Recycling behavior of thermomechanical pulp: effects of refining energy

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ABSTRACT

Recycling characteristics of thermomechanical pulps produced from jack pine and black spruce have been studied using standard laboratory procedures. The results indicate that the specific energy input has a profound effect on the papermaking properties of pulps during recycling. Short-fiber fractions behave differently when compared with long-fiber fractions. The sheet density and tensile strength of high-energy pulps tend to increase somewhat, while those of low energy tend to decrease. In most cases, the tear index augments slightly or remains unchanged during recycling. In almost all the pulps studied, specific light scattering suffered significant loss. The new recycling effect on pulp characteristics seems to depend on the distribution of fiber fractions in the pulps under study. However, much research is needed.

Application:

The pulping history of the virgin fibers affects the recycling responses of recovered papers.

RESPONSES TO REPEATED DRYING-rewetting processes exhibited by lignocellulosic fibers are related to both the physical and chemical nature of the virgin fibers. Hence, pulping conditions are one of the determining factors influencing the behavior of wood fibers during the recycling process. In chemical pulping, the lignin component is almost completely removed, leaving mainly carbohydrate materials in the fibers. When these fibers are subjected to repeated drying and rewetting, they are "hornified"—or hardened—and partially lose their bonding potential *(1)*. On the other hand, the strictly mechanical pulps such as stone groundwood and refiner mechanical pulp contain nearly all the chemical components originally present in the wood from which the pulp is produced. In contrast to the low-yield chemical pulps, these mechanical fibers improve their papermaking potential as a result of increased flexibility and conformity during repeated drying and rewetting *(2, 3)*. In a comprehensive pilot-scale investigation on the recyclability of thermomechanical pulp (TMP) fibers, Alanko *et al. (4)* concluded that the recyclability of thermomechanical pulp is good. Ferguson *(5)* found, in a study on the effects of deinking chemicals on the recyclability of ONP/OMG (70%/30%), substantial improvement in fiber bonding potential and brightness and, unavoidably, some loss in sheet opacity. The increase in bonding was attributable to the influence of alkaline peroxide treatment.

In a recent study, Law *et al. (6)* observed that mildly sulfonated mechanical pulp fibers exhibited different drying–rewetting characteristics when compared with untreated mechanical fibers, in spite of the presence of the mass of lignin in the fiber wall. This characteristic indicates the complexity of drying and rewetting of lignocellulosic fibers.

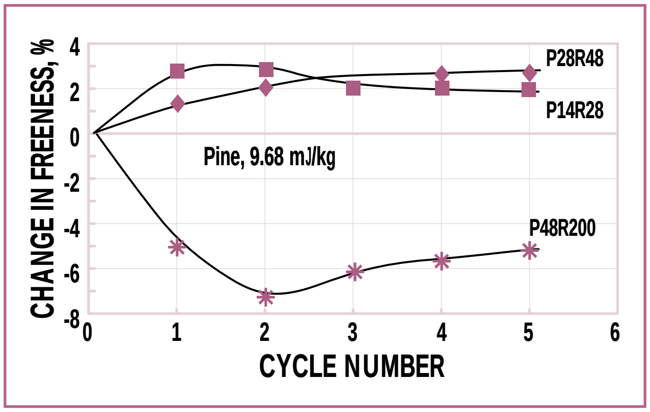
Mechanical pulps differ from chemical pulps both chemically and physically. The former is greatly heterogeneous in physical distribution of the fibrous elements, while the latter is relatively homogenous. Depending on the specific energy input and the refining temperature, the mechanical fibers are present in different forms and dimensions ranging from intact fibers to fragments and debris of the cell wall *(7–9)*. In addition, each fibrous element can have different chemical composition *(10)* and physical structure *(11)* and a different role in consolidation of the sheet *(10, 12)*. Mohlin *(12)* observed that coarse fibers showed large variation in bonding ability, mainly due to differences in fiber flexibility. For the fibers of the middle-size fraction, the variation in properties was explained by the forms of fiber fragments.

