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PRODUCTION OF NEWSPRINT FURNISH FROM MIXTURES OF WHITE BIRCH AND BLACK SPRUCE

PAR

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SUMMARY

In Québec, hardwoods represent about 30% of the total forest merchantable volume, in which the primary dominant hardwood species are birches with 44,6% of volume and the most popular birch species being white birch. Until now, the utilization of dense hardwoods, such as birch, is still on a relatively small scale in the Canadian pulp and papermaking industry. This study concerns the utilization of white birch as a raw material in thermomechanical and chemi-thermomechanical pulping for newsprint furnishes. The objective is not only to determine the effects on mechanical and optical properties due to the substitution of white birch (B) (*Betula papyfera* Marsh) for black spruce (S) (*Picea mariana)* to produce TMP and CTMP but also to study the fibre morphology in order to better understand the behavior of the short fibres of hardwood in co-refining. Since hardwoods comprise large-diameter vessel elements besides fibres and parenchyma cells, and their fibres are stiff and short, a proper chemical pre-treatment will soften the wood and thereby improve the fibre separation during refining. In addition, hardwoods and softwoods respond differently to chemical treatment. Hence, the feasibility of upgrading the white birch chips by chemical pre-treatment followed by co-refining with untreated black spruce chips is studied in comparison with the reference TMP and CTMP of fresh B/S chip mixtures. Finally, a theoretical mechanism of co-refining is elaborated.

The thermomechanical pulps from chip mixtures (B/S) containing up to 20% of white birch had similar tear strength when compared to 100% black spruce TMP, while the tensile and burst strengths were slightly lower. Increased substitution up to 40% with white birch decreased largely the strength properties of the pulps, when compared with the 100% black spruce TMP. The main advantages resulting from the use of white birch were the slight increases in light scattering coefficient and brightness. On the other hand, the CTMP pulps of the chip mixtures (20%) had comparable tensile, tear and burst strength when compared to 100% black spruce TMP, although somewhat lower than those of 100% black spruce CTMP. Both the substitution ratio (30 to 60%) and the chemical pre-treatment of white birch chips prior to mixing with untreated black spruce

chips yielded little effect on the strength of spruce TMP. The main disadvantage of using chemicals was the reduction of light scattering. The chemical pre-treatment of white birch prior to mixing with black spruce followed by co-refining is a compromise alternative to improve the strength properties by modifying the quality of white birch fibres while reducing the loss of light scattering due to the absence of alkaline treatment on black spruce fibres. This implied that it is possible to increase the substitution of white birch for black spruce without much deterioration of the balance of pulp qualities (strength and optical properties) when the white birch chips are pre-treated by chemicals prior to mixing with black spruce followed by a co-refining without chemicals.

The linting propensity test showed that the 100% white birch TMP may have a linting problem when used as a newsprint furnish. A significant reduction in linting was achieved for CTMP-B in comparison with TMP-B due to the use of chemicals. For both TMP and CTMP, the use of white birch with black spruce yielded little influence on linting propensity compared to the pulps of 100% black spruce probably due to the fact that certain amount of vessel fragments and ray cells could be compensated by the introduction of high quality fibres and fines from black spruce.

The morphology studies showed that white birch had a fibre development (such as delamination and fibrillation) in refining poorer than that of black spruce when no chemicals were used. Although little difference in fibre stiffness and fibrillation was noted microscopically in the long-fibre fraction of TMP-B and TMP-S, large improvement in the fibrils content can be found in the short-fibre and fines fraction of TMP-S but not of TMP-B. These observations were in agreement well with the measurements of fibre flexibility and hydrodynamic specific volume. These characteristics caused the low strength properties of TMP-B but with superior light scattering. The alkaline sulfite treatment was more effective in improving the fibre flexibility and collapsibility of white birch, increasing the fibre-bonding potentials. Unfortunately, the superior light scattering of TMP was lost due to the use of chemicals, especially for white birch.

The fibre distribution measured by Bauer-McNett showed that the use of white birch in TMP of black spruce decreased the long-fibre content and increased the short-fibre content but has no significant effect on fines content at a given refining energy consumption. Co-refining of white birch with black spruce in producing TMP showed a little influence on the long fibre qualities, but decreased largely the qualities of the short fibre and especially the fines, as measured by the flexibility and hydrodynamic specific volume. These influences were well in agreement with the microscopic observations. It seems that the co-refining of chip mixtures without chemicals does not change the tendency of fibre development for white birch and black spruce, when compared to the refining of simple species. However, a synergetic effect on relative bonded area (RBA) of R200 was found when the white birch and black spruce were refining together probably due to the impact of a small amount of vessel fragments on fibres bonding.

In the CTMP process, the use of white birch decreased also the long-fibre content as well as increased the short-fibre content and somewhat the fines content, irregardless the substitution degree. Similar to the TMP, the use of white birch showed little influence on the long fibre qualities, but decreased the short fibre and especially the fine qualities, as measured by the flexibility and hydrodynamic specific volume. These reductions were not as high as those found in TMP since the use of chemicals improved largely the white birch qualities, such as fibre flexibility. And again, these changes were marginally affected by the replacement degree (up to 60%). It seems that there is a positive effect of mixing white birch with black spruce to produce CTMP due to the benefits from chemicals treatment and on white birch fibres against fibre cutting from black spruce fibres during co-refining.

Keywords:*Betula papyfera* Marsh, *Picea mariana*, chemical pre-treatment, thermomechanical pulp, chemithermomechanical pulp, newsprint furnish, morphology, flexibility, linting propensity.

RÉSUMÉ

1. Problématique

Historiquement, les bois résineux sont utilisés comme matériel dans la mise en pâte mécanique et les bois feuillus sont considérés peu convenables à cause de leur structure fibreuse différente, comme une densité élevée, des fibres plus courtes à paroi plus épaisse, et la présence de vaisseaux. Au Canada, la coupe annuelle permise de bois résineux est différente de celle des bois feuillus. Des statistiques récentes indiquent que l'utilisation de bois résineux a atteint la vitesse de croissance de la forêt, donc une utilisation maximale. Par contre, les bois feuillus, particulièrement les essences de moyenne et haute densité, sont encore une ressource sous-exploitée. Le bouleau est la deuxième essence la plus répandue parmi les bois feuillus avec un volume de plus d'un milliard de m^3 distribué au travers de presque tout le Canada. Au Québec, les bois feuillus représentent environ 30% du volume marchand forestier. L'essence dominante est le bouleau avec une proportion de 44,6%. Bien qu'une attention considérable se porte sur l'utilisation de bois feuillus de haute densité dans la mise en pâte mécanique due à leur disponibilité et leur prix, jusqu'à présent, l'utilisation de bois feuillus à haute densité, comme le bouleau, reste encore marginale dans l'industrie canadienne des pâtes et papiers.

Au niveau des pâtes mécaniques, la mise en pâte thermomécanique (TMP) et chemithermomécanique (CTMP) sont les deux procédés les plus répandus au Canada et aussi au Québec. Le procédé TMP a des avantages comme :

- Un haut rendement, permettant d'améliorer l'utilisation du bois comparativement aux pâtes chimiques;
- L'acceptation non seulement des copeaux mais aussi des résidus de la scierie en comparant avec les procédés comme la pâte de meule (SGW) et la pâte de meule pressurisée (PGW), etc.;

- Du point de vue environnemental, l'absence de soufre, odeur et sous-produits chlorés;

- Très flexible, les deux stages de raffinage permettent l'utilisation de petites quantités de produits chimiques comme pré-traitement avant ou durant le raffinage ou le traitement après le raffinage pour améliorer les propriétés papetières (par exemple : CTMP, APMP et OPCO);

- Les fibres de la pâte TMP résistent mieux à la détérioration lors du recyclage que les fibres de pâte chimique.

Jusqu'à présent, les essences les plus populaires utilisées dans les pâtes TMP sont les bois résineux, comme l'épinette noire et le sapin. Pour les pâtes CTMP, seulement les bois feuillus avec une basse densité sont utilisés, comme le tremble. Les pâtes TMP sont généralement utilisées pour remplacer le mélange de pâte chimique et de pâte SGW pour la production de papier journal. Ainsi, l'utilisation de pâte chimique coûteuse est diminuée. Les pâtes CTMP peuvent être utilisées comme pâtes de renforcement pour quelques productions spéciales de papier journal et papier couché.

En général, les raisons limitant l'utilisation du bouleau dans les pâtes mécaniques sont:

- Les fibres du bouleau blanc sont plus rigides dans le raffineur que celles du bois résineux en raison de leurs parois épaisses et d'une faible longueur de fibres originale. Bien que la pâte TMP du bouleau blanc ait une bonne opacité, elle a de trop faibles résistances pour produire du papier de bonne qualité.

- La pâte CTMP de bouleau blanc a de bonnes résistances grâce au traitement chimique tandis que l'opacité et la blancheur sont beaucoup diminuées en raison de la présence de produits chimiques.

- Le co-raffinage de bouleau blanc en mélange avec des résineux a l'avantage de baisser la consommation d'énergie du raffinage lors de la mise en pâte TMP. Mais les propriétés de résistance diminuent gravement lorsque la quantité de bouleau blanc dépasse 20%.

- Le peluchage est une propriété importante influençant la qualité d'impression. Le bouleau blanc a plus de volume de rayon que l'épinette noire ainsi qu'environ une proportion de 11% de vaisseaux. De plus, la liaison potentiel de la fibre de bouleau est faible que celle de la fibre d'épinette. Ces caractéristiques peuvent augmenter le degré de peluchage lorsque le bois feuillu est introduit dans la pâte mécanique.

Des études précédentes montrent que le traitement chimique et le co-raffinage en mélange avec le bois résineux sont considérés comme les deux moyens possibles pour élargir l'utilisation de bouleau blanc dans le domaine des pâtes mécaniques. Mais, comme mentionné ci-dessus, chacune des deux méthodes a ses avantages et ses inconvénients. De plus, jusqu'à présent, plusieurs études ont favorisé les propriétés physiques et optiques lors de la mise en pâte mécanique dans un mélange d'essences. Peu de travaux se sont préoccupés du développement de la fibre dans le co-raffinage. Il est devenu nécessaire d'étudier la morphologie de la fibre pour mieux comprendre le comportement de la fibre d'essences différentes lors de la mise en pâte mécanique en mélange. Ainsi, en tant que bois feuillu le plus populaire au Canada et au Québec, une substitution partielle ou totale du résineux par le bouleau blanc dans la mise en pâte mécanique pour la production de papier journal présente un défi intéressant non seulement en recherche, mais aussi pour l'industrie papetière.

2. Objectifs

Le but du projet dans son ensemble est d'étudier l'impact de la présence de bouleau blanc (B) (*Betula papyrifera* Marsh) dans la composition de base en ciblant non seulement les propriétés papetières mais aussi le développement des fibres d'épinette noire (S) (*Picea Marianne*) et de bouleau blanc dans le raffineur, soit comme essence pure ou en mélange. Les pâtes finales pourraient être utilisées pour la production de papier journal. Puisque le bois feuillu se compose de vaisseaux en plus des fibres et des rayons du bois, et que ses fibres sont plus rigides et courtes comparativement à celles de bois résineux, un pré-traitement chimique ramollira le bois et ainsi aidera à la séparation des fibres dans le raffineur. De plus, le bois feuillu et le bois résineux répondent différemment au traitement chimique. La possibilité d'améliorer les copeaux de bouleau blanc par un pré-traitement chimique suivi d'un co-raffinage avec des copeaux non-traités d'épinette noire sera étudiée et comparée avec les pâtes TMP et CTMP conventionnelles obtenus à partir des copeaux B/S en mélange. Les intérêts de recherche sont:

- L'impact du bouleau blanc sur la consommation d'énergie spécifique du raffinage des pâtes TMP et CTMP avec un indice d'égouttage entre 80 et 200 ml lorsque les copeaux de bouleau blanc traités ou non traités sont mélangés avec ceux d'épinette noire ;

- L'influence sur le développement de la fibre quand les copeaux d'essences différentes sont raffinés séparément ou ensemble dans les procédés TMP et CTMP par analyse des structures morphologiques de la fibre. L'effet d'un pré-traitement chimique du bouleau blanc avant son intégration avec l'épinette noire est également considéré ;

- Une comparaison s'effectue sur les propriétés physiques et optiques entre les différentes pâtes ;

- L'impact de l'addition des copeaux traités ou non traités de bouleau blanc sur le peluchage.

3. Méthodologie

Divers mélanges ont donc été effectués pour des contenus en bouleau blanc variant de 0 à 100%, avec ou sans traitement chimique. Puis, les procédés TMP et CTMP sont appliqués. Les pâtes ont ensuite été étudiées, tant au niveau des propriétés morphologiques des fibres que des propriétés des papiers produits. Un complément d'information est aussi obtenu par analyse visuelle au microscope optique et au microscope à balayage. La recherche inclut deux sections :

Section 1 – TMP : les pâtes TMP contrôlées sont fabriquées de mélange des copeaux avec des proportions de 0, 10, 20, 30, 40 et 100% de bouleau blanc. Aussi, une pâte est produite à partir de mélange de copeaux avec une proportion de 30% de bouleau blanc qui est pré-traité par une combinaison d'hydroxyde du sodium à 1,5% en poids et de sulfite du sodium à 2,5% en poids pour une période de 4 h à 75-80°C de façon à obtenir une distribution uniforme de produit chimique dans les copeaux. La même condition de co-raffinage est utilisée dans cet essai.

Section 2 – CTMP : les essais de raffinage comportent une pâte de référence où le mélange de copeaux a été traité ensemble avec 2,5% de sulfite et de 2,5% d'hydroxyde de sodium selon le procédé CTMP-a conventionnel. La proportion de bouleau blanc utilisée était de 0, 30, 60 et 100%. De plus, dans deux autres essais avec 30% de bouleau blanc, un pré-traitement chimique a été appliqué sur les copeaux de bouleau blanc seuls avant leur incorporation au mélange avec les copeaux d'épinette noire non-traités. Dans ce cas, le traitement CTMP-b consistait en une addition d'hydroxyde de sodium seulement lors du trempage, suivi d'un raffinage CTMP utilisant 2,5% du sulfite de sodium seulement. Le procédé CTMP-c présente une addition simultanée de 2,5% de sulfite et de 2,5% d'hydroxyde de sodium par trempage des copeaux de bouleau avant leur raffinage TMP conventionnel en mélange avec l'épinette non traitée.

3.1 Matières premières

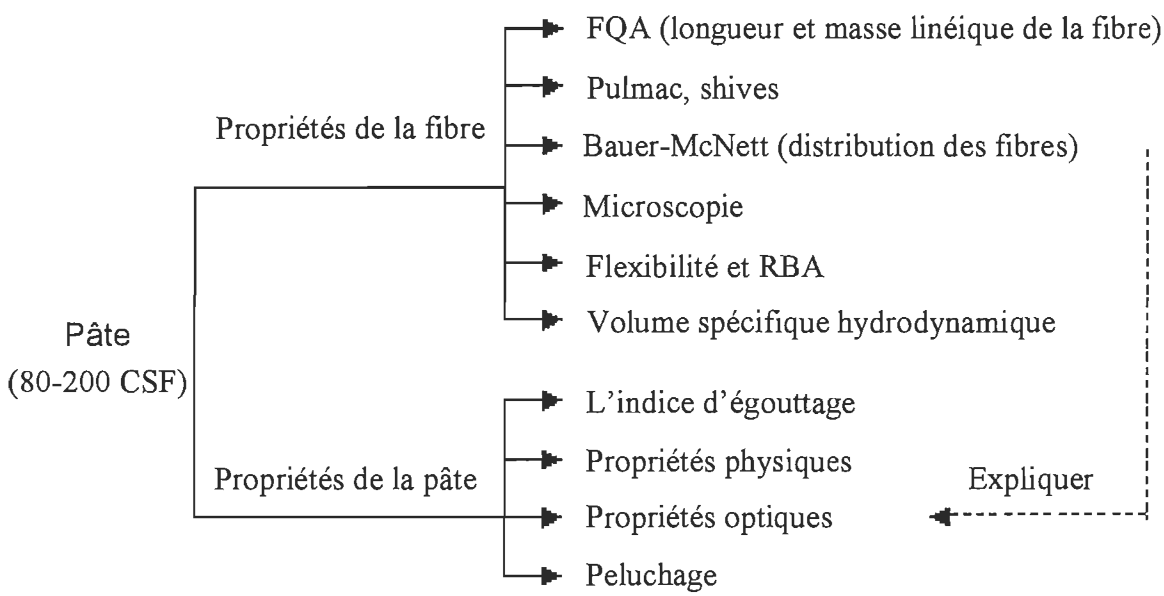
Les copeaux d'épinette noire provenaient de l'usine Kruger de Trois-Rivières tandis que les billes de bouleau blanc venaient de la compagnie Malette de St-Georges-de-Champlain (Québec, Canada). Les billes de bouleau blanc ont été écorcées et mises en copeaux. Les copeaux ont été classés avec un classificateur à disque de type Rader en acceptant les copeaux de moins de 6 mm d'épaisseur avec enlèvement des matières fines. Les copeaux ont été lavés séparément et ont été mélangés en poids.

3.2 Conditions de raffinage

Les pâtes TMP et CTMP ont été produites en deux stages avec le raffineur de laboratoire CD 300 (Metso inc.) du Centre de recherche en pâtes et papiers de l'UQTR. Le premier stage du raffinage s'effectue sous pression tandis que le second stage est à pression atmosphérique.

