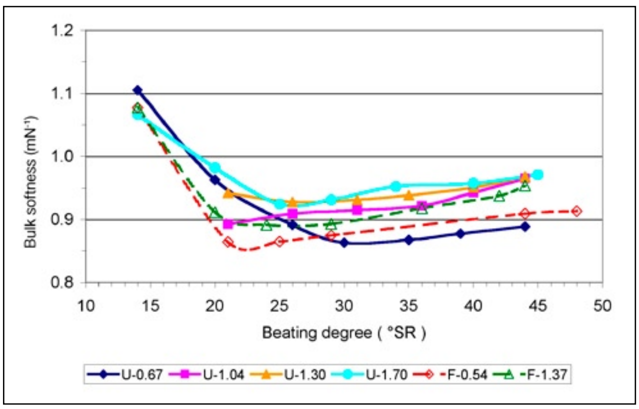
Figures 3 and **4** show the influence of beating degree and specific edge load on bulk softness of TFC and ECF bleached spruce kraft pulps. Bulk softness of TFC and ECF bleached spruce kraft pulps refined with a universal refiner tackle decreases steeply from 20°SR to 25°SR, depending on specific edge load, and then increases slowly. TCF bleached spruce kraft pulp is more sensitive to refining conditions. Increasing specific edge load significantly increases bulk softness of TCF pulp. Consequently, TCF bleached spruce kraft pulp has higher bulk softness than ECF pulp. For the application of both EFC and TCF bleached spruce kraft pulps in tissue paper furnishes, refining with a universal refiner tackle at



3. Influence of specific edge load of universal refiner tackle on bulk softness of TCF bleached spruce kraft pulp (refining conditions: universal refiner tackle [U] – specific edge load 1.30, 1.70, 2.00, and 2.40 J/m).



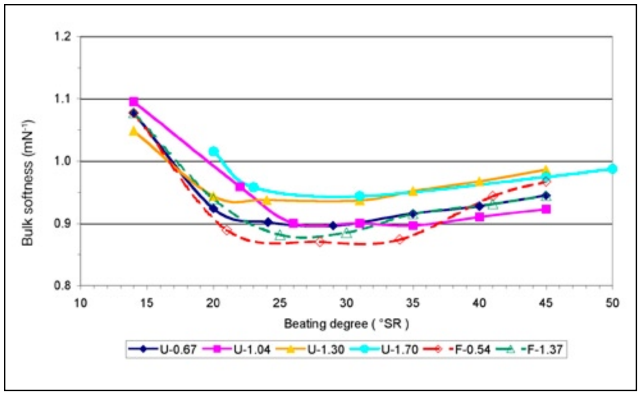
4. Influence of specific edge load on bulk softness of ECF bleached spruce kraft pulp in refining with a universal refiner tackle (refining conditions: universal refiner tackle [U] – specific edge load 1.30, 1.70, 2.00, and 2.40 J/m).



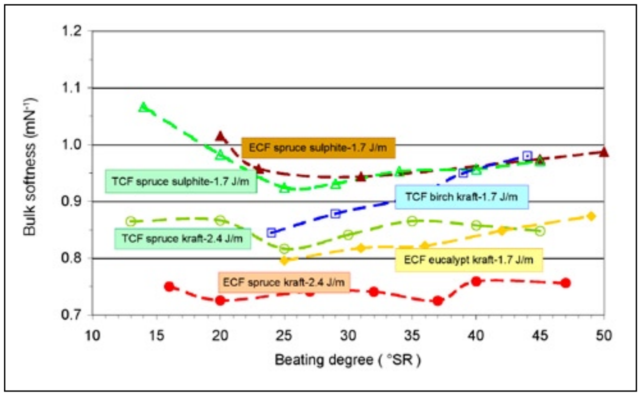
5. Influence of universal and fibrillation refiner tackle and specific edge load on bulk softness of TCF bleached spruce sulphite pulp (refining conditions: universal refiner tackle [U] – specific edge load 0.67, 1.04, 1.30, and 1.70 J/m; fibrillation refiner tackle [F] – specific edge load 0.54 and 1.37 J/m).

higher specific edge load up to 20°SR (max. 25°SR) can be recommended. In terms of bulk softness, TCF bleached spruce kraft pulp is more suitable. ECF bleached spruce kraft pulp is not suitable for high softness products.