Evidently, the heterogeneity of the fibrous elements in a mechanical pulp can play an important role in determining the recycling behavior of pulp. We used a thermomechanical pulping process to investigate the effect of refining energy on the recycling behavior of two commercial softwood TMPs. Pulps having different particle-size distribution were produced by varying the specific refining energy input. This paper presents the results obtained from the repeated drying and rewetting of the experimental pulps prepared from black spruce and jack pine.

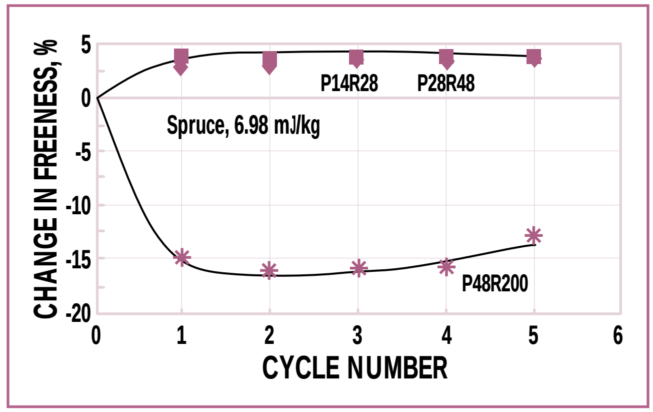
EXPERIMENTAL

Thermomechanical pulping

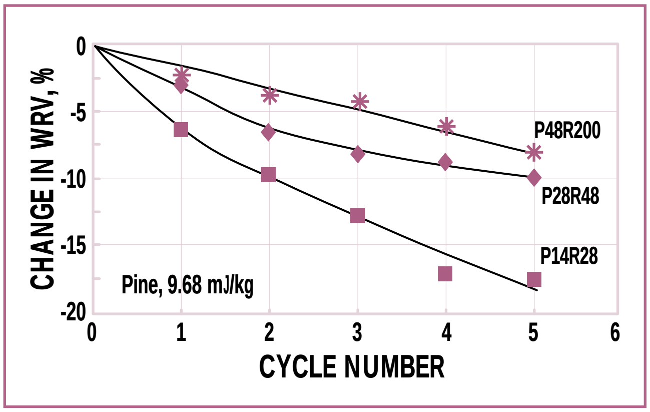
Two commercial softwoods (black spruce and jack pine) were used in the study. Spruce chips were obtained from a local saw mill, while the pine chips were prepared from freshly felled and debarked trunks (50–60 years old) by means of an



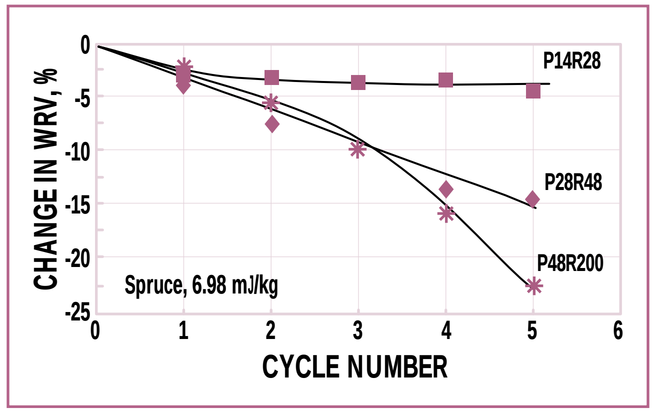
1. Change in freeness of jack pine fiber fractions during recycling



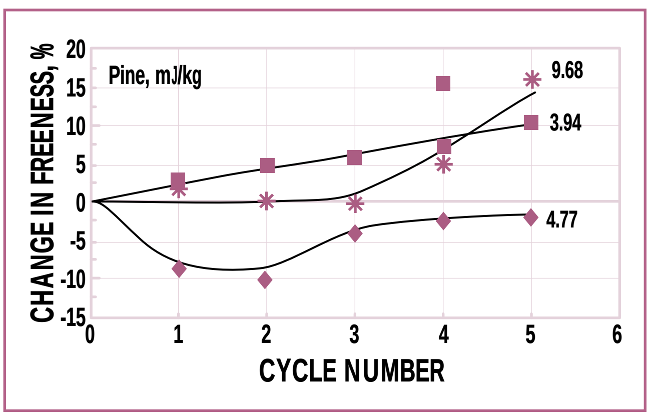
2. Change in freeness of black spruce fiber fractions during recycling