3.3 Évaluation des pâtes

La latence des pâtes a été enlevée avant l'évaluation des propriétés physiques de la fibre et des propriétés papetières. Les propriétés de la fibre comportent la longueur, la masse linéique, la flexibilité, le volume spécifique hydrodynamique et aussi l'inspection visuelle avec des aides de microscopes optique et à balayage. Les propriétés papetières incluent les propriétés physiques et optiques. L'impact de l'utilisation de bouleau blanc sur le peluchage est aussi évalué. Les paramètres analysés sont expliqués ci-dessous :



L'appareil FQA est utilisé pour mesurer la longueur et la masse linéique (C) des fibres (Équation 1). La distribution des fibres est analysée par Bauer-McNett. L'analyseur CyberFlex est utilisé pour mesurer la flexibilité de la fibre à l'état humide (WFF) basée sur la méthode Steadman et aussi la surface de liaison fibre à fibre (RBA). Dans la mesure de flexibilité, les fibres sont déposées sur un fil métallique et la longueur de non-contact est reliée à la flexibilité de la fibre (Équation 2). Le CyberFlex permet d'analyser de 100 à 1,000 fibres automatiquement et puis une flexibilité moyenne est obtenue. Dans la mesure de RBA, les fibres sont déposées directement sur le verre et le RBA est calculé comme le ratio entre l'aire de contact et de non-contact de la fibre et du verre

(Équation 3). Le volume spécifique hydrodynamique (HSV) est évalué selon la méthode de Marton *et al* et Luukko. Les fibres ou les fines sont déposées dans un liquide avec 0,5 mg/L de $MgSO_3$ durant 24 heures. Puis, le volume du dépôt est lu et le poids sec de la pâte dans le liquide est déterminé. Le volume spécifique hydrodynamique est calculé selon l'Équation 4.

$$C = M / (N*La) \qquad \text{Éq. 1}$$

C : masse linéique (coarseness) (mg/m)

M : masse sèche d'une petite quantité de fibres (mg)

La : longueur moyenne arithmétique (m)

N : nombre total des fibres dans la masse M.

$$WFF = 72\ (\text{Diamètre du fil}) / (\text{Pressure} \times \text{Largeur de la fibre} \times \text{Enjambée}^4) \qquad \text{Éq. 2}$$

$$RBA = 100 \times \text{Zone de lien} / \text{Surface de la fibre} \qquad \text{Éq. 3}$$

$$HSV\ (cm^3/g) = V/W \qquad \text{Éq. 4}$$

V : volume du dépôt (cm^3)

W : poids sec de la pâte (g)

Pour bien comprendre les structures morphologiques des fibres, les pâtes sont séparées par Bauer-McNett et puis chacune fraction est observée par microscopie optique. Le microscope électronique à balayage (MEB) est utilisé pour évaluer la surface des fibres et le degré de dommage des fibres de la fraction R48.

Les propriétés physiques des papiers ont été mesurées conformément aux procédures de l'ATCPP. Les propriétés optiques des papiers ont été analysées avec un photomètre Technibrite. De plus, le peluchage est évalué par l'appareil RNA-52.

4. Résultats

Comme mentionné précédemment, la pâte TMP de bouleau blanc ne satisfait pas les exigences de fabrication d'un papier journal de bonne qualité à cause de sa faible résistance. Cette recherche montrera d'abord que cette faible résistance est liée à la structure morphologique des fibres. Puis, l'impact du bouleau blanc dans les mélanges sur les caractéristiques du raffinage et sur les propriétés des fibres et du papier des pâtes au cours de la mise en pâte TMP et CTMP sont évalués. Les effets du pré-traitement chimique de bouleau blanc sont également évalués.

4.1 Consommation d'énergie spécifique

L'utilisation de bouleau blanc avec l'épinette noire consomme autant d'énergie de raffinage que 100% d'épinette noire pour produire une pâte thermomécanique d'indice d'égouttage équivalent. Dans le procédé CTMP, un mélange avec une proportion jusqu'à 60% de bouleau blanc nécessite une consommation d'énergie du raffinage légèrement inférieure pour atteindre un niveau d'égouttage équivalent à la pâte CTMP de 100% d'épinette (CTMP-S), mais beaucoup plus élevée que pour la pâte CTMP de 100% de bouleau (CTMP-B) et la pâte TMP de 100% d'épinette (TMP-S). Le pré-traitement chimique du bouleau blanc par alcali et sulfite du sodium avant mélange avec l'épinette noire, suivi d'un raffinage sans produit chimique (CTMP-Bns30) peut diminuer la consommation d'énergie de raffinage. La raison s'explique par le fait que ni l'alcali ni le sulfite du sodium ne sont appliqués durant le procédé du raffinage, et que par conséquent il n'y a pas de traitement chimique effectué sur les copeaux d'épinette noire.

4.2 Propriétés physiques de la fibre

Les études de la morphologie des fibres montrent que le bouleau blanc a un faible développement de la fibre dans le raffineur sans produit chimique. La fibre originale de bouleau blanc a une masse linéique inférieure de 30% à celle d'épinette noire. Après le raffinage, la différence de masse linéique entre les fibres de la pâte TMP-B et celles de la pâte TMP-S diminue à environ 20% pour la pâte entière et à 15% pour la fraction des fibres courtes. La mesure de la flexibilité des fractions montre que les fractions R28, R48 et R100 ont une flexibilité semblable à celle de la pâte TMP de 100% de bouleau (TMP-B) tandis qu'une augmentation de flexibilité est observée suivi la réduction de la longueur de la fibre pour la pâte TMP-S. Bien que peu de différence de flexibilité ne soit remarquée dans la fraction R28 des pâtes TMP-B et TMP-S, la fraction R100 de la pâte

TMP-B a une flexibilité beaucoup plus faible que celle de la pâte TMP-S. Une tendance similaire est observée dans la mesure du volume spécifique hydrodynamique. Peu d'amélioration du volume spécifique hydrodynamique est observée dans les fractions de la pâte TMP-B. Par contre, les fines de la pâte TMP-S ont un volume spécifique hydrodynamique supérieur à celui des fractions de fibres longues et courtes. Aussi, la différence de volume spécifique hydrodynamique entre les pâtes TMP-B et TMP-S augmente définitivement avec la réduction de longueur de la fibre.

La relation entre la flexibilité et la masse linéique démontre que peu de développement de la flexibilité apparaît suite à la réduction de la masse linéique pour la pâte TMP-B. Par contre, la baisse de la masse linéique contribue fortement à l'augmentation de la flexibilité pour la pâte TMP-S. De ce point de vue, les fibres de bouleau blanc ont un comportement semblable aux fibres d'automne d'épinette noire dans le raffineur.

L'observation du microscope optique s'accorde bien avec les mesures de flexibilité et le volume spécifique hydrodynamique. Avec l'aide de l'observation du microscope optique, une forte augmentation des fibrilles est observée dans les fractions des fibres courtes et des fines de la pâte TMP-S mais non de la pâte TMP-B. Donc, puisque peu de différence entre la pâte TMP-B et la pâte TMP-S est observée dans la fraction des fibres longues, les fractions des fibres courtes et des fines de la pâte TMP-B sont plus faibles que celles de la pâte TMP-S

La mesure par Bauer-McNett montre que la pâte TMP-B a un contenu de fibres courtes et de fines plus élevé que celui de la pâte TMP-S à une consommation d'énergie équivalente.

Toutes les caractéristiques ci-dessus causent la faible résistance papetière de la pâte TMP-B mais avec un indice de diffusion de la lumière supérieur. Il signifie aussi qu'une forte limitation quand à l'amélioration des propriétés physiques de la fibre de bouleau blanc par le traitement mécanique. Dans ce cas, le traitement chimique devra nécessairement être utiliser afin d'améliorer les propriétés physiques de la fibre de bouleau blanc.

Le traitement chimique avec alcali et sulfite du sodium est plus efficace à améliorer la flexibilité et la collapsibilité de la fibre de bouleau blanc et par conséquent à augmenter la liaison potentielle de la fibre comparativement à celles d'épinette noire. Plus de 60% et de 100% d'amélioration sont observées sur la flexibilité de la fibre de la fraction R48 et R100 de la pâte CTMP-B, respectivement, en comparant avec la pâte TMP-B. Par contre, environ 20% et 3% d'augmentation sont observées sur la flexibilité de la fibre des fractions R48 et R100 de la pâte CTMP-S, respectivement, en comparant avec la pâte TMP-S. De plus, la sulfonation de la lignine amène une amélioration de la qualité des fines. Un indice de rupture plus élevé est remarqué sur la pâte CTMP par rapport à la pâte TMP fabriquée du même échantillon avec un contenu équivalent en fines. Évidemment, un potentiel de liaison supérieur profitera à une amélioration de la flexibilité de la fibre et de la qualité des fines. Malheureusement, la diffusion de la lumière obtenue avec la pâte TMP est perdue en même temps due à l'utilisation de produits chimiques, particulièrement pour le bouleau blanc.

La distribution des fibres mesurées par Bauer-McNett montre que l'utilisation de bouleau blanc dans la pâte TMP d'épinette noire diminue la quantité de fibres longues et augmente celle de fibres courtes tandis que le contenu en fines demeure presque inchangé, ceci pour un même niveau d'énergie spécifique de raffinage. Puisqu'une grande différence existe entre les fibres de bouleau blanc et d'épinette noire, la mesure de la masse linéique devient moins importante pour expliquer l'effet de l'addition de bouleau blanc. Les analyses de flexibilité et de volume spécifique hydrodynamique démontrent que l'utilisation de bouleau blanc influence que légèrement la qualité des fibres longues, mais diminue graduellement celles des fibres courtes et des fines. Ces influences s'accordent bien avec les observations de microscopie optique. Les raisons sont qu'une forte différence est observée dans les fractions de fibres courtes et de fines des pâtes d'essence pure tandis que la fraction des fibres longues démontre une caractéristique similaire entre les pâtes TMP de bouleau blanc et d'épinette noire. Donc, le co-raffinage des copeaux en mélange sans produit chimique ne change pas la tendance du développement de la fibre du bouleau blanc et d'épinette noire comme observée dans le raffinage de l'espèce pure. Cependant, une petite quantité de fibres et de vaisseaux de bouleau blanc peut être compensée par les fibres de bonne qualité d'épinette noire. Cette compensation sera perdue avec une augmentation de bouleau blanc dans le mélange.

Une réduction de la quantité de fibres longues et une augmentation de la quantité des fibres courtes et des fines sont remarquées lors de l'intégration du bouleau blanc avec l'épinette noire lors de la mise en pâte du procédé CTMP. Comme pour les pâtes TMP, l'utilisation de bouleau blanc a peu d'effet sur la qualité des fibres longues, mais diminue la qualité des fibres courtes, surtout celle des fines, telle que démontré par les mesures de la flexibilité et du volume spécifique hydrodynamique. La réduction de qualité des fibres courtes et des fines est beaucoup plus faible que celle de la pâte TMP grâce à l'utilisation de produits chimiques qui amène une amélioration de la flexibilité de la fibre ainsi que de la qualité des fines, surtout celles de bouleau blanc. Aussi, le degré d'introduction de bouleau blanc dans les mélanges a un effet léger sur les changements des propriétés de la fibre.

Le pré-traitement chimique du bouleau blanc par une combinaison d'hydroxyde et de sulfite du sodium (CTMP-Bns30) permet une augmentation de quantité de fines en comparant avec la pâte CTMP-B30. Cette situation s'explique par la raison qu'aucun produit chimique ne s'applique sur les copeaux d'épinette noire dans le raffinage de CTMP-Bns30 et, ainsi, plus de fines d'épinette noire sont produites. Un coefficient de diffusion de la lumière plus élevé est observé pour la pâte CTMP-Bns30 comparé à celui de la pâte CTMP-B30, comme expliqué dans la prochaine section.

4.3 Propriétés papetières

La pâte TMP de bouleau blanc ne produit pas du papier de bonne qualité à cause de ses fibres rigides et ses fines de surface spécifique inférieure qui donne au papier une faible résistance. L'addition de produits chimiques lors d'un procédé CTMP permet d'améliorer significativement la résistance papetière du bouleau blanc mais au prix d'une perte importante du coefficient de diffusion de la lumière et de la blancheur puisque l'on utilise de l'hydroxyde de sodium, lequel produit un noircissement alcalin.

Pour les pâtes thermomécaniques, avec une proportion de 20% de bouleau blanc, l'indice de déchirure est inchangé tandis que l'indice de rupture et l'indice d'éclatement sont diminués légèrement en comparant avec ceux de 100% d'épinette noire. Une plus grande augmentation du bouleau blanc diminue significativement la résistance papetière. Les avantages principaux de l'utilisation de bouleau blanc dans l'épinette noire sont une augmentation du coefficient de diffusion de la lumière et de la blancheur. D'autre part, dans le procédé CTMP, les mélanges avec substitution de bouleau blanc jusqu'à 60% avec ou sans un pré-traitement chimique peuvent générer des propriétés physiques supérieures ou équivalentes à la pâte TMP-S mais avec un faible coefficient de diffusion de la lumière. Le degré de substitution par le bouleau blanc avec ou sans pré-traitement chimique devient moins important pour les propriétés physiques en comparant avec le procédé TMP.

Puisque l'utilisation de bouleau blanc a peu d'influence sur la quantité et la qualité des fibres longues, les effets des fines sur les propriétés physiques et optiques sont étudiés et comparés entre les pâtes TMP et CTMP. Les fines des pâtes TMP et CTMP contribuent différemment aux propriétés physiques et optiques. Une augmentation de l'indice de rupture est remarquée suivant l'augmentation du contenu en fines pour toutes les pâtes TMP et CTMP. Mais, une amélioration du coefficient de diffusion est seulement observée suivant l'augmentation du contenu en fines pour les pâtes TMP. Par contre, le coefficient de diffusion est presque inchangé pour les pâtes CTMP. C'est-à-dire que les fines des pâtes CTMP contribuent plus aux liaisons entre les fibres qu'à l'augmentation du coefficient de diffusion. D'autre part, les fines des pâtes TMP contribuent davantage à l'augmentation du coefficient de diffusion de la lumière qu'aux propriétés de résistance. Un compromis devra nécessairement s'effectuer entre le traitement chimique et le traitement mécanique, d'où les copeaux de bouleau blanc sont traités par des produits chimiques avant leur incorporation au mélange. Ainsi, on peut tirer profit de l'augmentation des propriétés de liaison des fibres de bouleaux tout en minimisant la perte au niveau du coefficient de diffusion en évitant de traiter les fibres résineuses qui ne requièrent pas de traitement chimique. Dans ce cas, une augmentation de coefficient de diffusion est nettement remarquée dans la pâte CTMP-Bns30.

4.4 Peluchage

La pâte thermomécanique de bouleau est très sensible au phénomène du peluchage dû au développement insuffisant de ses fibres et de ses vaisseaux. Un traitement chimique permet également d'augmenter la flexibilité des fibres de bouleau à un seuil suffisant pour assurer l'intégrité du matelas, d'où une forte réduction du peluchage pour la pâte CTMP-B en comparaison avec la pâte TMP-B. Le nombre total de fibres détachées passe de plus de 2000 par 65 cm^2 à moins de 720 par 65 cm^2, et la longueur cumulative des fibres diminue de plus de 150 m/m^2 à moins de 42 m/m^2. Par contre, avec l'utilisation de produits chimiques, le peluchage de la pâte CTMP-S demeure presque inchangé lorsque comparé avec celui de la pâte TMP-S. Pour les pâtes TMP et CTMP, la présence de bouleau blanc n'a qu'un effet léger sur le peluchage, résultant en une valeur acceptable, possiblement due à la présence des fines d'épinette de bonne qualité qui permet de tenir le matelas fibreux en place et aussi à cause du traitement chimique qui introduit les groupes sulfoniques dans la lignine et amène une amélioration de la séparation des fibres ainsi que la qualité des fines produites.

La mesure de la distribution des particules arrachées durant le test de peluchage par FQA démontre que plus de 90% du matériel détaché est fin pour toutes les pâtes sauf pour la pâte TMP-B. Pour la pâte TMP-B, environ 20% du matériel détaché sont des fibres longues et courtes. En réalité, la pâte TMP-B a un contenu plus élevé dans toutes les fractions par rapport aux autres pâtes. Ceci s'accorde bien avec les résultats antérieurs montrant que les fibres de la pâte TMP-B sont plus rigides et que les fines ont une surface spécifique inférieure à celle des autres pâtes.

L'examen au microscope optique indique que le matériel détaché est principalement constitué de rayon du bois et de fibres intactes peu développées. Quelques fragments de fibres sont aussi observés dans le matériel de peluchage, qui se sont possiblement détachés en même temps que les fibres intactes. Quelques débris sont observés dans le matériel de peluchage de la pâte TMP mais non dans celui de la pâte CTMP, ce qui signifie que la séparation de la fibre dans le procédé CTMP est bonne due à l'ajout de produits chimiques.

4.5 Théorie du co-raffinage

Il semble que le co-raffinage des copeaux en mélange sans produit chimique ne change pas la tendance du développement de la fibre de bouleau blanc et d'épinette noire comme observée dans le raffinage de l'essence seule. Ainsi, une réduction de la qualité (comme la flexibilité et le volume spécifique hydrodynamique) des fibres et des fines est observée avec l'addition de bouleau blanc. Finalement, les propriétés papetières diminuent proportionnellement à l'utilisation de bouleau blanc.

Un effet synergique est présent dans le mélange lors de la mise en pâte CTMP due aux bienfaits du traitement chimique et peut-être aussi à une protection des fibres de bouleau blanc contre la coupe de la fibre par les fibres d'épinettes noire. Les mélanges avec substitution de bouleau blanc jusqu'à 60% avec ou sans un pré-traitement chimique peuvent générer des propriétés physiques supérieures ou équivalentes à la pâte TMP-S mais avec un faible coefficient de diffusion. Une augmentation du coefficient de diffusion est obtenue lorsque les copeaux de bouleau blanc sont traités par les produits chimiques avant leur intégration avec l'épinette noire.

Mots clés : *Betula papyfera* Marsh, *Picea mariana*, pré-traitement chimique, pâte thermomécanique, pâte chimico-thermomécanique, papier journal, peluchage.

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ABBREVIATIONS

APMP	Alkaline peroxide mechanical pulp
B/S	White birch / black spruce
CMP	Chemi-mechanical pulp
CPD	Critical point drying
CPPA	Canadian Pulp and Paper Association
CTMP	Chemithermomechanical pulp
CTMP-B	Chemithermomechanical pulp of 100% white birch
CTMP-B30	Chemithermomechanical pulp of 70% black spruce / 30% white birch
CTMP-B60	Chemithermomechanical pulp of 30% black spruce / 60% white birch
CTMP-Bn30	Chemithermomechanical pulp of 70% black spruce / 30% white birch in which the white birch was treated by caustic before mixing
CTMP-Bns30	Chemithermomechanical pulp of 70% black spruce / 30% white birch in which the white birch was treated by caustic and sulfite before mixing
CTMP-S	Chemithermomechanical pulp of 100% black spruce
FQA	Fibre quality analyzer
HSV	Hydrodynamic specific volume
IWP	Ink weight on plate, g/m^2
L_{af}	Average cumulated fines length per unit of printed area, m/m^2
L_{am}	Average cumulated medium fibres length per unit of printed area, m/m^2
L_{at}	Average cumulated long fibres length per unit of printed area, m/m^2
L_f	Average fines length, mm (length < 0,85 mm)
L_l	Average long fibres length, mm (length ≥ 1,35 mm)
L_m	Average medium fibres length, mm (0,85 mm ≤ length < 1,35 mm)
L_t	Average fibres length, mm (whole samplepulp)
N	Total number of fibres removed during printing
Na_2SO_3	Sodium sulfite
NaOH	Sodium hydroxide

NSSC	Neutral sulfite semichemical pulp
PAPTAC	Pulp and Paper Technical Association of Canada
PGW	Pressurised stone groundwood pulp
RBA	Relative bonded area
RMP	Refiner mechanical pulp
S	100% black spruce
SBK	Sulfite bleaching kraft pulp
SEC	Specific energy consumption
SGW	Stone groundwood pulp
TAPPI	Technical Association of the Pulp and Paper Industry
TMP	Thermomechanical pulp
TMP-B	Thermomechanical pulp of 100% white birch
TMP-B10	Thermomechanical pulp of 90% black spruce / 10% white birch
TMP-B20	Thermomechanical pulp of 80% black spruce / 20% white birch
TMP-B30	Thermomechanical pulp of 70% black spruce / 30% white birch
TMP-B40	Thermomechanical pulp of 60% black spruce / 40% white birch
TMP-S	Thermomechanical pulp of 100% black spruce
WFF	Wet fibre flexibility
WRV	Water retention value

INTRODUCTION

Historically, softwoods were used as raw materials in mechanical pulping and hardwoods were considered unsuitable due to their different fibre morphology such as high density, short fibre length, thick cell wall and the presence of vessels (Table 0.1) [1, 2, 3, 4]. In the past the softwood resources were sufficient to supply the needs of mechanical paper grades. But as the production volumes increased, pressure was put on these resources meanwhile as the pulping technology improved, in the past decade or so, the species previously considered undesirable, such as hardwoods, were introduced into the furnish system. In Canada, the annual allowable cuts for softwood is different from the hardwood species [5]. Recent statistics indicate that the utilization of softwoods has reached the current rates of growth, while at the opposite, the hardwoods, especially the medium or high density species, are still a under-exploited resource. Although considerable attention has been given to the utilization of hardwoods in mechanical pulping due to their availability and low cost, the utilization of the dense hardwoods, such as birch, is still relatively small in the Canadian pulp and papermaking industry.