Figures 5 and **6** show the influence of beating degree and specific edge load on bulk softness of TFC and ECF bleached spruce sulfite pulps. Bulk softness of both pulps is



6. Influence of universal and fibrillation refiner tackle and specific edge load on bulk softness of ECF bleached spruce sulphite (refining conditions: universal refiner tackle [U] – specific edge load 0.67, 1.04, 1.30, and 1.70 J/m; fibrillation refiner tackle [F] – specific edge load 0.54 and 1.37 J/m).

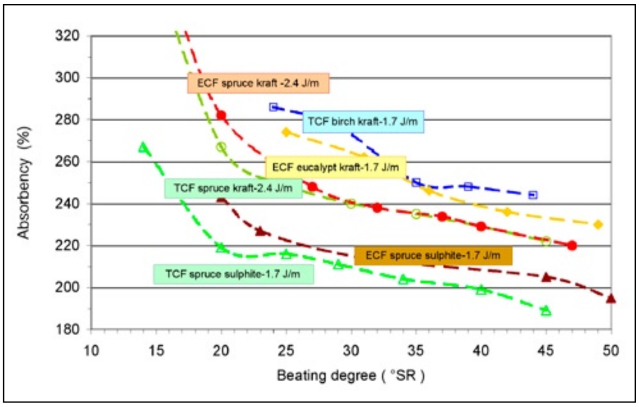


7. Influence of refining with universal refiner tackle on bulk softness of bleached kraft and sulfite pulps (refining conditions: hardwood kraft pulps and spruce sulfite pulps refined at specific edge load 1.7 J/m and spruce kraft pulps at 2.4 J/m; solid marks indicate ECF bleached pulps, hollow marks indicate TCF bleached pulps; circles indicate spruce kraft pulps, triangles indicate sulfite pulps; squares indicate birch pulp, and rhombuses indicate eucalypt pulp).

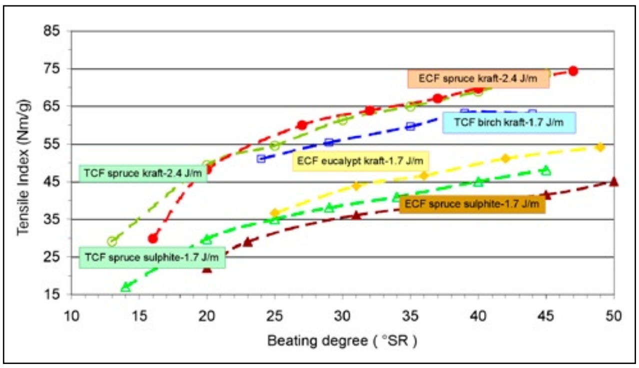
practically identical in the whole range of beating degrees. Best results with both sulfite spruce pulps are achieved by refining at a high specific edge load. The highest bulk softness was achieved with a universal refiner tackle at high specific edge load. The advantage of TCF and ECF bleached spruce sulfite pulps is high bulk softness, because sulfite fibers have higher flexibility than kraft fibers.

Figure 7 shows changes in bulk softness of bleached spruce sulfite pulps, bleached birch, eucalypt, and spruce kraft pulps refined with a universal refiner tackle. Specific edge load for the bleached spruce sulfite and kraft hardwood pulps was 1.7 J/m, and 2.4 J/m for bleached spruce kraft pulps. Bleached sulfite pulps have the highest bulk softness and, consequently, impart high bulk softness to tissue papers. Bleached birch kraft pulp has similar qualities as bleached sulfite spruce pulps if it is refined to more than 35°SR.

ECF bleached spruce kraft pulp has the lowest bulk softness.



8. Influence of refining with universal refiner tackle on absorbency of bleached kraft and sulfite pulps (refining conditions: hardwood kraft pulps and spruce sulfite pulps refined at specific edge load 1.7 J/m and spruce kraft pulps at 2.4 J/m; solid marks indicate ECF bleached pulps, hollow marks indicate TCF bleached pulps, circles indicate spruce kraft pulps, triangles indicate sulfite pulps; squares indicate birch pulp, and rhombuses indicate eucalypt pulp).

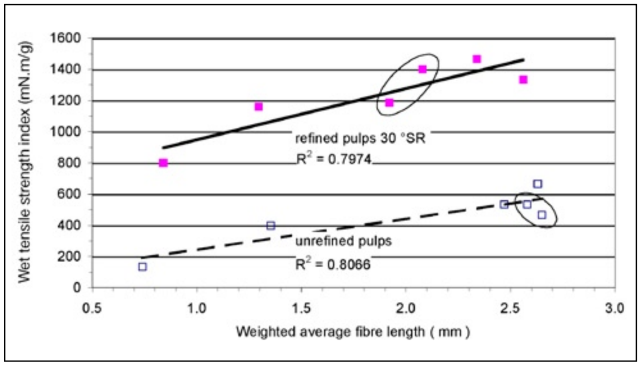


9. Influence of refining with universal refiner tackle on tensile index of bleached kraft and sulfite pulps (refining conditions: hardwood kraft pulps and spruce sulfite pulps refined at specific edge load 1.7 J/m and spruce kraft pulps at 2.4 J/m; solid marks indicate ECF bleached pulps, hollow marks indicate TCF bleached pulps; circles indicate spruce kraft pulps, triangles indicate sulfite pulps; squares indicate birch pulp, and rhombuses indicate eucalypt pulp).