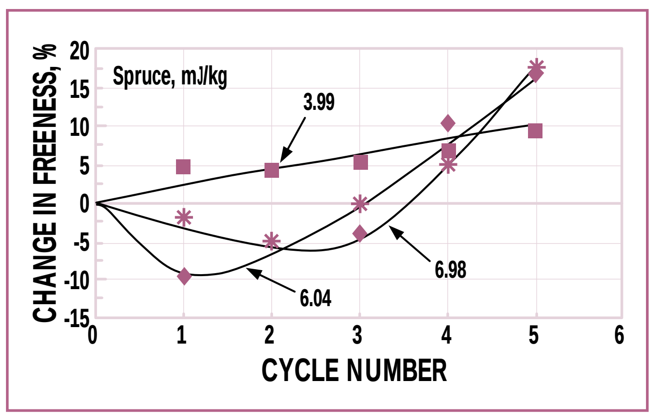
3. Change in WRV of jack pine fiber fractions during recycling



4. Change in WRV of black spruce fiber fractions during recycling



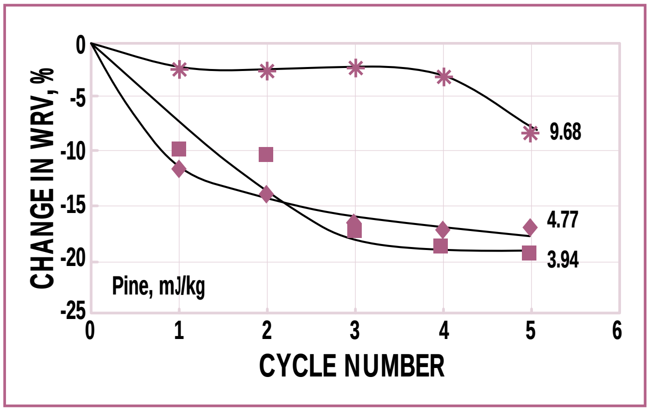
5. Change in freeness of jack pine whole pulps during recycling



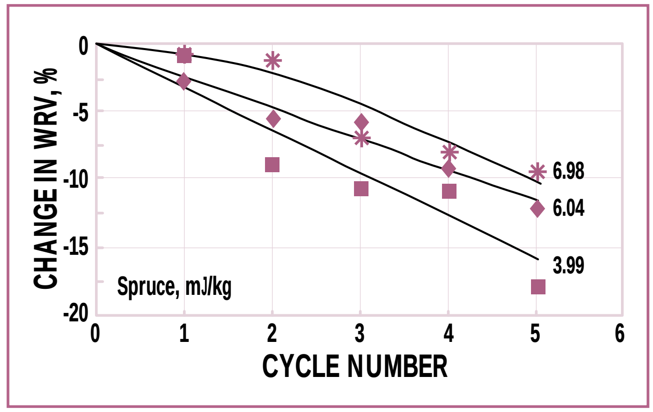
6. Change in freeness of black spruce whole pulps during recycling

industrial chipper. The chips were screened by a Rader laboratory classifier to eliminate the fines (<2 mm) and the overthicks (>8 mm) and washed prior to refining.

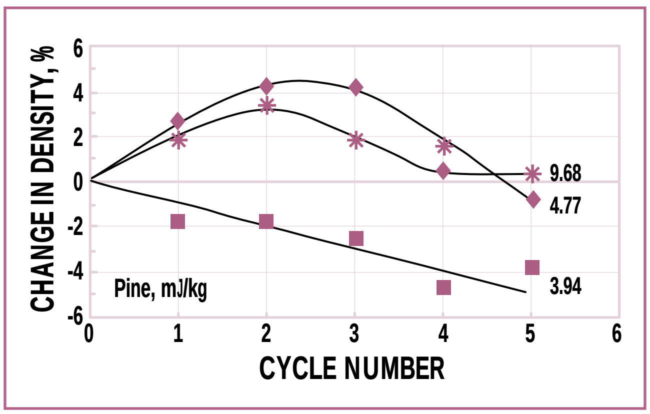
Thermomechanical pulping of the chips was conducted using a Sunds Defibrator CD300 pilot unit. Chips were presteamed under atmospheric pressure for 10 minutes and heated for 5 minutes at 126°C and then refined at that temperature. The discharge consistency was about 26%. A subsequent second-stage atmospheric refining was car-