Table 0.1 Technical development of high-yield pulping [1].

Year	1900-1965	1965-1985	1975-1985	1985-1994
Pulping process	SGW	RMP TMP PGW	CMP	CTMP APMP
Capacity*	18,3	0,8 1,57 2,3	0,7	6,3 1,0
Wood species	– Spruce – Pine	– Spruce – Pine – Aspen – Cottonwood	– Spruce – Pine – Low, medium & high density hardwoods	– Spruce – Pine – Low, medium & density hardwoods
Products	– Newsprint – Speciality	– Newsprint – Speciality – Board	– Newsprint – Printing/writing – Tissue/towel – Corrugating medium	– Publication papers – Fine papers – Tissue / towel – Board

* Estimated World Capacity (1994) × 1,000,000 tpy

The most commonly used hardwoods in mechanical pulping are poplars, such as aspen and cottonwood, for their low density and high initial brightness, as shown in Table 0.1. Dense hardwood species, such as birch, find limited use in mechanical pulping, except in the process with chemical treatment such as CMP, CTMP and APMP.

Table 0.2 Various pulp production of Québec [6].

Production	1970	1980	1990	1999	2000
TMP	N.D.	N.D.	2205	3060	3305
CTMP	N.D.	N.D.	529	1223	1193
Other mechanical pulp	N.D.	N.D.	1863	607	610
Total mechanical pulp	3145	3256	4597	4890	5108
Kraft (sulfate)	1324	1570	1815	2227	2261
Other pulp	1447	1452	804	395	393
Total production	5916	6278	7216	7512	7762

N.D.: Non-determined.

Among the mechanical processes, the thermomechanical pulping is the most important in Québec (Table 0.2). The TMP produced from softwoods has a better combination of strength and opacity properties for newsprint than the other mechanical pulps despite its high-energy consumption. For example, although the TMP has lower optical properties compared with SGW because of its relative low fines content, it is much stronger than SGW. In comparison with CMP, the TMP possesses high fines content, which gives the paper a good opacity, and it has higher yield. Besides, the TMP fibres withstand better the wear of recycling when compared to the chemical pulp fibres [7]. Thermomechanical pulping process is recognized as a flexible process [8]. In its' two refining stages, chemicals may be used for chip treatment prior to refining or in inter-stage treatment or post-treatment, such as in the CTMP and the APMP. Another benefit of thermomechanical pulping is that sawmill residues can be utilized. During the last few years, the energy consumption of thermomechanical pulping has been reduced due to novel technologies, such as Thermopulp® (Metso Inc.) and RTS® process (Andritz Ltd) [9, 10]. The main end-use of TMP is newsprint due to its relatively low cost, high opacity and excellent printability.

White birch TMP is unsuitable for the manufacture of paper due to its significantly poor strength properties [11]. Several methods were proposed to increase the utilization of white birch in mechanical pulping [3, 12, 13, 14]. One way to increase the white birch TMP strength properties is by the use of chemicals. Law *et al* [3] compared the properties of CTMP pulps of white birch, grey birch and aspen under similar pulping conditions. Blodgett *et al* [13] studied the APMP properties made from birch and maple. Birch wood responded better to alkaline treatment in terms of increased pulp strength than did other hardwood species. In both CTMP and APMP, a relatively high concentration of alkali is necessary for the treatment of birch chips. The disadvantage is that the high concentration of alkali decreases quietly the opacity of pulps, and affects the brightness of the pulp to different extents despite the use of sulfite or peroxide.

Another way to broaden the use of birch in mechanical pulping is to produce acceptable TMP pulps by mixing the birch with softwoods. Several studies have been carried out especially on the physical and optical properties of the mechanical pulp of mixed species [12, 14, 15, 16, 17, 18]. The results showed that the physical properties of the pulp from chip mixtures are related to the proportion of each species used in the TMP process. A synergistic effect was observed on some physical properties of mechanical pulps from chip mixtures when chemicals were used in CTMP process. But, until now, only a few investigations have reported on the fibre behaviour of different species in co-refining of chip mixtures.

This study concerns the utilization of white birch (*Betula papyrifera* Marsh) (B) as a raw material in thermomechanical and chemi-thermomechanical pulping for newsprint furnish. The objective is to determine the effects of the substitution of white birch for black spruce (*Picea mariana*) (S) on the mechanical and optical properties in TMP and CTMP processes, and to study the fibre morphology in order to better understand the behaviour of the short fibres of white birch in co-refining. In addition, considering the different response to chemical treatment of hardwoods and softwoods, we also study the feasibility of modifying the white birch chips by chemical pre-treatment before co-refining then with untreated black spruce chips.

Chapter 1 - WOOD SPECIES

1.1 Introduction

The morphological properties of wood are usually recognized to be the most important factors determining the mechanical pulp and paper quality [4]. Morphological variations, such as fibre length, diameter, cell wall thickness and flexibility, exist between different groups, genus, and species and even within the individual tree.

The basic density of wood is an important physical property for predicting some of the pulp and paper properties because it is determined by several characteristics, such as cell size and cell wall thickness, and volumes of vessel and ray cells [19, 20, 21]. A high wood density generally indicates a slow beating/refining response, low strength and great bulk. For example, northern spruces are recognized as the best species for making TMP with good strength and optical properties. They require lower refining energy when compared to the denser softwoods, such as pines and Douglas fir. In the case of hardwood species, poplars have lower density and produce stronger mechanical pulp than the dense hardwood species, like birch and maple. But it is not always the case when comparison is carried out between softwoods and hardwoods since the essential differences exist besides the basic density. For example, spruce produces stronger TMP than aspen although it has a relative higher density than aspen. In this case, some other properties, such as wood composition and fibre properties, should be considered.

Softwood consists of tracheids and ray parenchyma (ray cells), while hardwood consists mainly of fibres, vessels and parenchyma (ray and longitudinal parenchyma). These cells have different shapes and chemical compositions for different species. They provide different contributions to pulp and paper properties. The parenchyma cells are fine with a brick-like structure and a highly lignified cell wall [22]. They are considered as the main component of lint material that accumulates on the offset blanket during printing and influences the print quality [23]. Sulfonation increases somewhat the bonding ability of the ray cells thus reducing linting [24]. The vessels have tube-like structure and composes of individual vessel elements. These cells have large diameter and shorter length with thinner cell walls as compared to the fibres. They are responsible for the vessel-picking problem [25, 26].

The principal fibrous component is fibre and tracheid for hardwoods and softwoods, respectively. They have similar structure but the hardwood fibres are smaller both in length and diameter in comparison with the softwood tracheids. In the pulp and paper industry, both of them are usually called fibre. The fibre morphology influences greatly the properties of pulp and paper. For example, the ratio of lumen diameter to fibre diameter determines the degree of deformation of fibres under load [21]. If the lumen is small and the cell wall is thick, the fibres are stiff and difficult to deform. Understanding the characteristics of fibre morphology, such as fibre shape, coarseness, flexibility, and cell wall structure help understand their influence on mechanical pulp properties and refining behaviour of wood.This knowledge is useful for developing better pulping strategies.

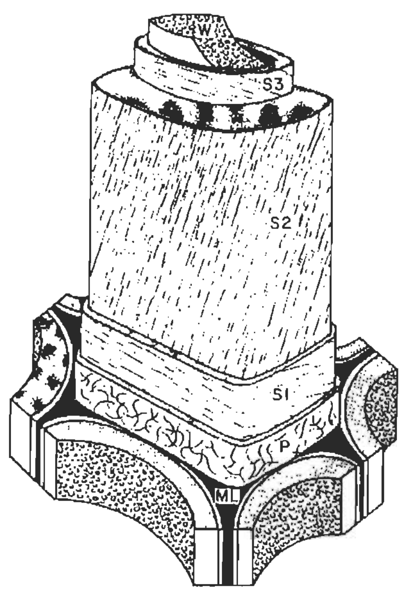


Figure 1.1 The cell wall structure of soft- and hardwood fibres [27].

ML = middle lamella, P = primary wall, S_1 = out layer of secondary wall, S_2 = middle layer of secondary wall, S_3 = inner layer of secondary wall, W = warty layer

Several layers build up the cell wall of fibres as shown in Figure 1.1. These layers differ from each other with respect to their structure as well as chemical composition [27]. The middle lamella together with the primary wall (containing microfibrils with little or no orientation) is referred to as the compound middle lamella (CML), in which lignin concentration is more than 85%. But it contributes only 20-25% of the total lignin in wood. The secondary wall consists of three layers: S_1, S_2 and S_3. The characteristics of S_2, such as layer thickness and microfibrillar angle, have a decisive influence on fibre stiffness and hence on the papermaking properties, due to its higher thickness (about 40 times thicker than the adjacent S_1 and S_3).

1.2 Forest resources

In Canada, birch is the second most abundant hardwood with a gross merchantable volume of over one billion m^3 distributed through most of Canada (Table 1.1) [28]. In Québec, the hardwoods represent about 30% of the total forest merchantable volume, in which the primary dominant hardwood species are birches which represent 44,6% of the total hardwood volume (Table 1.1).

Black spruce, the most popular and typical species for mechanical pulping, is chosen in this study. In Canada, spruce is the most abundant softwood and it accounts for 42,5% of the softwood volume (Table 1.2). In the next section, physical and chemical compositions of white birch and black spruce will be examined.

Table 1.1 Volume of hardwood species in Canada and Québec, 1999 [28].

Species	**Volume, millions of m^3**		**%**	
	Canada	**Québec**	**Canada**	**Québec**
Poplar	3525	322	62	24,9
Birch	1198	576	21	44,6
Maple	683	313	12	24,2
Other	291	81	5	6,3
Total	5699	1292	100	100

Table 1.2 Volume of softwood species in Canada and Québec, 1999 [28].

Species	Volume, millions of m^3		%	
	Canada	Québec	Canada	Québec
Spruce	8189	1761	42,5	60,6
Pine	4539	276	23,6	9,5
Fir	2951	734	15,3	25,2
Hemlock	1690	28	8,8	1,0
Cedar	900	90	4,6	3,1
Douglas fir	823	-	4,3	-
Larch	172	17	0,9	0,6
Total	19267	2906	100	100

1.3 Physical properties

Table 1.3 illustrates the morphological properties of birch and spruce. Aspen is also shown for comparison because it is a popular hardwood species accepted by the pulp and paper industry. In birch, the fibre accounts approximately for 76% of the wood volume, while the spruce tracheid 90% and aspen 55% [29]. Birch fibre is much shorter with thicker cell wall and smaller lumina when compared to spruce tracheid. But it is longer with thicker cell wall relative to the aspen fibre. A relatively thicker S_1 layer of birch fibres is considered to impede fibres flexibility [30, 31]. The density of birch fibres is higher than those of spruce and aspen. With these characteristics the birch fibre give a rigid structure and less responsive to refining compared to spruce and aspen. However, the small dimension of birch fibres could play an important role in forming a strong fibrous network when blended with the long fibres of softwood.

As mentioned previously, obvious morphological variations exist between speciesand within the same species. In temperate zones, the wood composes of earlywood and latewood due to the seasonal changes. Large variability in fibre morphology appears between early- and latewood. The proportion of latewood in black spruce is about 20% [32]. The earlywood fibres are thin-walled with large radial diameter and large lumen in contrast to the latewood fibres, as shown in Figure 1.2. Recent researches [33, 34, 35, 36] reported that early- and latewood fibres behave differently in mechanical refining.

Table 1.3 Morphological properties of softwood/hardwood [37].

Properties	Fibre/Tracheid			Vessel		Parenchyma	
Species	**Birch**	**Aspen**	**Spruce**	**Birch**	**Aspen**	**Birch/Aspen**	**Spruce**
Length, mm	1,5	1,1	3,5	1,0	1,0	0,12	0,12
Diameter, μm	20	18	35	65	90	12	12
L/D	70	60	100	15	15	10	10
Coarseness, mg/m	13	9	18	-	-	-	-
Wall thickness, μm	3,8	2,6	1,5	2,7	2,4	1,0	1,0
Volume, %	76	55	90	11	33	13/12	10
Density, g/cm³	0,53	-	0,48	-	0,39	-	-

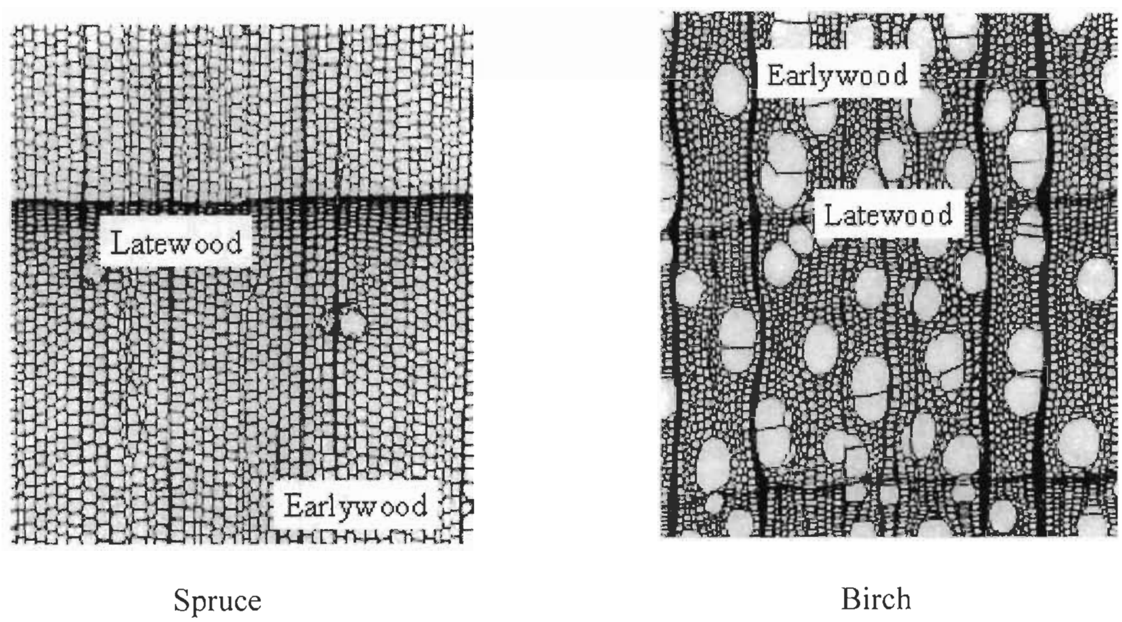


Figure 1.2 Wood cross-section, 65X [38]

The fibre distribution in birch wood is much more uniform compared to spruce due to its lower content of latewood and little difference observed between early- and latewood vessel segments (Figure 1.2). Similar to latewood fibres in spruce, the birch fibres also have a rigid structure with a thick wall but shorter length.

Table 1.3 also shows that birch wood possesses much more parenchyma cells than spruce, which may increase the linting propensity in offset print for the paper produced from birch mechanical pulp. Besides the fibres and parenchyma cells, birch contains vessels, which amount to 11% of the wood volume. In the manufacture of printing paper products, the vessel elements can cause difficulty with respect to the surface quality of the paper since they have lower bonding ability. But the vessel elements are beneficial for liquid penetration into the wood during impregnation.

1.4 Chemical properties

White birch contains significantly lower amounts of lignin and higher levels of hemicellulose but a similar cellulose content when compared with spruce (Table 1.4). Like spruce, the lignin concentration in white birch fibre is high in the middle lamella but low in the secondary wall (Tables 1.5 and 1.6). White birch has a lower degree of lignification in both S and ML than spruce. The low lignification of the cell wall gives birch better swelling in alkali than spruce.

The birch vessels have a different chemical composition from the fibres. The lignin of vessels is mostly composed of guaiacyl (Gu) units while the lignin in the S layer of birch fibres is rich in syringyl (Sy) units (Table 1.6).

Table 1.4 Chemical composition of different species [39].

Properties, %	Hardwood		Softwood
	White birch	Aspen	Black spruce
Holocellulose	-	80,3	71,7
Cellulose	41,0	49,4	51,1
Polyoses	27,3	21,2	15,2
Pentosanes	-	17,2	7,6
Lignin	18,5	181	27,3
Ethanol-benzene extract	-	3,8	2,6
Hot water solubility	2,8	2,8	2,5
Ash	0,4	04	0,2

Table 1.5 Distribution of lignin in spruce tracheid [40].

Wood	Morphological region	Tissue volume, %	Lignin, % of total	Lignin concentration
Earlywood	S	87	72	23
	ML	9	16	50
	CC	4	12	85
Latewood	S	94	82	22
	ML	4	10	60
	CC	2	9	100

S: secondary wall; ML: middle lamella; CC: cell corner.

Table 1.6 Distribution of lignin in white birch [41].

Cell	Morphological region	Lignin type	Tissue volume, %	Lignin, % of total	Lignin concentration, %
Fibre	S	Sy	73	60	19
	ML	SyGu	5	9	40
	CC	SyGu	2	9	85
Vessel	S	Gu	8	9	27
	ML	Gu	1	2	42
Ray cell	CC	Sy	11	11	27

S: secondary wall; ML: middle lamella; CC: Cell corner.
Sy: syringly; Gu: guaiacylSyGu: syringly-guaiacyl

1.5 Conclusions

- Birch wood is more heterogeneous in tissue composition compared to spruce by having higher content of parenchyma cells and vessel elements. These two components can cause linting problems of paper containing birch mechanical pulps, such as newsprint.