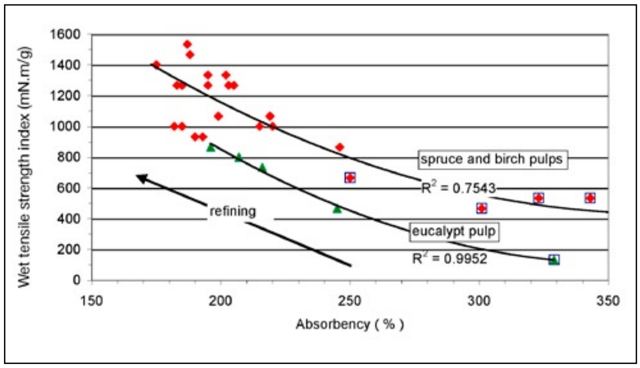
TCF bleached spruce kraft and ECF bleached eucalypt kraft pulps have significantly higher bulk softness. The different bulk softness of TCF and ECF bleached spruce kraft pulps can be related to different cooking conditions (lower kappa number of pulp for TCF bleaching) and to bleaching conditions.

Absorbency

Absorbency is another important property of pulps used in tissue paper production. Several major factors contribute to high tissue absorbency, such as pulp types, wetting agents, and machine adjustments. **Figure 8** shows the influence of refining with a universal refiner tackle at specific edge load of 1.7 and 2.4 J/m on absorbency of tested pulps. With increasing beating degree, absorbency steeply decreases to about 25°SR, then slowly increases. Bleached birch kraft pulp



10. Wet tensile strength index vs. weighted average fiber length of bleached kraft and sulfite pulps (hollow squares indicate unrefined pulps and solid squares indicate refined pulps; sulfite pulps are in ellipses).



11. Wet tensile strength index vs. absorbency relationship of bleached kraft and sulfite pulps (arrow shows influence of refining on relationship between evaluated properties; rhombuses indicate relationship of spruce kraft and sulfite pulps and birch kraft pulp, triangles indicate relationship of eucalypt pulp; marks in squares indicate unrefined pulps).

had the best absorbency of all tested pulps. The absorbency of bleached eucalypt kraft pulp in comparison with bleached birch kraft pulp is lower. To achieve the maximum possible absorbency of tissue paper, it is advisable to apply a higher specific edge load (1.7 J/m) for refining of bleached kraft birch and eucalypt pulp. The absorbency of bleached spruce kraft pulps is lower compared with bleached birch and eucalypt kraft pulps, but higher than the absorbency of bleached spruce sulfite pulps. The absorbency is lowest for bleached spruce sulfite pulps. If the highest possible absorbency of tissue paper is required, then a universal refiner tackle and a higher specific edge load (1.7 J/m) should be applied for refining of bleached spruce sulfite pulps. Tissue papers from kraft pulps are more absorbent than from sulfite pulps, according to the literature [4].

Tensile index

Figure 9 shows the tensile index of tested pulps refined with a universal refiner tackle and a specific edge load of 1.7 and 2.4 J/m. The tensile index of bleached spruce kraft pulps is the highest. The tensile index of bleached birch kraft pulp is also very high and reaches nearly the level of bleached spruce kraft pulps. The tensile index of bleached eucalypt kraft pulp is significantly lower and is comparable with the strength of bleached spruce sulfite pulps. Tensile strength of bleached spruce sulfite pulps is as much as 40% lower than the tensile strength of bleached spruce kraft pulps. We obtained the highest tensile index of bleached birch and eucalypt kraft and spruce sulfite pulps by fibrillation refining with low specific edge load (under 0.70 J/m).

The fiber strength of tested sulfite pulps is significantly lower than that of kraft pulps. Kraft spruce, birch, and eucalypt pulps have a fiber strength of 77-90 Nm/g. The fiber strength of sulfite spruce pulps is 59-61 Nm/g. This is why papers prepared from sulfite spruce pulps have lower tensile strength.