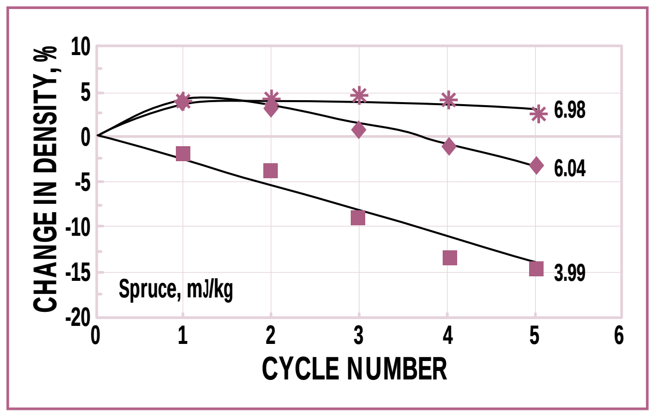
7. *Change in WRV of jack pine whole pulps during recycling*



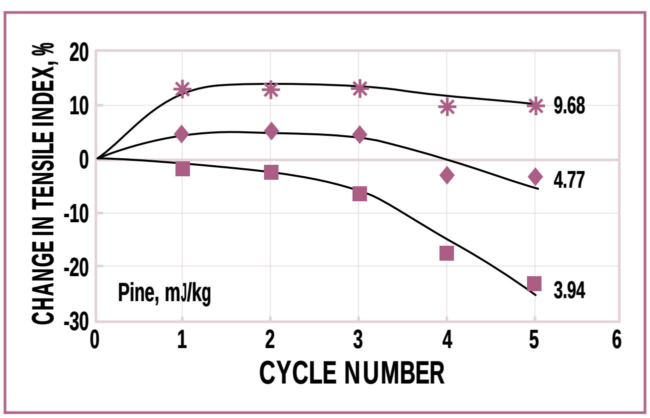
8. *Change in WRV of black spruce whole pulps during recycling*



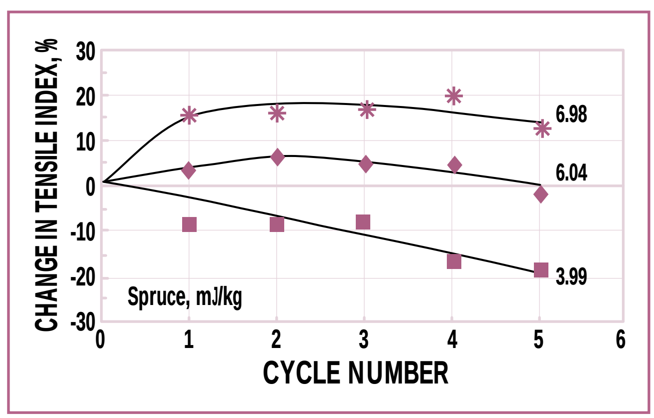
9. *Change in handsheet density of jack pine whole pulps during recycling*