- Birch fibres have a more rigid structure than those of spruce, such as higher density, shorter fibre length and thicker cell wall. These properties cause low responsive to refining and give low strength properties in mechanical pulp and in the paper produced.

- Chemically, the birch has higher hemicellulose content and lower lignin in the cell wall. However, birch wood is more responsive to alkaline treatment compared to the softwoods which have higher lignin content.

Chapter 2 - MECHANICAL PULPING

2.1 Introduction

The purpose of mechanical pulping is to transform the raw material into fibres and fines by absorption of energy through shear action as well as repeated compression and decompression of the fibre without heavy loss of yield [42, 43]. In contrast to chemical pulps, lignin is kept in mechanical pulp or is just modified by chemical treatment to make it more elastic and than facilitate the mechanical separation of fibres. The mechanical pulps can be divided into two distinctly different processes:

- Stone grinding based mechanical pulping process, such as SGW and PGW.
- Refiner based mechanical pulping process, such as TMP and RMP, CTMP and APMP, etc.

Grinding process was the first successful commercial way of using wood as papermaking fibre resources [44]. It uses logs as raw material and produces relatively low strength pulp compared to other mechanical pulps. During the last two decades, world capacity of SGW has gradually declined due to the development in modern mechanical pulps, such as TMP, CTMP and APMP. In fact, in the past few decades, the growth in production capacity of mechanical pulping is largely attributed to refiner based mechanical pulping process, especially thermomechanical pulping that started in 1968. In 2000, TMP combined with CTMP accounts for 31% of the total pulp products in Canada. In Québec, the TMP accounts for 43% of total pulp products [6, 45].

Until now, the most popular wood species used for thermomechanical pulps are softwoods, such as spruce and balsam fir. Hardwood species produce a thermomechanical pulp with poor strength unless a chemical treatment is applied. CTMP and APMP are recognized as two suitable mechanical pulping processes for hardwood species.

TMP is now generally used in replacement of the mixture of chemical pulps and SGW to produce newsprint, reducing the use of expensive chemical pulp due to its relatively lower cost, high opacity and excellent adaptability to printing applications. CTMP can be used as reinforcement pulps for some special newsprint and coated printing papers. It can be used also at higher freeness levels for tissue and fluff grades.

2.2 Thermomechanical pulp (TMP)

2.2.1 TMP process

Thermomechanical pulping process consists usually of a pre-steaming of wood chips and first-stage refining at elevated temperature and pressure followed by a second-stage atmospheric or pressurised refining, as shown in Figure 2.1 [46]. The main objective of preheating the chips at 110 - 135 °C is to soften lignin and to make the refiner operation more uniform. In commercial process, the heat is recovered from both refining stages.

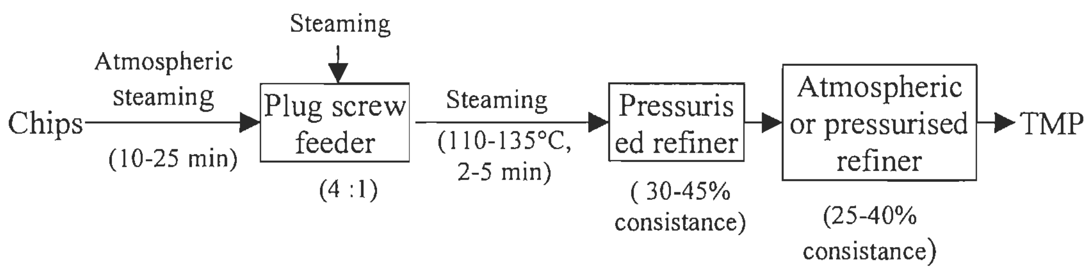


Figure 2.1 Schematic of two-stage TMP refining.

Generally, the thermomechanical pulping process has several advantages:

- Very high yield, improving the utilization of wood in comparison with chemical pulp;
- Using both pulpwood chips and sawmill residues in contrast to the stone grinding processes (SGW, PGW and PGW-S);
- From an environmental point of view, no sulfur or odor emission and no chlorinated by products;

- Very flexible, the two stages refining process allow the use of small amount of chemicals in the form of chip pre-treatment prior to refining, inter-stage or post-treatment to improve pulp properties.

- TMP fibres withstand the wear of recycling better than chemical pulp fibres [7].

2.2.2 Refining theory

Since the first application of chips refining developed by Arne Asplund in 1931, attention has been given to the understanding of the mechanism of chips refining [47, 48, 49, 50, 51]. A detailed description on the development of refining mechanism is summarised by Petit-Conil [52] and Tyräinen [53]. Karnis gave a relative complete mechanism schema for fibre separation and the fibre development during refining [51], as shown in Figure 2.2. It is generally recommended that refining takes place in two concurrent stages: a defibration stage and a fibre development stage. It means that after the initial breakdown of chips to shives and then to individual intact fibres in the defibration stage, the following predominate process is the delamination (*internal fibrillation*) of the fibres and peeling off of the primary and S_1 layers and exposing the S_2 layers (*external fibrillation*) (Path II in Figure 2.2, peeling-off mechanism). At the same time, some fibres are broken down to shorter fibres and fines (Path I in Figure 2.2, breakage or cut mechanism). The majority of the broken fibres in TMP is created during the initial defiberization of chips in the primary refiner [54]. The initial separation of fibres from wood matrix controls the degree of surface exposure of TMP fibres [55]. The fines produced from the first-stage refining consist mainly of fibre wall and thin fibrils, probably originated from the outer layers of fibre, as well as ray cells [56]. Most of the fines are flake-like materials and are considered as part of the lint candidate materials in the final pulp. In the second-stage refining, the principal change is an increasing proportion of fibrillated and shorter fibres with some little increases in fibrillar content of the fines and in the fines content.

Historically, the refining process was considered as a pulping process by absorption of energy through repeated compression and decompression of the wood matrix. But recent research suggests that refining is conducted with a very high shear-to-compression ratio in contrast to the conventional concept of compression-decompression cycles [43]. The shear mainly causes fibre separation and fragmentation (peeling, cutting, splitting and external fibrillation), while the compression contributes principally to fibre deformation and delamination (internal fibrillation), thus increasing fibre flexibility (Figure 2.3). A predominant shear action may be a limit in current refining technology to further improve pulp quality. Apparently, in an ideal refining process, the shear action predominates at the beginning of first stage refining and causes the breakdown of chips. Later, the compression becomes important for fibre development.

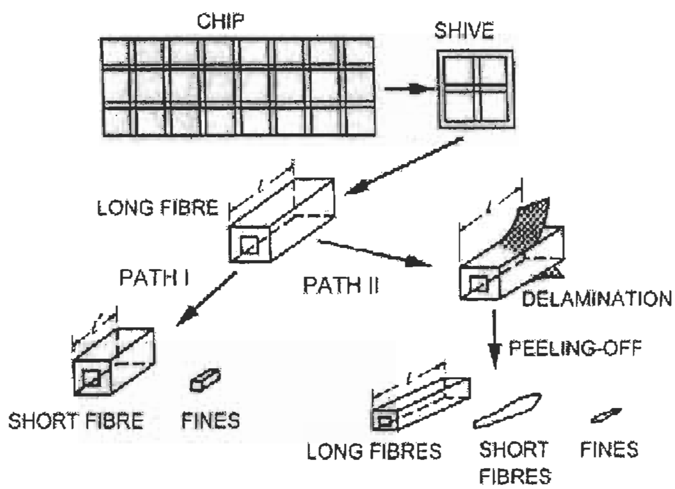


Figure 2.2 Fibre refining mechanism process proposed by Karnis [51].

Late- and earlywood fibres behave differently in refining. Several studies have been carried out on the behaviour of latewood and earlywood during refining and different results were obtained. Iwamada [57] reported an increase in the amount of thick-walled latewood fibres following the augmentation of refining energy. Koljonen *et al* [58] found that the number of latewood fibres decreased but their properties seemed to be unchanged. Recent studies by Reme *et al* [34] explained that latewood fibres had a larger reduction in wall thickness than earlywood fibres. It is generally accepted that most of the split fibres were earlywood fibres and they occurred mainly during the 1st refining stage [33, 34, 35]. Clearly, further studies are necessary to understand better the refining mechanism in detail.

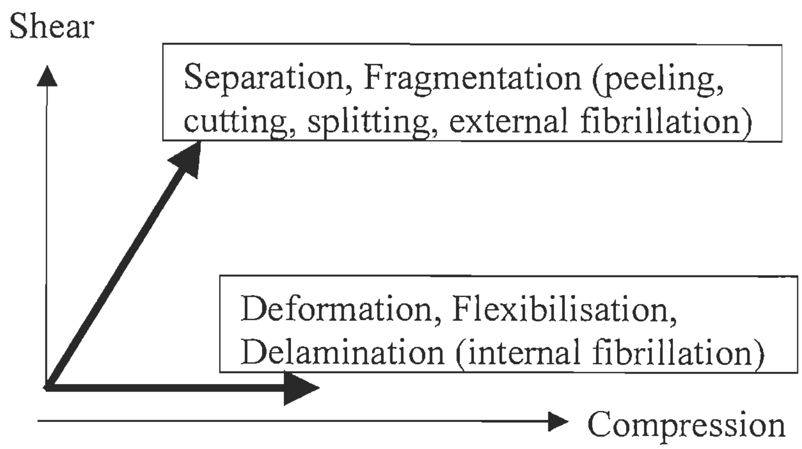


Figure 2.3 Relative contributions of shear and compression actions in chip refining [43].

2.2.3 Energy consumption

The TMP quality depends largely upon the applied specific energy [59]. Compared to other mechanical pulps, the main disadvantage of TMP is its high-energy requirement. Studies by Stationwala *et al* [60] indicated that a minimum level of specific energy is needed in the first stage before the effect of refining intensity on pulp quality became apparent. Above this minimum level, a relatively low specific energy at high intensity in the pressurised first stage followed by high specific energy at low intensity in the atmospheric second stage can produce pulps of the same quality as a conventional TMP at only about 75% of its total energy consumption. In 1995, Sunds Defibrator [61, 9] introduced the Thermopulp® process in which the primary stage is operated under the conventional TMP conditions where the temperature is below the lignin softening temperature. During the second stage, the pulp is heated above the lignin softening temperature to give efficient fibre fibrillation. Commercial application of this process showed that 10-20% savings in specific energy consumption could be obtained without sacrificing pulp quality. Almost at the same period, Andritz Ltd [10, 62] introduced the RTS® process in 1996 and commercialised it soon thereafter. In this process, the chips are subjected to an elevated temperature (T) for a short residence (R) time (10s to 18s) prior to a high speed (S) primary stage refining. The temperature (approx. 166°C) is higher than the glass transition thermal softening of lignin, at which the fibre wall is softened prior to refining. But the retention time should be short to avoid the brightness loss of pulp. A significant reduction (10-25%) in specific energy consumption resulted with no loss of pulp quality.

2.2.4 TMP properties

TMP made from some softwoods, such as spruce, have an excellent combination of strength and opacity properties. In comparison with CTMP, TMP produces paper with good opacity and excellent printability with a comparable strength due to its high fines content, as shown in Table 2.1. On the other hand, TMP is much stronger than SGW and RMP although it has slightly lower light scattering coefficient due to its relative low fines content.

Table 2.1 Properties of different mechanical pulps at 100 ml CSF [63].

Pulp type	SGW	RMP	TMP	CTMP
Burst index, kPa·m²/g	1,37	2,37	2,86	3,35
Tear index, mN·m²/g	4,44	6,91	7,49	7,30
Bulk, cm³/g	2,30	2,65	2,40	2,40
Wet breaking length, m	170	270	290	360
Scattering coef., m²/kg	65,0	68,5	64,0	59,0
Shives content, %	0,50	0,30	0,20	0,04
Specific energy, MJ/kg	5,33	7,39	8,81	8,74

According to the fibre shapes and sizes, Karnis [51] divided TMP contents into the following four categories:

- Fibre bundles, such as shives and minishives;
- Long fibres: fibres retained on the 48-mesh screen of a Bauer McNett classifier, they have a length longer than 1,44 mm
- Short fibres: fibres passed the 48-mesh screen but retained on a 200-mesh screen; they have a length between 0,52 and 1,44 mm
- Fines, the particles passed the 200-mesh screen with a length less than 0,52 mm.

The long-fibre and the fines fractions are recognized as the most important parts for TMP properties. High long-fibre content or high average fibre length determines the TMP strength, especially the tear strength, which gives paper machine and print machine good runnability [64, 4]. But the mechanical long fibres remain rigid with a high degree of coarseness and freeness (more than 700 ml CSF) [65]. They tend not to collapse spontaneously during sheet forming and the paper made from them is bulky with a poor tensile strength. Apparently, the removal of the outer layer of the long fibres or the decrease in coarseness is not enough to improve the flexibility and promote any substantial bonding ability. In this case, the presence of fines becomes very important to reinforce the pulp strength.

Fines play an important role in tensile strength and optical properties [66, 67, 68]. The TMP fines bring fibres into closer contact, form new inter-fibre connections, cause some fibre bending and deflection thus improving the paper strength and light scattering property by augmenting the number of scattering sites in the sheet. It is generally accepted that the fines can be classified into two groups: fibrillar (e.g. fibrils) and non-fibrillar materials (e.g. flakes) [69, 70, 71, 56, 72]. The fibrils and the non-fibrillar materials contribute differently to the strength and optical properties. The fibrils are thread-like particles peeled off from the secondary wall while the non-fibrillar materials are flake-like particles from the middle lamella and primary wall, ray cells and vessels. An increased fibrillar content in the fines augments the strength properties and has little effect or decreased the light scattering [56]. The flake-like fines behave probably like filler particles and contribute mostly to increasing the number of scattering sites in the sheet and thus the light scattering. The relationship between the chemical composition of fines and their physical properties is not clear. Generally, the lignin content decreases due to an increase in the proportion of lignin-poor fibrillar fines following the application of higher levels of refining energy.

2.2.5 Wood species influence

Wood species have a significant effect on TMP quality [73]. Different species respond differently to the refining action. Several investigations on TMP pulps of different softwood species showed that high-density wood species (e.g. pines), which have rigid and thick-walled fibres, require high refining energy and produce low strength pulp compared to those woods with thinner-walled fibres (e.g. spruce) [19]. The ideal wood material for TMP is of low density with long fibre length, thin cell walls and large lumen, such as spruce and balsam fir, which give TMP excellent strength, as shown in Table 2.2.

Table 2.2 TMP from different species [11, 74].

Species	White birch	Aspen	Black spruce	Balsam fir
Energy, MJ/kg	-	-	6,1	-
Freeness, CSF	100	100	99	90
Bulk, cm^3/g	3,23	2,74	2,19	2,36
Burst index, $kPa \cdot m^2/g$	0,5	0,90	3,0	3,0
Tear index, $mN \cdot m^2/g$	2,7	3,10	9,0	8,2
Tensile index, N·m/g	14	23	53	49
Stretch, %	0,9	-	-	2,6
ISO Brightness, %	50	58,0	59,4	54,6
Opacity, %	99	-	96,5	97,0
Shives content, %	-	0,50	0,09	0,44

Hardwoods were considered unsuitalbe for mechanical pulping due to their original short fibres and rigid structure of fibre cell wall as well as the abundant ray cells and vessels (see Chapter 1). Compared to spruce and balsam fir, both aspen and birch with low and medium density, respectively, produces TMP with adequate light scattering ability but poor strength quality (Table 2.2). Marton *et al* [75] reported that it was the thickness of the S_1 layer that might be responsible for the poor response of dense hardwoods to TMP process (Table 2.3). But studies by Cisneros *et al* [55] indicated that birch TMP fibres with thicker S_1 layer showed less retention of this layer than did aspen. However, the birch TMP showed lower strength properties than aspen TMP (Table 2.2). The possible explanation is that birch fibres are more rigid (higher coarseness and thicker cell wall) than those of aspen. Apparently, the high exposure of S_2 layer does not mean high strength properties for the pulp. Some other properties, such as fibre length and flexibility, participate in the final elaboration of the pulp properties.

Giertz [76] compared the fines and fibres quality respectively from hardwood and softwood mechanical pulps. He indicated that the fines from hardwood CMP (90% yield) produced a paper of low quality either in combination with the hardwood fibres or with softwood fibres. But the fibres of hardwood CMP (90% yield) produced good strength properties in combination with the fines from softwoods. Apparently, the poor quality of fines is one of the main reasons for the low strength properties of hardwood mechanical pulps.

Table 2.3 Thickness of fibre cell wall layers of white birch and Norway spruce [75].

Cell wall layers	Norway spruce		White birch
	Earlywood	Latewood	
S_1, μm	0,13	0,18	0,21
S_2, μm	1,26	3,81	1,44
S_3, μm	0,13	0,10	0,09
Total, μm	1,52	4,09	1,74

2.3 Chemi-thermomechanical pulp (CTMP)

Hardwood fibres are shorter and more rigid than softwood tracheids. This feature imparts smooth printing surface and excellent optical properties to TMP pulps but with low strength properties. One way to improve the mechanical pulp qualities of hardwood species is to apply a chemical treatment to the wood chips. Sodium hydroxide is considered as the best solvating and swelling agent for hardwood species. Microscopic analysis proved that alkaline soaking of wood chips can swell the secondary wall of the fibre, which reduces rapidly the resistance to compression of the cell wall and changes the ability of the fibre to absorb energy and to bond [77]. Since alkaline treatment alone will darken the chips and decrease the brightness of pulps, sulfite or hydrogen peroxide is combined with alkali to treat the chips to reduce the influence of alkaline darkening. Based on these results, two ways for chemical pre-treatment are commercially available for mechanical pulping: alkaline sulfite as in CTMP and alkaline peroxide as in APMP [78, 12, 79, 80]. Only CTMP is discussed in this research.

2.3.1 Chemical impregnation of wood chips

The major concern with the chemical pre-treatment of chips prior to refining is the thorough distribution of chemicals throughout the chip matrix. In fact, an ideal uniform distribution of chemicals in the chips requires a severe treatment condition, such as high temperature and long time, which is not convenient for commercial units. According to Kurra *et al* [81], slightly uneven impregnation does not significantly affect the shives content and energy consumption as well as the pulp properties, but the totally unimpregnated areas present in the chips do affect. Generally, steaming and compression of chips are the two most effective methods to improve the impregnation uniformity [82, 83]. Steaming can displace the air in the chips and create a partial vacuum as the hot chips are submerged in the cool pulping liquor. The chips can also be compressed mechanically by using screw feeding, such as the Prex™, Impressafiner™ and Bi-Vis™ systems. The compression squeezes out some of the water-soluble organic components of the wood and shred the chips to open up the wood structure. Thus the chips absorb liquid like a sponge.