Wet tensile strength

Wet tensile strength of fully wetted paper is by 1-2 place value lower than fiber strength and is on the level of initial wet strength, provided no wet strength additive was used in preparation of test sheets. **Figure 10** shows the influence of weighted average fiber length on wet tensile strength of test sheets. Birch kraft, eucalypt kraft, and spruce sulfite pulps were refined on a conical refiner with universal refiner tackle and a specific edge load of 1.7 J/m. Spruce kraft pulps were refined with the same tackle, but with a specific edge load of 2.4 J/m. Data for unbeaten pulps are represented in Fig. 10 by a dotted line with hollow squares; pulps beaten to 30°SR are represented with a solid line and solid squares. The evaluated relationships are linear having a good correlation. By refining pulps to 30°SR, wet tensile strength increases 3–4 times. The fiber length of spruce sulfite pulps is significantly reduced by refining; however, kraft pulp fibers are shortened minimally. In Fig. 10, the properties of sulfite pulps are marked by a circle. Fiber length and fibrillation of fibers influence wet tensile strength of wetted paper similarly as initial wet strength of paper web (before drying).

Figure 11 shows the relationship between water absorbency and wet tensile strength separately for pulps with longer fibers (spruce kraft and sulfite pulps, including birch kraft pulp) and for pulps with shorter fibers (eucalypt kraft pulp). Unbeaten pulps are represented by hollow squares; eucalypt kraft pulp by triangles; and spruce kraft, sulfite, and birch kraft pulps by rhombuses. Refining of pulps increases wet tensile strength and decreases water absorbency. Application of eucalypt kraft pulp in tissue furnishes leads to low wet tensile strength index which is required in case of products such as toilet tissue. Spruce sulfite pulps which have lowest absorbency and tensile strength (dry) are suitable for the manufacture of toilet tissue in a furnish with eucalypt kraft pulp. The application of spruce and birch kraft pulps supports a suitable combination of absorbency and wet tensile index, a combination required for towels.

CONCLUSIONS

The type of pulp, conditions of refining, and furnish composition influence the physical and mechanical properties of paper and make it possible to fulfill various requirements of sanitary papers. Bleached hardwood kraft pulps are used to make tissue paper for facial tissue and napkins, where bulk softness and absorbency prevail. If greater strength is required in addition to bulk softness and absorbency, bleached birch kraft pulp can be used with advantage. The long and thin fibers of birch pulp make it possible to fulfill various requirements on sanitary papers. If high strength and deep embossing is important, softwood kraft pulps should be used. Spruce sulfite pulps have the lowest absorbency and (dry) tensile strength are suitable for the manufacture of toilet tissue in a mixture with eucalypt kraft pulp. The application of spruce and birch kraft pulps in tissue papers supports a good combination of absorbency and wet tensile index, as required for paper towels. Eucalypt kraft pulp in the furnish supports the low wet tensile index required for toilet tissue.

Application of higher specific edge load when using a universal tackle increases the bulk softness and absorbency of bleached hardwood kraft pulps. Refining pulp increases the wet tensile strength of paper and decreases absorbency. **TJ**

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INSIGHTS FROM THE AUTHORS

The tissue paper market demands quality and is highly competitive. Quality requirements for various tissue paper grades differ to a great extent. Consequently, a high level expertise is needed when manufacturing these products to fulfill the quality requirements. Industry representatives asked us to investigate refining parameters of various pulp grades in conditions similar to mill operations with regard to their effects on specific tissue paper properties, especially softness. Fortunately, our Institute has an industrial type Jylhä 0 steep cone refiner with universal and fibrillation tackle. The hardest decision was selecting testing procedures suitable for quick evaluation of pulps in mill conditions. Previously, we evaluated softness by psychophysical scaling trials with several testing persons. This is a good, but lengthy procedure. Therefore, we decided to determine flexural rigidity as a measure of bulk softness. We refined six commercial softwood and hardwood pulps and summarized the influence of refining on bulk softness, absorbency, and dry and wet tensile index. We also were interested in finding out how wet tensile index changes with increased weighted average fiber length when mixing softwood and hardwood pulps and the relationship between wet tensile index and absorbency. The results of this study may help tissue paper mills in improving the quality of their products.

Gigac

Fišerová

Gigac is director of papermaking research and Fišerová is director of pulping research at the Pulp and Paper Research Institute in Bratislava, Slovak Republic; email Gigac at gigac@vupc.sk.

Editor's Note

JAN BOTTIGLIERI | EDITOR,
jbottiglieri@tappi.org

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