10. *Change in handsheet density of black spruce whole pulps during recycling*



11. *Change in tensile index of jack pine whole pulps during recycling*

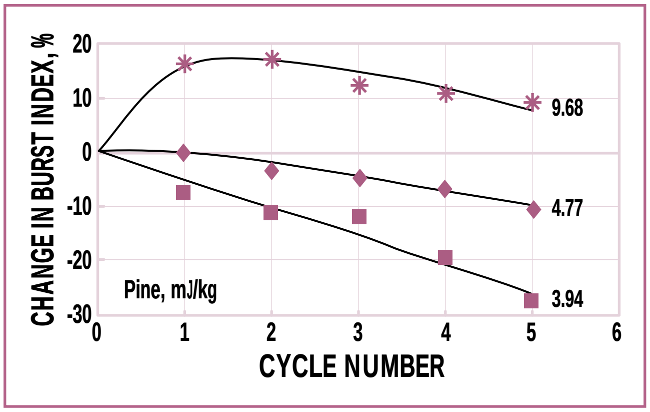


12. *Change in tensile index of black spruce whole pulps during recycling*

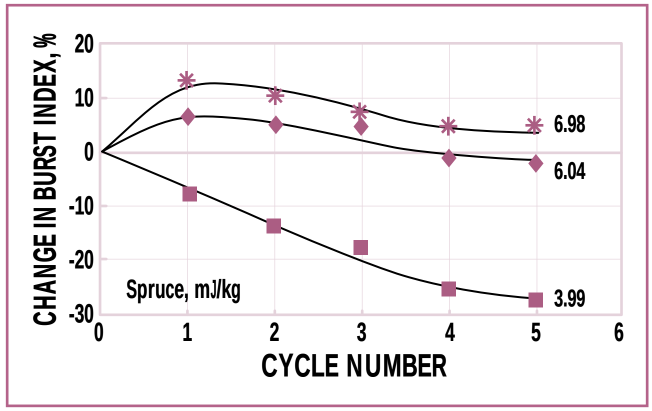
ried out at approximately 17% consistency to produce pulps with various levels of freeness.

Pulp characterization

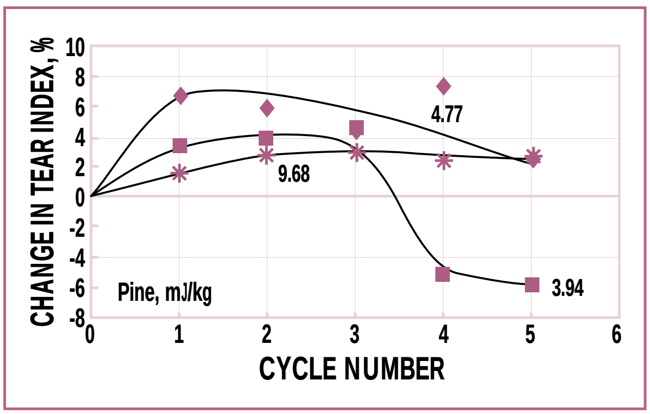
All pulps were disintegrated in hot water to remove latency. Freeness measurements, handsheet formation, and optical and mechanical property determinations were conducted in accordance with TAPPI test methods. The water retention value (WRV) of pulps was determined, with four replicates, using a method



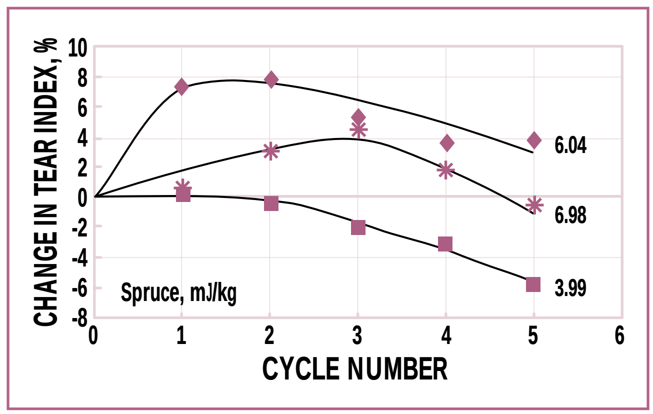
13. Change in burst index of jack pine whole pulps during recycling