The sulfite treatment of spruce chips followed by refining showed that 80% of the sulfonation takes place during the preheating stage and 15% during refining and 5% after the refining (post sulfonation) [84]. This means that in the CTMP process, the sulfonation of lignin is completed substantially in a few minutes before the chips enter the refiner. This implies that a high liquor-uptake is important for increasing the sulfonation degree of pulps, thus strengthening fibre-fibre bonds and reducing the degree of alkaline darkening during the sulfonation reaction. Jackson *et al* [85] studied the relative effects of atmospheric pre-steaming and impregnation time on water uptake by chips. They indicated that a short atmospheric pre-steaming (10 minutes) is sufficient to get a significant increase in liquid uptake during subsequent impregnation. After presteaming, the liquor uptake occurs rapidly in the first 6 minutes during the following impregnation and then increases slightly.

In the CTMP process, the chemical treatment of chips with (alkali-) sulfite is so mild that it dissolves only small amounts of monomeric end groups and brings about partial sulfonation of the lignin, which improves the fibre flexibility and the pulp brightness. The main reactions are the sulfonation of lignin and the release of hydrolysable coniferaldehyde end groups [86].

2.3.2 CTMP properties

Hardwood and softwood respond differently to chemical pre-treatment by sodium sulfite and sodium hydroxide. The cell wall of softwood tracheids is more lignified (see Table 1.5 and 1.6 in Chapter 1) and thus restricts the swelling in alkali compared to the hardwoods. In addition, the vessel elements in hardwood are beneficial for penetration of liquids into the interior of the wood in impregnation stage with chemicals, as discussed in Chapter 1. Due to these reasons, the use of sodium hydroxide as a pre-treatment chemical is restricted to hardwoods [85]. Valade *et al* [12] confirmed this conclusion by comparing the CTMP properties of spruce/balsam fir and white birch by using different chemical composition of sodium sulfite and sodium hydroxide. Alkaline treatment improved significantly the strength properties of hardwood pulps with decreasing refining energy requirement but yielded little effect on those of softwood. Obviously, in the case of softwoods, sodium sulfite alone is enough to yield the pulps of high strength with high density and brightness. For hardwood, a combination of sodium hydroxide and sodium sulfite has a synergistic effect on the softening of chips while reducing the influence of alkaline darkening during the sulfonation of lignin and increasing the pulp strength due to the use of alkali (Table 2.4) [12, 40]. The typical pulping conditions of CTMP for hardwood and softwood are shown in Table 2.5. The degree of sulfonation is about 0,8 to 1,5% bound SO_3^{-2} for CTMP.

Table 2.4 compares the CTMP and TMP properties from aspen and spruce. Increasing the sulfite from 1,7% to 4,6% for spruce improves the burst and tensile strength as well as the brightness. For aspen, the impregnation of chips with the combination of 3% sodium hydroxide and 1,5% sodium sulfite is necessary to improve the sheet density and strength properties with somewhat lower brightness in comparison with TMP. For birch, a dense hardwood, a high alkaline charge is necessary to produce CTMP with reasonable strength. In this case, the pulp opacity and brightness decrease definitively although sulfite is used [12].

Table 2.4 Comparison of CTMP and TMP from aspen and spruce [75].

Properties	Aspen[1]			Spruce[2]		
	TMP	CTMP	CTMP	TMP	CTMP	CTMP
Na_2SO_3, %	0	1,5	1,5	0	1,7	4,6
NaOH, %	0	3,0	3,0	0	0	0
Yield, %	100	90-94		100	-	-
Specific energy, MJ/kg	-	8,4	7,3	7,1	7,7	8,3
Freeness (CSF), mL	100	75	105	100	100	100
Density, kg/cm^3	365	490	470	405	438	445
Burst index, $kPa{\cdot}m^2/g$	0,90	2,9	2,5	2,35	2,55	2,90
Breaking length, m	2350	4800	4400	4200	5200	5350
Tear index, $mN{\cdot}m^2/g$	3,10	5,1	5,0	8,6	8,4	8,2
Scattering coef., m^2/kg	68,0	-	-	43,5	40,0	38,0
Opacity, %	-	92,3	92,5	-	-	-
ISO Brightness, %	58,0	48,1	48,6	53,0	56,5	57,0

1. For aspen: impregnation with sodium hydroxide and sodium sulfite, 8 min preheating at 125°C.
2. For spruce: impregnation with sodium sulfite at pH 9.5, 3 min preheating at 125°C.

Table 2.5 Typical pulping condition of CTMP for hardwood/softwood [87].

Conditions	Softwood	Hardwood
Na_2SO_3, %	1 – 4	1 – 3
NaOH, %	–	1 – 7
Temperature, °C	130 – 140	100 – 120
Time of preheating, min	2 – 5	0 – 5
Yield, %	91 – 96	88 – 95
ISO Brightness, %	82	85
Sulfonation degree, %	0,8 – 1,5	

Cisneros *et al* [55] compared the effects of different refining processes (TMP, CTMP and CMP) on aspen and birch fibres surface development by microscopic studies. They found that chemical treatment of chips did not improve fibre surface quality in comparison with TMP process. The S_2 layer was less exposed in CTMP than in TMP for the same species. They suggested that the main modification was the increase of fibre flexibility. For this reason, the paper strengths from CTMP were substantially higher than that of TMP.

2.4 Mechanical pulps of chip mixtures

Another way to improve the strength properties and broaden the use of hardwoods in mechanical pulp is to blend hardwoods with softwoods to produce mechanical pulps. Several studies have been reported on mechanical pulping of hardwood/softwood (H/S) chip mixtures [12, 14, 15, 16, 17, 18]. The pulping process includes RMP, CMP, TMP and CTMP.

Hatton and Johal [16] studied the RMP and CMP pulps from chip mixtures of trembling aspen/white spruce and red alder/western hemlock. Specific energy consumption decreased consistently with increasing hardwood content for both RMP and CMP. The strength increased in CMP when 25% of spruce chips were replaced by aspen. But decreases in strength were observed in direct proportion to hardwood content for both species combinations in RMP process. No significant differences appeared between the strength properties of handsheets prepared from the co-refined pulp and the mixed pulp of separate refining, at the same freeness. They indicated that hardwood and softwood chips appeared to act independently of each other in mixed refining. Later studies [17] on TMP and CTMP of trembling aspen/white spruce chip mixtures showed that increasing aspen substitution had no change in the specific energy requirements in both TMP and CTMP processes for a given freeness. A partial replacement of spruce by aspen appeared to have no effect on the strength properties for CTMP. Increasing the substitution of aspen decreases the strength of TMP pulps. Decreases in long fibre fraction (+48 mesh) for both TMP and CTMP were observed with increasing substitution of aspen. The fines contents (P200 mesh) were similar and independent of aspen content. They proposed a protection-mechanism of co-refining in which the longer fibre of spruce protected the shorter aspen fibre.

Valade *et al* [12] studied the use of white birch in spruce/balsam CTMP and TMP. Using of white birch reduced the energy consumption for TMP and CTMP. Synergetic effects appeared only on certain strength properties, such as tear and burst, for CTMP of chip mixtures. The TMP pulps from chip mixtures containing 15% of poplar hybrid showed strength properties (tensile and tear) similar to those from western hemlock alone [18], while the brightness, scattering coefficient and surface smoothness increased substantially.

Law *et al* [88] compared the properties of CTMP of white birch, grey birch and aspen under similar pulping conditions. The CTMP of white birch and aspen mixtures has physical properties comparable to the pulp of 100% aspen when the proportion of white birch ranged up to 10%. In their studies, synergetic effect existed when the dense hardwood species is mixed with the less denser hardwood species.

Generally, the effect of addition of hardwood in softwood depends on the wood species used and the pulping method. Adding up to 10-20% of hardwood chips in mixture with softwood in TMP process showed equivalent or better combination of optical properties but the strength properties are lightly lower than those from softwood alone. Further increases in the proportion of hardwood in the softwood in TMP process decrease gradually the strength properties of pulp. No synergetic effect was found in mechanical pulping of hardwood/softwood chip mixtures without chemical treatment. Synergetic effect was only found in mechanical pulping with the addition of chemicals (such as CTMP and CMP) for hardwood/softwood chip mixtures.

Unfortunately, most of the studies discussed above are concentrated on the physical and optical properties relative to the utilization of hardwood species in mixing with softwood species or other hardwood species. Little research is carried on the studies of fibre morphology to better understand the mechanism of co-refining. It is obvious that further studies must be done to understand more the mechanism of co-refining.

Chapter 3 - NEWSPRINT PRODUCTION

3.1 Introduction

As the largest segment of the Canadian paper and paperboard industry, newsprint sector represents almost 50% of the paper and paperboard capacity [89]. In the province of Québec, newsprint accounts for 38% of provincial pulp and paperboard capacity and accounts for 44% of Canadian newsprint production [6], as shown in Table 3.1. SGW was traditionally the primary furnish used for newsprint. However, TMP has become more and more commonly used in the last five to ten years [90]. The addition of chemical pulp decreases also due to the use of mechanical pulps with high strength (Table 3.2). In most mills, newsprint is now produced from 100% TMP.

Table 3.1 Pulp and paper production of Québec ('000 metric tons) [6].

Production	1970	1980	1990	2000	2001	%
Newsprint	3766	3921	4107	3848	3561	37
Paperboard & other paper	1298	1886	2801	4765	4716	49
Commercial pulp	N.D.	N.D.	N.D.	1666	1359	14
Total production	5712	6487	7717	10278	9636	100

N.D.: Non-determined.

Table 3.2 Fibre furnish of newsprint (CPPA, 1999) [91].

Year	Chemical wood pulp	Mechanical wood pulp	Recycled fibre	Other pulps	Total
1965	23,5	76,2	0,1	0,2	100
1975	25,1	74,9	0,0	0,0	100
1982	22,4	76,5	1,0	0,0	100
1990	15,7	82,8	1,4	0,0	100
1992	10,1	80,5	9,4	0,0	100

At the same time, the newsprint producers are always facing new challenges to meet quality requirement, such as paper printability (e.g. optical and surface properties) and runnability (e.g. strength properties). In 1970, letterpress accounted for virtually all newsprint printing. But after 1990, because letterpress is not able to satisfy the increasing print quality standards, the choice of printing methods is narrowing to almost completely offset and flexographic. Linting is the most important characteristics influencing the print quality in offset newspaper printing.

3.2 Newsprint furnish

Newsprint is defined as a paper between 40g/m^2 and 57g/m^2 generally used in the publication of newspapers [92]. The conventional furnish is largely mechanical wood pulp with some chemical wood pulp. Groundwood has been traditionally the primary furnish used for newsprint. Compared to chemical pulp, SGW has high fines content and shorter, stiffer lignified fibres. These characteristics confer high opacity and light scattering coefficient and bulk, good formation and dimension stability, excellent printing properties and smoothness. But, on the other hand, these characteristics gives low strength to newsprint. So the upper practical proportion of SGW content in newsprint is 70-80%. The remaining 20-30% is chemical pulp as a reinforced pulp. In the last decade, the mechanical pulps developed rapidly with respect to strength properties and TMP has replacing more and more SGW in newsprint furnishes [90]. TMP has superior strength properties and opacity similar to that of SGW (Table 3.3). These characteristics give the papermakers the possibilities to increase the amount of mechanical pulp in the furnishes and reduce the expensive chemical pulp, the cost of which is about 2 to 4 times that of mechanical pulp [93]. The increased proportion of mechanical pulp improves also the printing properties of paper. The properties of principal furnishes used in newsprint production are shown in Table 3.3. As previously discussed, the chemical pulp SBK has superior wet web and dry strength than the mechanical pulps but lower opacity due to lower fines quantity and higher fibre-to-fibre bonding. On the other hand, the mechanical pulp has lower strength properties both in wet web and dry conditions but has excellent opacity.

The 45g/m^2 newsprint were made from different furnishes and their properties were compared in Table 3.4. As discussed early, replacement of PGW by TMP decreased the use of SBK, which was added as a reinforced pulp. The newsprint made from 100% TMP had strength and optical properties similar to those of the other papers.

Table 3.3 Physical properties of newsprint pulps [94].

Pulp type	SGW	TMP	SBK	HYBS
Yield, %	95	94	43	65
CSF, ml	90	150	550	550
Breaking length, km	3,2	4,0	8,0	9,5
Burst index, $kPa \cdot m^2/g$	1,3	1,7	6,0	6,0
Tear index, $N \cdot m^2/kg$	5,0	8,0	14,0	7,0
Apparent density, kg/m^2	400	400	660	625
Wet web tensile, 20% solids, N/m	25	35	55	50
ISO Brightness, %	59	56	70	50
Opacity, %	97	96	75	82
Long fibre, % (R48)	40	55	80	80
Fines, % (P100)	50	35	8	20

Table 3.4 Comparison of $45 g/m^2$ newsprint from Canada & Scandinavia [95].

Sample from	SCAN 1	SCAN 2	CAN
Furnish, %			
SBK	10	<5	
TMP	36	>95	100
PGW	54		
Ash content, %	2	1	1
Bulk, cm^3/g	1,56	1,64	1,76
Air resistance, ml/min	210	275	295
Roughness*, ml/min	90	110	145
Tensile index*, Nm/g	36,3	31,9	29,9
Tear strength*, mN	215	233	200
Tear strength*, mN	215	233	200
Opacity, %	92,4	91,4	92,4
Light scattering, m^2/kg	52,3	49,5	51,0
ISO Brightness*, %	59,9	57,8	59,3

* Values on averages of top and wire sides.

3.3 Linting

In North America over 60% of the daily newspaper and 95% of the weekly newspaper are printed by offset lithography [96]. Offset printing is sensitive to the removal of the fibres and fines from the paper surface during printing. The accumulation of these fibres and fines on the offset blanket results in interruptions of printing for washing the blanket and causes deterioration in print quality [97].

3.3.1 Nature of linting

Linting is defined as the tendency of the loosely bound fibres and the fines to be removed from the paper surface during the printing operation [97]. It is the most important characteristic influencing the runnability and print quality. Because of the technology development in mechanical pulping, the lint material composition has changed a lot [98]. Lint material from 1975 consisted mainly of mechanical pulp particles, such as fibre fragments, ray cells and shives. Now, the amount of fibre fragment and shives decreased largely while the amount of ray cells (over 80%) remained relatively constant, due to the use of stronger mechanical pulps in newsprint, such as TMP.

Generally, the lint materials are less than one mm long and one to three fibre diameters thick. They are stiff, unfibrillated and of low specific surface, which induces low bonding potential. The degree of linting depends on the paper properties, particularly the surface strength of the paper. In addition, it is influenced by several printing variables, such as press speed, ink viscosity and tack.

3.3.2 Linting analysis

One of the linting evaluation methods developed by Wood and Karnis [97] is based on pulp characteristics. They separated the fines using a hydrocyclone and measured their specific surface ((SS) s) by a turbidity meter, and defined the pulp linting propensity index (PLPI) as the amount of fibrous material with a value of (SS) s $\leq 2{,}5 m^2/g$. For a paper produced in a given paper machine, there was a good correlation between the paper linting index measured in a laboratory offset press and PLPI.

Another alternative of analysing the linting propensity is based on paper properties [99], measured by an Apollo offset press and a GEL (Grafiska Forshing Laboratory's) surface strength testers. One of the most successful methods was developed by Mangin *et al* [100, 101]. They used the IGT printability tester to analyse the linting propensity of paper. After printing, the linting materials were collected and analysed by Kajaani FS100 Fibre analyser and a microscope. The principal parameters describing the linting propensity are: the total number, the average length and the cumulated length of fibres removed per unit area of paper. Linting propensity analysis is influenced by the printing speed and the viscosity of ink, which regulate the forces applied to the paper surface during printing and confers different degree of fibrous material removed. As shown in Figure 3.1, at low force levels, the dust only will be removed. At high force levels, well-bonded surface fibres are also removed. This phenomenon is considered as picking which causes further printing impossible. Both cases cannot show correctly the linting propensity. When medium intensity force is applied, the loosely bonded material is removed. In this case, a solution of 12% hydrocarbon-based resins in pure mineral oil with low viscosity (7950 ± 106, cps, Brookfield, spindle #4, #6, #7 at 22°C) and tack (5,6 ± 0,4, Tack-O-Meter, 32°C, 800 rpm, 2 min) was used. More than 90% fraction of the lint materials has length lower than 1,0 mm (Table 3.5).

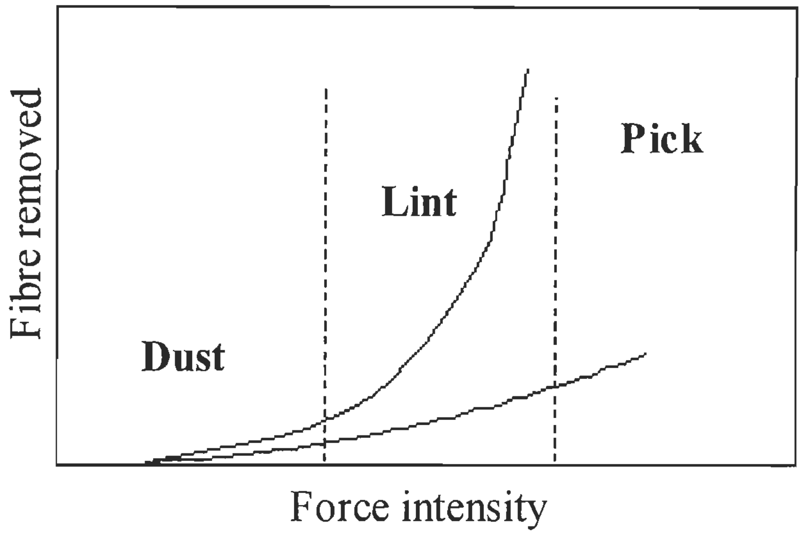


Figure 3.1 Fibre removed as a function of force intensity [100].

Table 3.5 Distribution of lint material of the PAPRICAN pilot offset press [100].

Average length	Weighted average length
Loose lint from non-image areas (first and second printing units)	
90% < 0,4-0,6 mm	90% < 0,8-0,9 mm
Loose lint from image areas (first and second printing units)	
90% < 0,4-0,6 mm	90% < 0,9-1,3 mm

* Average values from over 100 print runs of newsprint from across Canada.

Chapter 4 - UTILISATION OF WHITE BIRCH IN PULP & PAPER INDUSTRY

White birch responds well to chemical pulping and chemimechanical pulping, such as Kraft [102, 103] and NSSC [104]. In the mechanical pulping area, when handling birch wood, the greatest effects are achieved using sodium hydroxide treatment of the chips which reduces the energy consumption and more importantly improves the pulp strength properties with processes such a treatment used in CTMP, APMP and OPCO processes [3, 12, 13, 105, 106]. In Canada, the commercial use of birch wood is still limited in chemical and chemimechanical pulping.

4.1 Kraft pulp

Table 4.1 Kraft pulp properties from Canadian hardwoods [103].

Wood species	Unbeaten pulps			Beaten pulps		
	White birch	Trembling aspen	Sugar maple	White birch	Trembling aspen	Sugar maple
CSF, ml	544	545	452	364	230	270
Bulk, cm^3/g	1,50	1,47	1,66	1,29	1,27	1,41
Breaking length, km	5,65	5,99	4,52	10,30	10,56	7,81
Stretch, %	3,23	2,95	2,34	4,43	4,23	3,76
Tear index, $mN \cdot m^2/g$	10,0	6,92	4,43	9,33	8,06	7,40
Light. scatt. coeff., cm^2/g	311	317	402	201	215	317
Zero-span breaking length, km	18,0	16,65	16,91	19,37	19,48	18,22
ISO Brightness, %	90,1	92,3	93,0	-	-	-

* Pulping conditions: active alkali 15,0-17,0%, sulfidity 25%, liquor to wood ratio 4:1, 90 min to 170°C maximum temperature, pulp yield 53,4-56,2%, rejects 0-0,5%.
* Beating: 11000 revolutions, PFI mill.

Birch wood responds well to kraft pulping and produces good quality paper compared to mechanical pulping. The unbeaten and beaten kraft pulp properties from white birch are compared with those pulps from trembling aspen and sugar maple, as shown in Table

4.1. Both of white birch and trembling aspen produce higher strength kraft pulps than maple. In comparison with trembling aspen, white birch even shows higher quality in certain physical properties, such as tearing index, for both of unbeaten and beaten kraft pulps due to its original longer fibres (see Chapter 1).

4.2 Neutral sulfite semichemical pulp (NSSC)

Table 4.2 Chemical composition of NSSC pulps from birch and spruce [107].

	Birch		Spruce	
	Wood	**Pulp**	**Wood**	**Pulp**
Yield, %		77,0		81,0
Pentosan, %	22,5	23,3	7,5	7,9
Uronic acids, %	4,7	2,8	2,3	1,1
Lignin, %	20,0	10,8	28,0	20,2
Methoxyl, %	6,1	4,4	4,9	3,5
Total carbohydrates, %	75,5	84,0	70,5	75,0

Like several of the North American hardwood species, white birch is found to be very suitable to NSSC pulping. Softwood species find limited utilisation in this area because they require higher chemical application and more refining energy. In NSSC process, the neutral nature of the pulping liquor restrains hydrolysis and dissolution of the hemicellulose during pulping. Birch NSSC contains more pentosans than either of the pulps cooked by any other common pulping process or softwood NSSC, as shown in Table 4.2. The yield and pulp strength benefit from the high retention of hemicellulose. Almost all NSSC pulps are used in corrugating medium.

4.3 Thermomechanical pulp

Koran [11] studied the thermomechanical pulp properties of white birch in comparison with spruce/balsam fir TMP produced under identical conditions. As shown in Table 4.3, the white birch TMP has lower average fibre length than spruce/balsam fir TMP. The BauerMcNett fibre classification data indicate that white birch TMP possesses lower percentage of long-fibre fraction than spruce/balsam fir TMP and it is rich in intermediate-fibre content. In addition, the fines of birch mechanical pulp contain mainly flour-like materials, which have poor ability to reinforce the inter-fibre bonding [76]. These properties explain the low strength properties of white birch TMP and why it is not suitable for the manufacture of paper like newsprint.

Table 4.3 Comparison between white birch TMP and spruce/fir TMP [11].

Parameters	White birch TMP			Spruce/Fir TMP		
	1	2	3	1	2	3
CSF, ml	596	360	100	472	218	77
Fibre length, mm	1,41	0,93	0,76	1,95	1,50	1,00
Bauer McNett fibre fraction, %						
Long-fibre fraction (+28)	34	13	8	63	46	28
Middle fraction (R28/200)	65	68	64	33	42	35
Fines fraction (P200)	1	19	28	4	12	38
Tear, $mN \cdot m^2/g$	1,4	2,1	2,7	9,1	11,5	9,0
Burst, $kPa \cdot m^2/g$	0	0,25	0,50	0,9	2,2	2,8
Breaking length, km	0,24	0,77	1,4	1,5	3,0	4,1
Stretch, %	0,2	0,9	0,9	1,4	2,0	2,0
Short span BL, km	6,1	6,2	6,2	7,5	9,0	8,6
Density, $kg/m^3 \times 10^2$	2,10	2,80	3,10	2.30	3,10	3,80
Brightness, %	46	49	50	49	52	54
Opacity, %	95	96	99	94	96	96
Light scattering coef., cm^2/g	405	509	674	402	520	678

As mentioned previously in Chapter 2, wood species have a significant effect on TMP quality [73]. Because the birch fibres have thick walls (3,5 μm) and short length (1,5 mm), they are significantly more resistant to refining than the corresponding spruce/fir tracheids. Besides, birch wood contains a high weight proportion of short, large-diameter vessel elements and small parenchyma cells. These properties influence the inter-fibre bonding and the surface strength properties of paper.

4.4 OPCO

Although the handsheet made from 100% white birch TMP yields significantly low strength properties, the OPCO process can produce high quality pulp from white birch at high yield (96%). Different from the conventional TMP process, a chemical treatment is added in the OPCO process at 10% or higher consistency consisting of a sodium sulfite solution (7-10%) applied for 15 to 120 min at 130-180°C. This cooking reaction may be applied either in between two refining stages or as a post-treatment. Koran [106] studied the white birch OPCO properties and compared it with spruce/balsam-fir OPCO. In his research, sodium sulfite was applied both at the inter-stage treatment and the post-refining treatment. The pulps were refined in a PFI mill. As shown in Table 4.4, both the inter-stage and post-refining treatment can improve significantly the pulp strength, especially wet tensile strength, and thus improving paper machine performance and print machine runnability. From this point of view, the white birch OPCO pulp is considered to replace the lower yield chemical pulp in the manufacturing of newsprint.

Table 4.4 Physical properties of white birch and spruce/balsam fir OPCO [106].

Properties	Inter-stage treatment				Post-refining treatment			
	White birch		Spruce/fir		White birch		Spruce/fir	
CSF, ml	170	150	185	119	170	110	175	115
Density, g/cm^3	0,48	0,50	0,42	0,45	0,45	0,50	0,41	0,43
Porosity, ml/min	164	100	128	100	310	127	192	100
Roughness, ml/min								
Felt	62	67	66	56	52	57	61	56
Wire	91	67	57	57	74	77	58	50
ISO Brightness, %	46	45	41	39	48	46	48	43
Opacity, %	91	91	94	96	96	95	95	94
Light scat. Coeff., %	280	276	316	316	337	323	415	333
Tear, $mN \cdot m^2/g$	5,0	4,7	5,9	5,9	5,2	5,4	7,6	6,2
Burst, $kPa \cdot m^2/g$	2,7	2,9	3,1	3,5	2,1	2,7	3,3	3,5
Breaking length, km	5,9	6,3	6,4	7,0	5,0	5,9	5,8	6,5
Zero-span BL, km	10,8	9,7	10,4	10,7	10,1	10,1	9,9	10,8
Stretch, %	1,6	1,9	2,0	1,9	1,5	1,7	2,1	2,3

* Chemical treatment conditions: 10% consistency in a 10% solution of sodium sulfite at 480 kPa / 150°C for 50 min.

4.5 Chemithermomechanical pulp

In chemithermomechanical pulping of white birch, the use of sodium hydroxide is helpful in reducing the refining energy requirement and improving the strength properties, but it has a negative effect on brightness [12]. The addition of sodium sulfite is considered as a way to minimise alkaline darkening. However, sulfite is only effective at low alkaline or near neutral pH condition. For white birch, a dense hardwood, the effect of NaOH on pulp properties tended to level off at about 7% charge based on oven dried weight of wood [3]. In this case, the effectiveness of sulfite against alkaline darkening becomes limited. In fact, the darkening occurred when 2,5% caustic charge is used with 2,5% sodium sulfite [12]. At the same time, the decrease in light scattering is notable.

4.6 Alkaline peroxide mechanical pulp (APMP)

The APMP process is considered as the best way to produce high quality pulp from dense hardwood species while preventing alkaline darkening. Recently, Boldgett *et al* [13] studied the APMP of three northeastern hardwoods: aspen, birch and maple. Among these species, birch showed the greatest response to this process with a six-fold increase in tensile index and a seven-fold in tear index compared to birch TMP. When 15g/l concentration of alkali was used. However, the light scattering coefficient decreased definitively. Their studies showed further that a threshold concentration of alkaline treatment is required for birch chips to avoid excessive fibre cutting during refining.

Generally speaking, the commercial use of birch wood is still largely limited to kraft and NSSC pulp in the area of pulp and papermaking industry. Further research is necessary to develop the use of birch wood in mechanical pulping by improving the pulp strength but without compromising much the optical properties and brightness.

Chapter 5 - RESEARCH PROPOSAL

5.1 Background

In Canada, the pulp and paper economy is primarily based on market mechanical pulps and newsprint which use softwood as the principal material, especially spruce. The utilisation of dense hardwood in mechanical pulping is still occurring on a relatively small scale. The limitation on using white birch in mechanical pulp is due to the following principal problems:

Firstly, white birch fibres are significantly more resistant to refining than the corresponding softwood (e.g. spruce and balsam fir) tracheids because of their thicker cell walls and shorter initial length. Although the TMP of white birch has good opacity properties, it has the strength properties too low to be suitable for the manufacture of paper [11].

Secondly, the CTMP of white birch is sufficient in strength but its opacity remains too low. The reduction of brightness is not avoidable either since a relative high dose of alkali is necessary to improve the strength properties of the mechanical pulp from white birch, and so the effectiveness of sulfite against alkaline darkening becomes limited [3, 12].

Thirdly, the TMP of mixtures of white birch and spruce/fir showed that a partial substitution of spruce/fir by white birch had advantages in reducing the refining energy and modifying the optical properties. But the strength properties were reduced largely when more than 20% of spruce/fir chips was replaced by white birch [14].

Fourthly, linting is one of the most important characteristics influencing print quality in offset printing of newspaper. In modern pulping and papermaking industry, lint materials consist mostly of ray cells. White birch has much more volume of parenchyma than spruce, in addition it has 11% in volume of vessel elements. These characteristics might increase the linting tendency when white birch chips are mixed with spruce to produce TMP.

Finally, the fibre behaviour of different species in co-refining is still not well known since most of the previous studies are focused on the physical and optical properties of the mechanical pulps made of mixed species. It becomes necessary and possible to study the fibre morphology in order to better understand the behaviour of the short fibres in hardwood in co-refining with the help of some new instrumental techniques, such as CyberFlex for fibre flexibility analysis.

As one of the dominant hardwood species in Canada and in Quebec, the utilization of white birch in mechanical pulping for newsprint furnish is very interesting not only for research but also for pulp and papermaking industry of this country. It will reduce also the pressure on the demand of softwood resource.

5.2 Objectives

This study concerned the utilization of white birch as a raw material in thermomechanical and chemi-thermomechanical pulping for newsprint furnishes. The objective was not only to determine the effects on mechanical and optical properties due to the substitution of white birch in black spruce to produce TMP and CTMP pulps but also to study the fibre morphology in order to better understand the behaviour of the short fibres of hardwood in co-refining (in this study, we defined co-refining as the process in which the chips of various species are mixed and refined together). Since hardwoods are comprised of large-diameter vessel elements in addition to fibres and parenchyma cells, and their fibres are stiff and short, a proper chemical pre-treatment will soften the wood and thereby improve a fibre separation in refining. In addition, considering the different response to chemical treatment of hardwoods and softwoods, the feasibility of upgrading the white birch chips by chemical pre-treatment followed by co-refining with untreated black spruce chips was studied in comparison with the reference TMP and CTMP from fresh B/S chip mixtures. The focus were on the following analyses:

- The energy consumption of TMP and CTMP pulps at freeness levels between 80 ml to 200 ml when the treated or untreated white birch chips either partially or completely replaced the black spruce chips;

- The influence of the thermomechanical and chemi-thermomechanical pulping processes on the fibrillation characteristics of co-refining of B/S chip mixtures by analysing the morphological feature of fibres; the effect of chemical pre-treatment of white birch chips prior to blending;

- The comparison of pulp strength and optical qualities affected by the substitution of untreated and treated white birch chips in TMP and CTMP pulping of black spruce;

- The importance of linting propensity produced by the addition of white birch chips which contain large amounts of vessel and parenchyma cells, and the possibility of decreasing the linting propensity by applying chemical pre-treatment to the white birch chips prior to blending with untreated black spruce chips.

5.3 Methodology

The white birch chips were mixed with black spruce chips as follows to investigate their impact on the thermomechanical and chemithermomechanical pulping processes. This work included two parts:

Part 1 - TMP: The reference thermomechanical pulps were produced from B/S chip mixtures with the white birch substitution of 0, 10, 20, 30, 40 and 100% (Table 5.1). Also, one trial (TMP-Bt30) was conducted on the thermomechanical pulping of B/S chip mixtures, in which 30% of black spruce was replaced by chemically pre-treated white birch chips. In this trial, the white birch chips were impregnated directly with 1,5% sodium hydroxide and 2,5% sodium sulfite at 75-80°C for 4 hours in order to obtain an uniform distribution of chemicals in the chips [108]. The chips were then drained and mixed with untreated black spruce chips prior to co-refining. The co-refining conditions were the same as those used to produce the other pulps.

Part 2 - CTMP: As a baseline study, reference chemithermomechanical pulps were produced from B/S mixtures composing of 0, 30, 60 and 100% white birch substitution (Table 5.2). Also, considering the different responses of hardwood and softwood to chemical treatment by sodium sulfite and sodium hydroxide (alkaline treatment improved significantly the strength properties of hardwood mechanical pulps but yielded little effect on those of softwood mechanical pulps), and to increase the effectiveness of chemicals, white birch chips were pre-treated with alkali or a combination of alkali and sodium sulfite prior to being blended with untreated black spruce chips at a substitution of 30% white birch. The CTMP pulps were then produced from the chip mixture containing pre-treated white birch chips and untreated black spruce chips. In this case, only sodium sulfite for alkali-treated birch chips or no chemicals for alkali-sulfite-treated birch chips were used in the co-refining process.

Table 5.1 Illustration of symbols used in the Figures for each trial pulp in Part 1.

Identification	White birch, %	Black spruce, %
TMP-S*	0	100
TMP-B10	10	90
TMP-B20	20	80
TMP-B30	30	70
TMP-B40*	40	60
TMP-B*	100	0
TMP-Bt30	30	70

* The pulping was repeated.

Table 5.2 Illustration of symbols used in the Figures for each trial pulp in Part 2.

Identification	Process	White birch, %	Black spruce, %
CTMP-S*	CTMP-a	0	100
CTMP-B*	CTMP-a	100	0
CTMP-B30	CTMP-a	30	70
CTMP-B60	CTMP-a	60	40
CTMP-Bn30**	CTMP-b	30	70
CTMP-Bns30***	CTMP-c	30	70

* The pulping was repeated
** White birch chips were pre-treated by alkali prior to mixing with black spruce chips
*** White birch chips were pre-treated by alkali-sulfite prior to mixing with black spruce chips

5.3.1 Raw materials

The black spruce chips were obtained directly from Kruger mill in Trois-Rivières. The white birch logs were obtained from Malette Company, St-Georges-de-Champlain (Québec), were debarked and chipped. All the chips were classified to remove the fines and the over-thick chips by a Rader chip classifier. The accepted chips, which had a thickness less than 6 mm, accounted for proximately 75% of the total chips. These chips were collected in plastic bags and were used within two to three weeks.

5.3.2 Chip pre-treatment and mixing

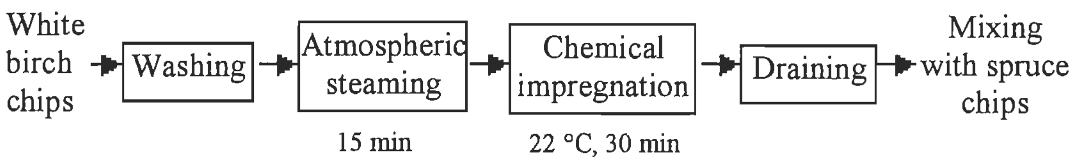


Figure 5.1 The pre-treatment condition of white birch chips.

Table 5.3 White birch chip chemical pre-treatment conditions in Part 2.

Series	% NaOH od wood	% Na_2SO_3 od wood	Temperature °C	Retention time, min	Liquor-to-wood ratio
CTMP-a	-	-	-	-	-
CTMP-b	2,5	-	22	30	4,5:1
CTMP-c	2,5	2,5	22	30	4,5:1

According to Jackson *et al* [85], a short atmospheric pre-steaming (10 minutes) is sufficient to get a significant increase in liquid uptake during the subsequent impregnation at room temperature. In this study, white birch chips were pre-treated following the impregnation process shown in Figure 5.1. The washed white birch chips were steamed for 15 min followed by soaking in an alkaline or alkaline sulfite solution at room temperature (22 °C) for 30 min (Figure 5.1 and Table 5.3). A charge of 2,5% sodium hydroxide and 2,5% sodium sulfite both on dry wood was chosen for relevance to industry application. After treatment, the chips were drained and then blended with untreated black spruce chips. For both Part 1 and Part 2, an appropriate quantity of treated or untreated white birch chips and untreated black spruce chips were thoroughly mixed to produce the desired mixtures before refining.

5.3.3 Refining processes

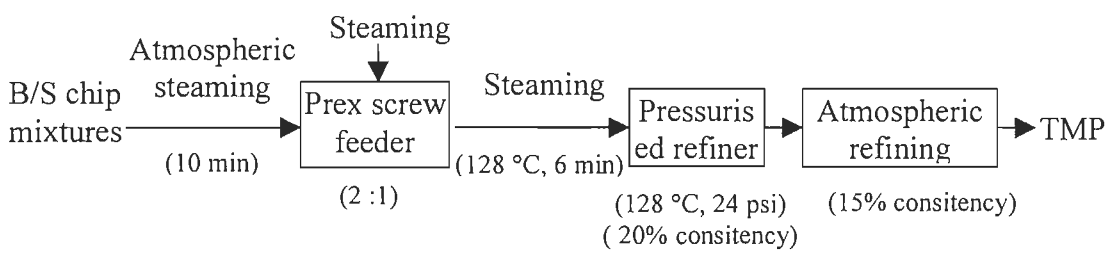


Figure 5.2 Schematic of two-stage TMP refining.