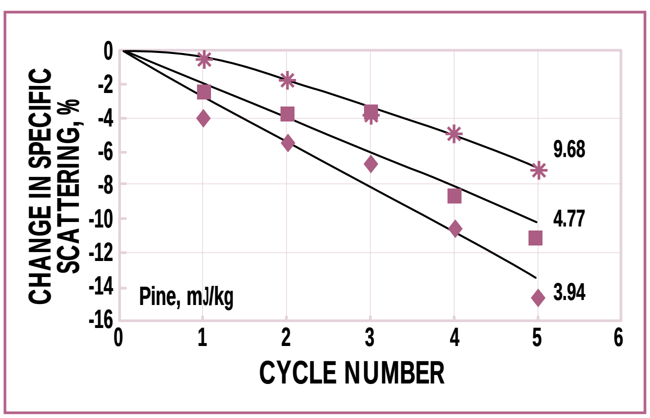
14. Change in burst index of black spruce whole pulps during recycling



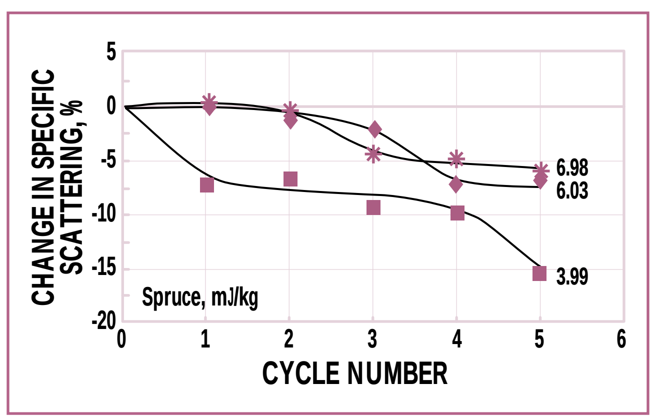
15. Change in tear index of jack pine whole pulps during recycling



16. Change in tear index of black spruce whole pulps during recycling



17. Change in specific scattering of jack pine whole pulps during recycling



18. Change in specific scattering of black spruce whole pulps during recycling

similar to that described by Allender and Waterhouse *(13)*. Briefly, a fiber mat was formed (using a pulp slurry of 52 mL at 0.25% consistency) onto the 100-mesh wire in the centrifuge tube and centrifuged (IEC UV Centrifuge) at 2500 rpm for 15 minutes. The centrifuged samples were weighed before and after drying

	Jack pine			Black spruce		
Specific energy, mJ/kg	3.94	4.77	9.68	3.99	6.04	6.98
Freeness, mL	616	406	119	602	268	163
Density, g/cm^3	0.236	0.260	0.322	0.253	0.312	0.336
Tensile index, N·m/g	18.16	23.27	28.54	24.18	35.19	36.8
Burst index, $kPa{\cdot}m^2/g$	0.83	1.10	1.26	1.16	1.88	2.02
Tear index, $mN{\cdot}m^2/g$	8.05	7.15	5.74	10.07	8.82	8.51
Brightness, ISO %	48.9	50.9	52.1	49.9	51.3	51.7
Opacity, %	93.1	95.3	97.4	94.1	96.2	97.0
Specific light scattering coefficient, m^2/kg	41.7	50.8	62.4	46.0	55.7	60.1
Specific light absorption coefficient, m^2/kg	3.72	4.12	5.03	3.77	4.30	4.78
Bauer-McNett fractions, %						
R14	21.5	10.2	0.8	31.7	18.7	11.9
R28	25.6	23.6	13.6	22.8	22.0	21.8
R48	20.0	23.2	26.0	16.5	19.4	21.1
R100	11.6	14.5	22.5	8.6	12.2	14.7
R200	4.3	5.2	9.1	2.6	4.9	6.0
P200	17.0	23.3	28.0	17.8	22.8	24.5
Wt. average fiber length, mm	1.53	1.21	0.83	1.73	1.38	1.21
Somerville shive, %	0.40	0.12	0.04	0.60	0.08	0.04

I. Basic properties of experimental TMP virgin pulps

overnight at 105°C. The water retention value is expressed as grams of water per gram of oven-dry pulp.

Some of the handsheets were set aside for recycling experiments. The unused handsheets were repeatedly reslushed up to five cycles by presoaking the handsheets in tap water overnight at room temperature before being disintegrated for 5 minutes in hot tap water using a British disintegrator. During each cycle, standard handsheets were made in the same way described earlier.