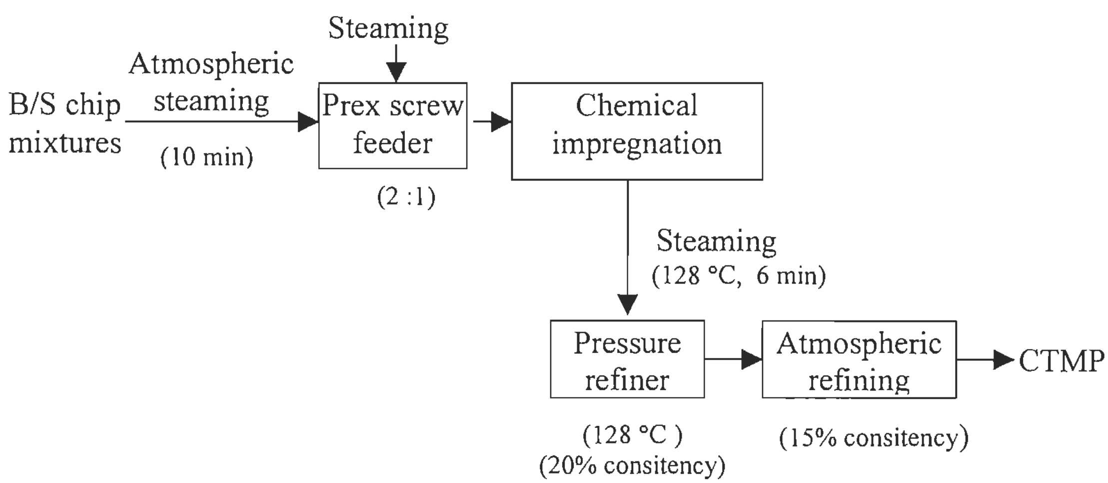


Figure 5.3 Schematic of two-stage CTMP refining.

The wood chips were refined by a Sunds Defibrator (Metso) CD300 pilot plant. The principal refining process conditions of TMP and CTMP are shown in Figure 5.2 and Figure 5.3, respectively. Also, the chemical treatment conditions in the CTMP process are shown in Table 5.4. The freeness of pulp from first stage refining was controlled between 300 and 450 CSF. During the secondary stage, pulps were sampled at four to five levels of refining energy covering a range of freeness between 80 ml and 200 ml. Different energy consumption (record of first and second stages) was obtained controlling the plate gap (0,2 to 1,0 mm). The energy consumption of both stages was recorded. After the two stages of refining, the latency was removed from the pulp before evaluation.

Table 5.4 Treatment conditions during CTMP process.

Process	Sodium sulfite %	Sodium hydroxide %	Presteaming (Atmos. Pressure) min	Time at 128°C, min
CTMP-a	2,5	2,5	10	6
CTMP-b	2,5	-	10	6
CTMP-c	-	-	10	6

5.3.4 Repeatability

To investigate the repeatability of refining process, three trials of thermomechanical pulping and two trials of chemithermomechanical pulping were repeated (Table 5.1 and 5.2). In these trials, the white birch chip substitution was 0, 40 and 100%, respectively.

5.3.5 Fibre analysis and pulp testing

The latency-removed pulps were evaluated by analysing the fibre properties, strength and optical properties of handsheets. In addition, the linting propensity of handsheets was determined. The principal aspects analysed are shown in Figure 5.4.

Fibre properties, such as fibre length, coarseness and shive content, give some idea of particle composition in the pulp and form the basis for understanding many of the paper properties. For better understanding the behaviour of the fibres in refining and co-refining, visual inspection with the help of microscopy is very useful. In addition, fibre flexibility is an important characteristic determining the ability of fibres to deform and contribute to inter-fibre bonding. Pulp strength and optical properties were determined from laboratory handsheets. Strength properties are very important for the runnability of both the paper machine and the printing press. Good optical properties are necessary for printability. Linting propensity is an important characteristic influencing the print quality. A list of employed test methods is found in Appendix C. Most of the methods used in this study are in accordance with the PAPTAC standards. Some methods which have no standard procedures will be described in detail.

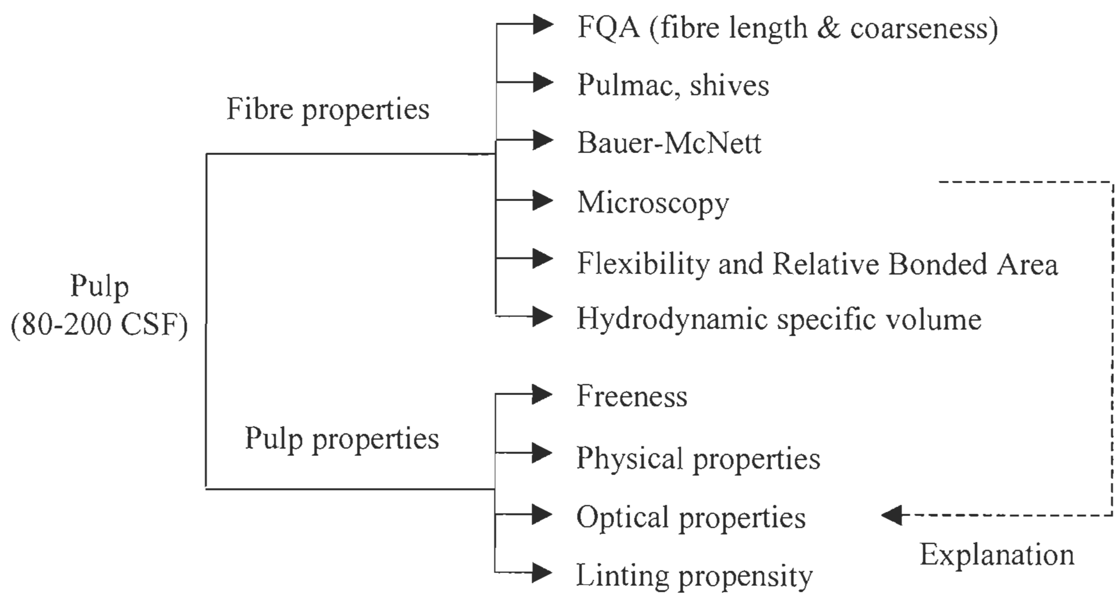


Figure 5.4 General outline of parameter analysis of the pulps.

5.3.5.1 Fibre properties

FQA analysis

FQA (Fibre Quality Analyzer, OpTest Equipment Inc.) was used to determine the average fibre length, fibre length distribution and fibre coarseness. Fibre coarseness is a measure of cell wall mass per fibre length (Equation 5.1). In this study, the coarseness value for each Bauer-McNett fibre fraction in addition to that of the whole pulp, since the distribution of pulp particles varies too largely to get a correct representation of average coarseness. Furthermore, small particles may not be detected by the FQA due to their high lignin content. In this case, a length-weighted percentage of particles below 0,2 mm length becomes meaningless. So according to Seth [109], the fines fraction (below 0,2 mm) determined by optical fibre length analyzers (e.g. FQA) may not be reliable.

$$C = M / (N \times La) \quad \textbf{Eq. 5.1}$$

Where: C: coarseness (mg/m)

M: dry weight of the fibres (mg)

N: number of the fibres

La: arithmetic mean length of the fibres.

Bauer-McNett classification

Till now, the most commonly used method for characterizing the fibre size distribution of mechanical pulp is Bauer-McNett fibre classification, which is based on length distribution. The pulps are divided in different proportions (long-fibre, short-fibre and fines fractions) by means of a Bauer-McNett classifier. The long-fibre fraction consists of R14+R28. The short-fibre fraction includes P28/R200. The fraction passing through a 200-mesh screen is defined as the fines fraction. This fraction consists mostly of fibrils, lamellae and some cell wall fragments. In addition, the ray cells are enriched in the fines fraction [72]. Generally, the long-fibre and the fines fractions are the two most important fractions influencing the strength and optical properties of TMP, as discussed previously.

Microscopy

The conventional pulp testing methods, such as Bauer McNett, are not enough to explain the different papermaking properties of mechanical pulps of B/S chip mixtures due to large variability of particles in the pulps. In this study, the fibre fractions were studied by means of light microscopy. The observed fibres were stained with Safranin O to enhance the contrast between the fibre and the glass slide. For assessing the fibre surface quality and cell wall damage degree, scanning electron microscopy was used to analyse the fibres of the fraction R48. In this analysis, the specimens must be dried since a high vacuum must be provided in the microscope column to allow the electrons to migrate from their emission source to interact with the specimens and give signals. Critical point drying (CPD) is generally considered as a satisfactory technique to preserve the fine details of fibres, but solvent-exchange drying and air drying are much simpler than the CPD. In this case, the solvent-exchange and air drying were compared with the CPD.

The SEM micrographs of the same pulp prepared by the different methods can be found in Appendix B. The air drying caused shrinkage of the fibre surface and the fines. Upon drying the fibrils were bonded onto the fibre surface. As a result, the fibre morphology changed drastically and lots of information (e.g., the fibrillation and the surface structure of the fibres) was lost. Similar to the CPD, the solvent-exchange can preserve the fine details of the fibres and hence was utilized in this study.

Wet fibre flexibility (WFF) and relative bonded area (RBA)

WFF is defined as the ability of fibres to deform and entangle under a flexing force. It is recognized as an important fundamental fibre property, influencing the physical (e.g. the ability of fibres interact and bond to each other), optical properties of the fibres, as well as paper formation. In this study, the method of conforming fibre on a wire developed by Steadman was utilized to measure the wet fibre flexibility with CyberFlex, an instrument developed by CyberMetrics Inc. (Figure 5.5) [110,111].

The CyberFlex Wet Fibre Flexibility Analyser (Figure 5.5) measures the flexural properties of 100 to 1,000 fibres automatically. To perform this analysis, a thin fibre network is made by means of a sheet machine wire, which is similar to a papermaking machine wire, but the consistency of the "pulp stock" is much more dilute. This fibre network is then transferred onto a metal wire anchored to a glass slide. The metal wire used has a 25 μm diameter. A certain pressure is used to press the fibres in contact with the glass, as shown in Figure 5.6. While the fibres are bonded onto the glass on either side of the wire, their unbounded spans will bring cover the wire. The length of the unbounded span is used along with the fibre diameter, pressure and wire diameter to calculate the fibre flexibility, as shown in Equation 5.2. Finally, a flexibility histogram is obtained and an average flexibility is given.

With the same CyberFlex instrument, the RBA can also be measured. In this method, fibres are pressed onto a glass slide. The RBA is calculated as the ratio of bonding area where the fibre is in optical contact with the glass, to the total fibre area, as shown in Equation 5.3.

$$WFF\ (N^{-1}m^{-2}) = 72\ (\text{Wire diameter})/(\text{Pressure} \times \text{Fibre Width} \times \text{Span}^4) \qquad \text{Eq. 5.2}$$

$$RBA\ (\%) = 100 \times \text{Bond Area}/\text{Fibre Area} \qquad \text{Eq. 5.3}$$

Figure 5.5 CyberFlex Wet Fibre Flexibility (WFF) Analyser [111].

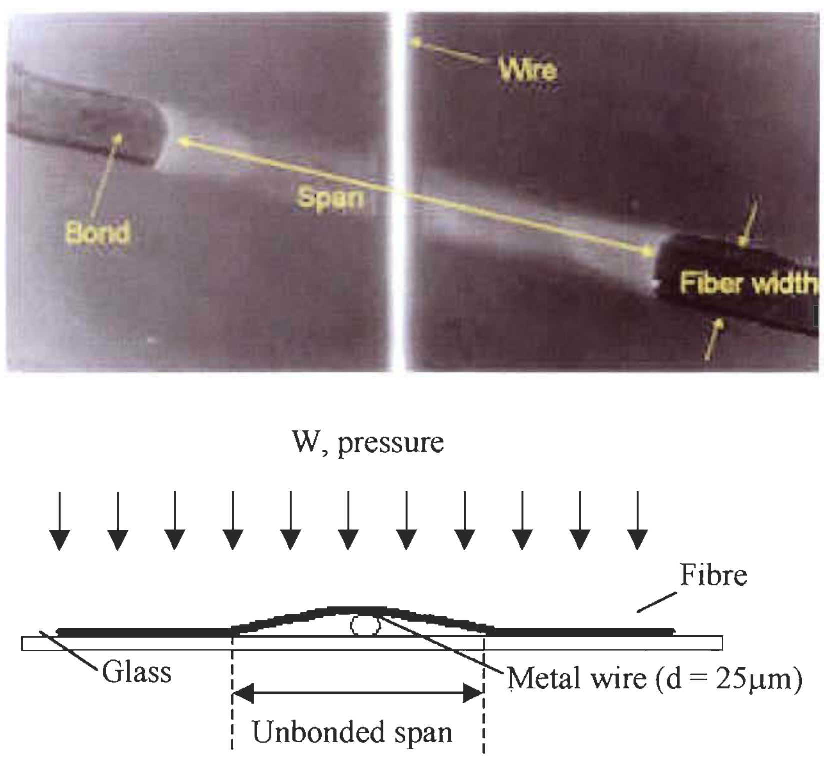


Figure 5.6 Image of conforming fibre on a wire [110, 111].

Hydrodynamic specific volume (HSV)

The HSV of the fractions was measured according to the method described by Marton *et al* [112] and Luukko [113]. The fibres or the fines (1,0 g/l) were settled in a 0,5 mg/l $MgSO_3$ aqueous solution for 24 hours in a metering glasses at room temperature. Before the settling, air was removed from the suspension for 10 min using a vacuum pump. After the settling, the sediment volume (V) was read and the pulp suspensions were filtered and the dry weight (W) of the sample was determined. The HSV of the fractions was calculated as in the following equation:

$$\mathbf{HSV\ (cm^3/g) = V\ /\ W} \qquad \textbf{Eq. 5.4}$$

5.3.5.2 Physical properties

Firstly, the structural properties of handsheets, including basis weight, bulk and density, were determined following the standard methods (Appendix C). For newsprint furnishes, the mechanical pulps should have high smooth surface and low porosity, so the roughness and the porosity were also measured. In this study, the main strength properties determined were tear index, burst index and tensile index. The index values were utilized because they include the influence of sheet basis weight allowing us to compare the sheets with different basis weight values. Generally, high strength properties are required for good runnability of the paper machine and the printing press.

5.3.5.3 Optical properties

The optical properties determined were brightness, opacity, light scattering coefficient and light absorption coefficient.

5.3.5.4 Linting propensity

Linting propensity was measured with a RNA-52 printability tester (Research North America Inc.) using a modified method of the PAPTAC useful method L.5U developed by Mangin *et al* [100, 101]. In this method, a Newtonian model fluid from Paprican was used since the viscosity of Newtonian fluid is not influenced by shear and can give almost the same force to different paper surface.

The printing conditions are:

- Printing speed: 2,5 m/s;
- Printing pressure: 1000 N;
- Printing disk: 50 mm wide metal printing wheel;
- Blanket: flexography;
- Oil: 12% Picco resins 6140 (Hercules) solution, no pigment is added;
- Amount of oil on disk: about 5,00 ± 0,05 g/m^2.
- Sample size: 63 × 150 mm; and printing size: 50 × 130 mm

Fibrous materials removed from the paper surface during the printing were collected by washing the disk using petroleum ether and then filtered. By means of a FQA, the total number and average fibre length (*lw*) were measured. These materials were classified into three fractions:

- Fines: length < 0,85 mm
- Medium: 0,85 mm ≤ length ≤ 1,35 mm
- Large: length > 1,35 mm

Then, the particle distribution and cumulated length of the fibres removed per unit area of paper were obtained. The main parameters determined by the FQA were shown in Table 5.5. In addition, the lint materials were collected also for observation using a light microscope.

Table 5.5 Linting distribution parameters [100].

Fraction	Fines	Medium	Large	Total
Number	N_f, $L_i < 0,85$	N_m, $0,85 \leq Li \leq 1,35$	N_l, $Li > 1,35$	N
Average length, mm	$L_f = (\Sigma n_i L_i)/n_i$	$L_m = (\Sigma n_i L_i)/n_i$	$L_l = (\Sigma n_i L_i)/n_i$	$L_t = (\Sigma n_i L_i)/n_i$
Cumulated length, m/m^2	$La_f = (N_f L_f)/S$	$La_m=(N_m L_m)/S$	$La_l = (N_l L_l)/S$	$La_t = (N L_t)/S$
Percentage, %	PC_f=100(N_f/N)	PC_m=100(N_f/N)	PC_l=100(N_f/N)	PC_t=100(N_f/N)

Li: average fibre length in class; i, expressed in mm; S: printed surface, square meter.

Chapter 6 - RESULTS & DISCUSSION (1)

Part 1. THERMOMECHANICAL PULPING

The reference thermomechanical pulps were made from fresh white birch/black spruce (B/S) chip mixtures with the white birch substitution levels of 0, 10, 20, 30, 40 and 100%. The detailed refining condition was presented in Chapter 5. For the sake of simplicity, the TMP of 100% white birch and of 100% black spruce is designated as TMP-B and TMP-S, respectively. The thermomechanical pulps from chip mixtures containing 10, 20, 30, and 40% white birch are designated as TMP-B10, TMP-B20, TMP-B30 and TMP-B40, respectively, as shown in Table 5.1. Also, one trial (TMP-Bt30) was conducted on the thermomechanical pulping of B/S chip mixtures, in which 30% of black spruce was replaced by chemical pre-treated white birch chips. In this trial, the white birch chips were soaked directly with 1,5% sodium hydroxide and 2,5% sodium sulfite at 75-80°C for 4 hours [108]. Then the chips were drained and mixed with untreated black spruce chips prior to refining. The refining conditions are the same as for the above pulps. All the data in this study are given in Appendix A.

6.1 Specific energy consumption

The specific energy consumption (SEC) of TMP included the energy consumed in the first and the second refining stages. As shown in Figure 6.1, white birch required much more refining energy for a given freeness than black spruce at the beginning of the second stage of refining. This is reasonable since the white birch has a higher wood density than black spruce. Increasing the refining energy input decreased largely the freeness of TMP-B compared to the TMP-S. The multiple regression analysis by Statgraphics Plus indicated that the chip mixtures containing up to 40% white birch required a similar SEC at the 90% confidence level to that of TMP-S at a given freeness.