RESULTS AND DISCUSSION

General observation

Table I shows that when the specific refining energy increased, the freeness of pulps decreased due to the increase in short and fine materials and the reduction in fiber length. The influence of refining energy on other basic pulp properties is also presented in Table I. It is evident that the drying–rewetting process of mechanical pulps can be a complex phenomenon.

Characteristics of recycled fiber fractions

Long fibers responded differently than short fibers during the recycling, as revealed in Figs. 1 and 2. The freeness of P14/R28 and P28/R48 fractions increased slightly in the first cycle and then remained mostly constant, while that of the P48/R200 fraction fell substantially in the first cycle of the repeated drying–rewetting process. This observation implies that the changes in freeness of mechanical pulps during recycling would depend on the amount of short fibers in the pulp. An increase in freeness during recycling might be expected with high-freeness pulps, meaning that refining energy can be a determining factor.

As seen in Figs. 3 and 4, all fiber fractions lost, more or less, their hygroscopicity as a result of drying and rewetting. It is understandable that the short fibers would suffer a greater loss in WRV compared with the long fibers, as in the case of spruce TMP (Fig. 4). However, the reverse was observed with pine TMP (Fig. 3). A similar phenomenon was also observed with other higher-freeness pulps prepared from spruce and pine, indicating a possible influence of wood species. No explanation of this phenomenon can be offered at this point.

Effects of refining energy on recycling behavior of whole pulps

Freeness. Specific energy consumption has a significant impact on the freeness of pulps (Figs. 5 and 6). High energy input produced low-freeness pulps that behaved differently than the high-freeness pulps during the recycling process. However, the changing tendency of low-freeness pulps during recycling was unpredictable; the freeness fell in the early cycles and then increased, in most cases, above the initial freeness levels.

Water retention value. We discussed earlier that all fiber fractions lost some water retention capacity during recycling (Figs. 3 and 4); therefore, it is understandable that the whole pulps also suffered some

KEYWORDS

Energy, mechanical pulps, Picea mariana, Pinus banksiana*, properties, pulp properties, recycling, refiner mechanical pulps, refining, thermomechanical pulps.*

loss in hygroscopicity, as seen in Figs. 7 and 8. The change in WRV was relatively small in all pulps, and, as a result, high- energy pulps showed the least percentage drop because of their relatively higher initial values.

Density. Refining energy input influenced the change in handsheet density during recycling, as indicated in Figs. 9 and 10, which show that the density of high-energy pulps tended to increase somewhat while that of the low-energy pulps decreased. This indicates the important effect of the distribution of fiber fractions in the pulp on the recycling characteristics of mechanical pulps.

Tensile index. The tensile index of virgin mechanical pulps, as well as the recycling characteristics of these pulps, were closely related to the specific energy applied during refining (Figs. 11 and 12). The tensile index of high-freeness pulps (low specific energy) decreased, while that of the low-freeness pulps (high specific energy) increased as a result of repeated drying and rewetting.

Burst index. In general, the burst index is directly correlated to the tensile index. Hence, the change in burst index during recycling (Figs. 13 and 14) is similar to that observed in tensile index (Figs. 11 and 12).

Tear index. The change in tear index during recycling is rather small (Figs. 15 and 16). In most cases, the greatest rate of change for each pulp was observed in the first cycle; then it decreased after reaching a maximum in one to three cycles. The low-energy pulps yielded a greater negative change after about three cycles.

Specific light scattering. As seen in Figs. 17 and 18, the specific light-scattering coefficient increased with increasing refining energy. This is due to the increased fines content in the high-energy pulps (Table I), yielding higher scattering coefficient. All pulps suffered some reduction in light scattering during recycling, regardless of the differences in specific energy consumption.

CONCLUSION

The heterogeneity in physical and structural nature of the fibrous elements in a mechanical pulp plays an important role in determining the recycling characteristics of the pulps. The heterogeneity increases with increasing specific refining energy input. Different fiber fractions behave dissimilarly during recycling. As a result, the net recycling effect on the whole pulp depends on the distribution of various fiber fractions in the pulp under study. TJ

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