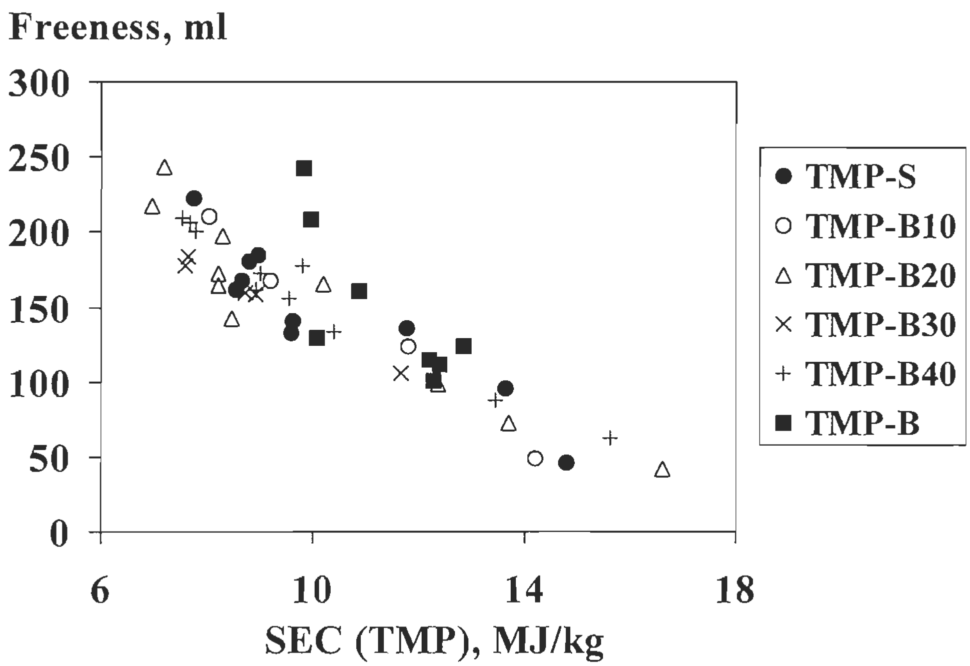


Figure 6.1 Specific energy consumption (SEC) of the TMP pulps vs. Freeness.

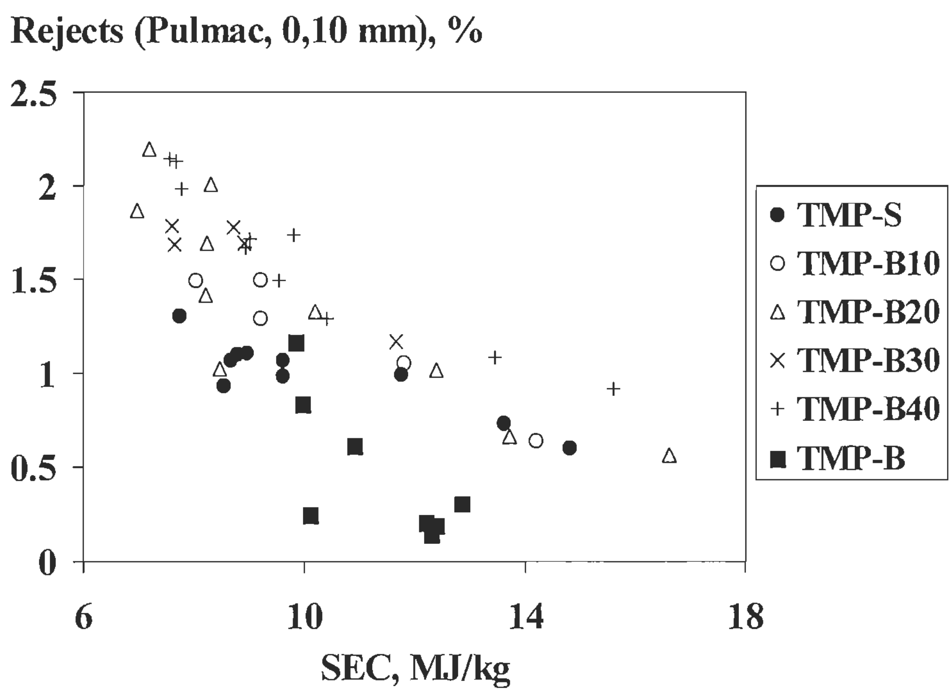


Figure 6.2 Rejects content of the TMP pulps vs. SEC.

6.2 Fibre properties

The fibre properties discussed here include the pulp particle size distribution and fibre/fines morphological characteristics.

Shives content

Low shives content is necessary for newsprint production since they can cause severe runnability problem on paper and printing machines. As shown in Figure 6.2, following the increase of SEC, the shives content of TMP-B decreased more rapidly than that of TMP-S. When the SEC was greater to about 10 MJ/kg, the TMP-B had a shives content lower than that of TMP-S. Reme *et al* [34] found also that a wood with thick walled fibres may yield pulp with less shives than the wood with thin walled fibres. The substitution of black spruce by white birch increased slightly the rejects content, especially at the beginning of the second stage refining. The probable reason is that the birch fibres and the spruce fibres have a different structure and absorb the energy at different speed during refining. Even in the same species, such as spruce, the earlywood absorbs the energy easier than the latewood. As a result, with the same form plate, the plate gap is controlled differently for these two kinds of woods to obtain a pulp with the same freeness (Table 6.1). Consequently, when birch and spruce are co-refined together, the rejects content increases in comparison with the TMP of the pure species. Increasing the SEC is effective to reduce this bad influence (Figure 6.2).

Table 6.1 The controlled plate gap for the TMP from birch and spruce.

Stage	Freeness, ml	Plate gap, mm	
		Spruce	Birch
First stage	~ 400	0,80	0,45
Second stage	~ 150	0,50	0,30

Visual inspection by means of light microscope showed that the rejects composed of shives and aggregates (Figure 6.3). The shives are the unfiberized debris particles. On the contrary, the aggregates are formed by the partially or wholly separated fibres which get entangled with each other probably due to the fibrillation during refining. The shives accounted for more than 90% in the rejects of TMP-B and less than 10% in those of TMP-S (Table 6.2). As discussed in Chapter 1, the fibres of birch have a rigid structure while those of spruce are flexible. For this reason, the fibres of spruce have more chance to get entangled with each other. Evidently, the birch fibres behave differently from the spruce fibres in the refiner when chemicals are not used. The use of birch in co-refining with spruce increased the relative amount of shives in the rejects.

Table 6.2 Composition of the rejects of TMP

Sample*	Shives **, %	Aggregates **, %	Total ***, %
TMP-S	~ 10	~ 90	1,064
TMP-B	~ 90	~ 10	0,612
TMP-B30	~ 50	~ 50	1,696

* The pulps have freeness about of 150 ml;
** The percentage of the total number of shives and aggregates;
*** The weight percentage of the whole pulp.

Fibre classification

The proportions of different fibre fractions were determined by means of a Bauer-McNett classifier. Figures 6.4, 6.5 and 6.6 show the contents of long-fibre fraction (R14+R28), short-fibre fraction (P28/R200) and fines fraction (P200) as a function of SEC, respectively. For all the pulps, the content of short-fibre fraction did not change much with increasing energy consumption while the long-fibre fraction decreased and the fines fraction increased. As expected, the TMP-S had the highest long-fibre content while the TMP-B had the lowest (Figure 6.4). Inversely, as shown in Figure 6.5, the short-fibre content was the highest for TMP-B but the lowest for TMP-S. For the substitution of 10% birch, the contents of these three fractions changed marginally, according to the multiple regression analysis made by Statgraphics Plus. Continuing to increase the amount of white birch in chip mixtures decreased gradually the long-fibre content but increased gradually the short-fibre content.

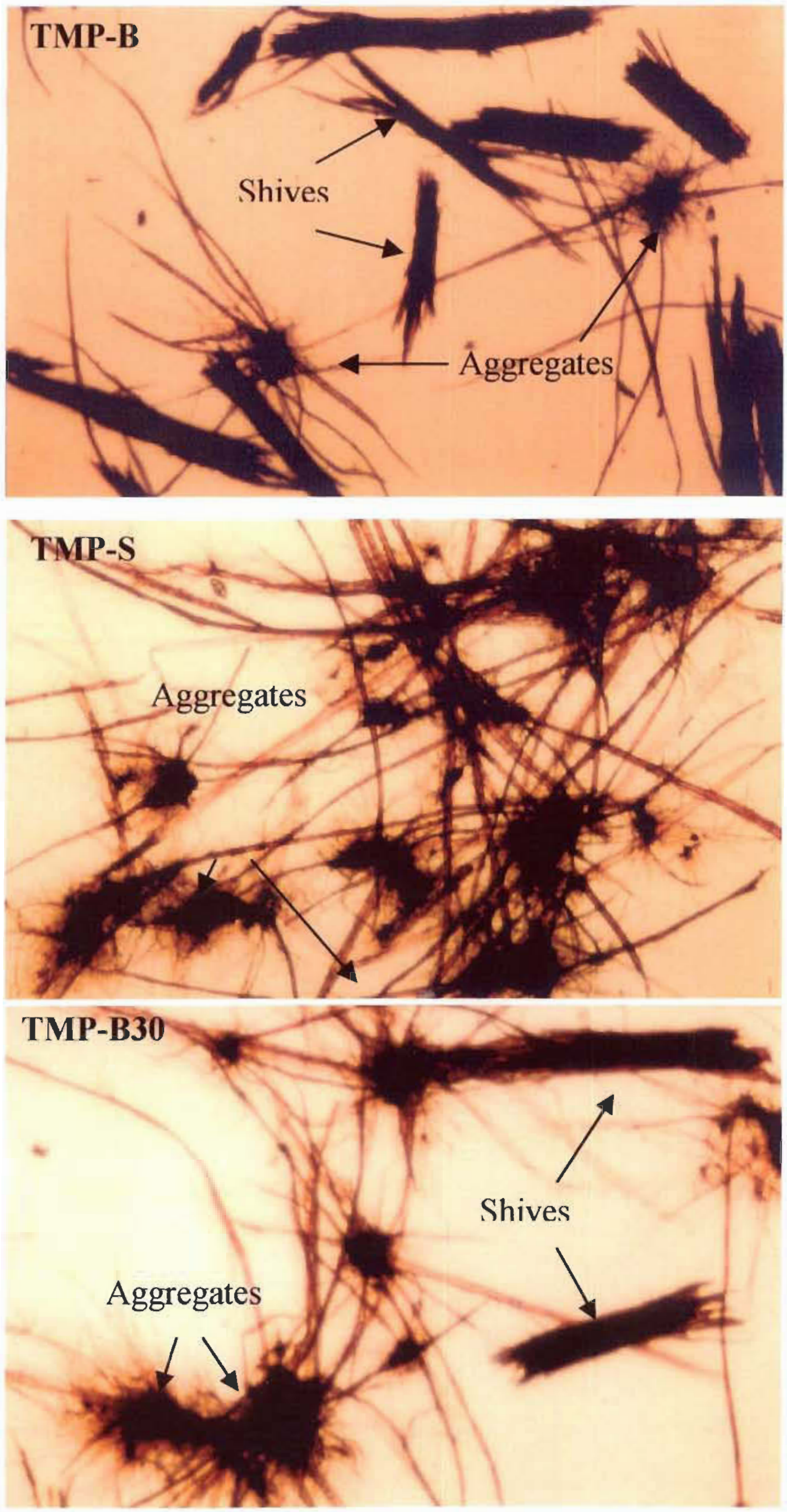


Figure 6.3 Light micrographs of the rejects of the TMPs, 16:1.

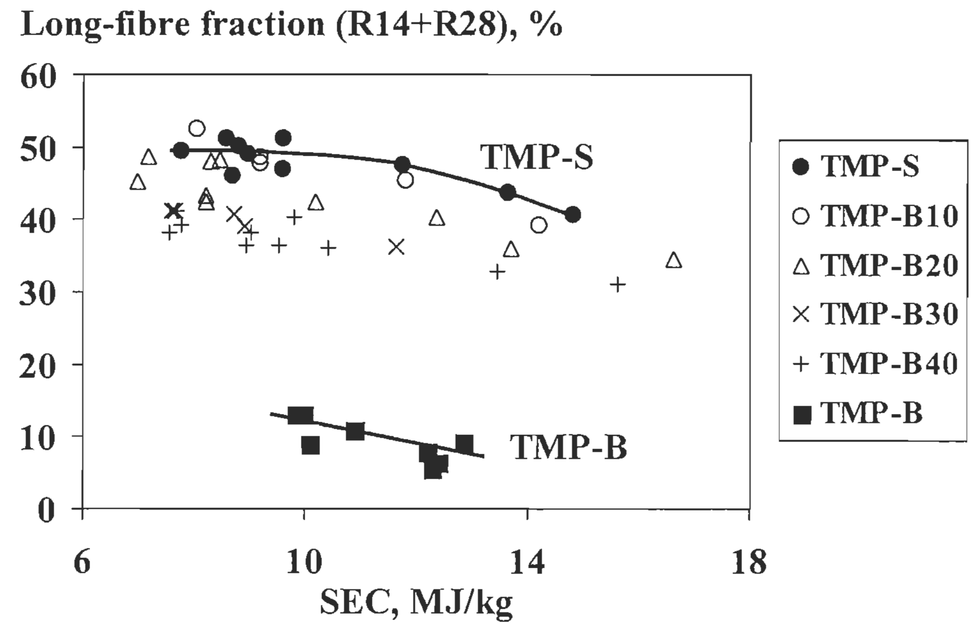


Figure 6.4 Long-fibre fraction of the TMP pulps measured by Bauer-McNett.

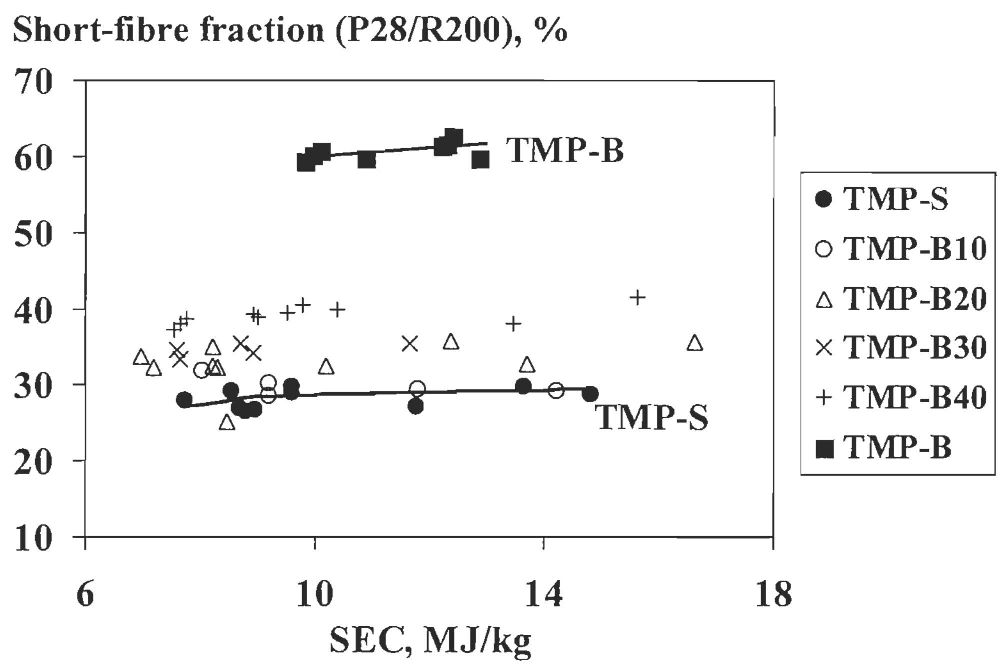


Figure 6.5 Short-fibre fraction of the TMP pulps measured by Bauer-McNett.

The TMP fines consist mostly of parenchyma cells, flake-like fragments from middle lamella and fragments from secondary wall [76]. Generally, the fines facilitate inter-fibre bonding and increase the strength properties of paper by a bridging and blocking mechanism [66, 68]. Besides the fines quality, a high fines content increases the light scattering coefficient. However, the fines from softwood and hardwood TMP influence differently the pulp properties [76]. The softwood TMP fines have a favourable effect on both strength and optical properties. The hardwood TMP fines produce paper with high optical properties but low strength qualities (such as the high wood density white birch and maple) either in combination with the hardwood fibres or with softwood fibres. Since the data are very scattered, it is difficult to distinguish the value of fines content from the background noise (Figure 6.6). The multiple regression analysis made by Statgraphics Plus showed that slight difference existed between the fines content of the TMP-S and that of the TMP-B. Furthermore, using up to 40% of white birch in chip mixtures influenced slightly the fines contents compared to the TMP-S at a given SEC.

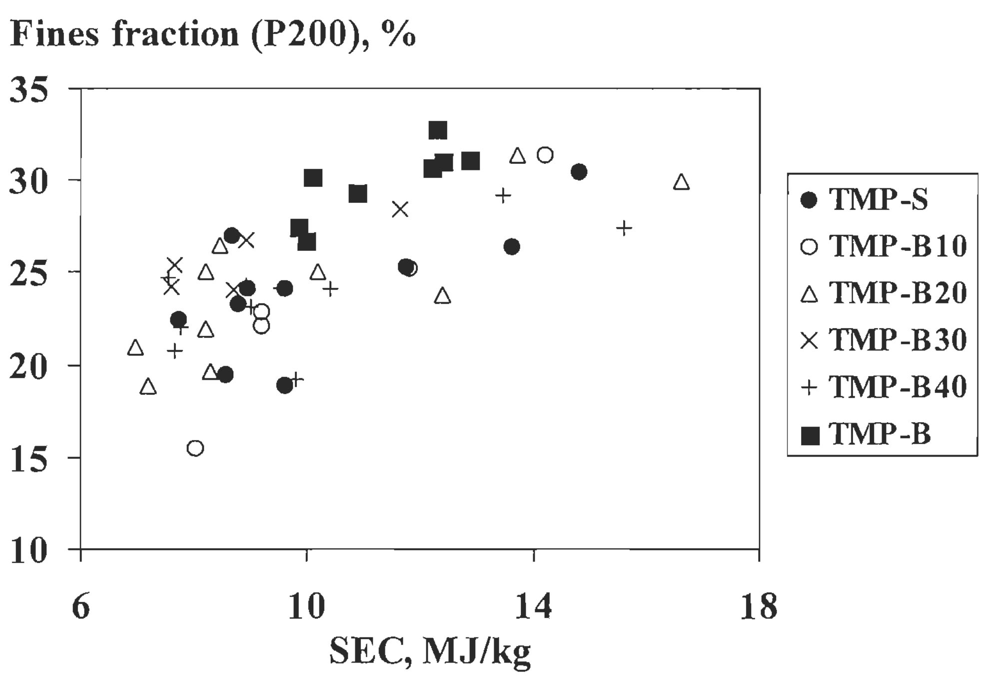


Figure 6.6 Fines fraction of the TMP pulps measured by Bauer-McNett.

Average fibre length

The content of fibre fractions give the detail information of the particles distribution in the pulps. On the other hand, the average fibre length could show us the effect of the changes in these fractions on the whole pulp. It is already recognized that the pulp fibre length is the most important factor in determining the TMP tear strength which gives paper making and printing machines good runnability [2]. As expected, the TMP-B had shorter average fibre length due to its substantially higher short-fibre content and lower long-fibre content than the TMP-S (Figure 6.7). For the substitution of 10% birch, the average fibre length changed slightly when compared to the TMP-S. Continuing to increase the amount of white birch to 40% in the chip mixtures decreased gradually the average fibre length due to the increases in short-fibre content as well as the reduction of long-fibre content.

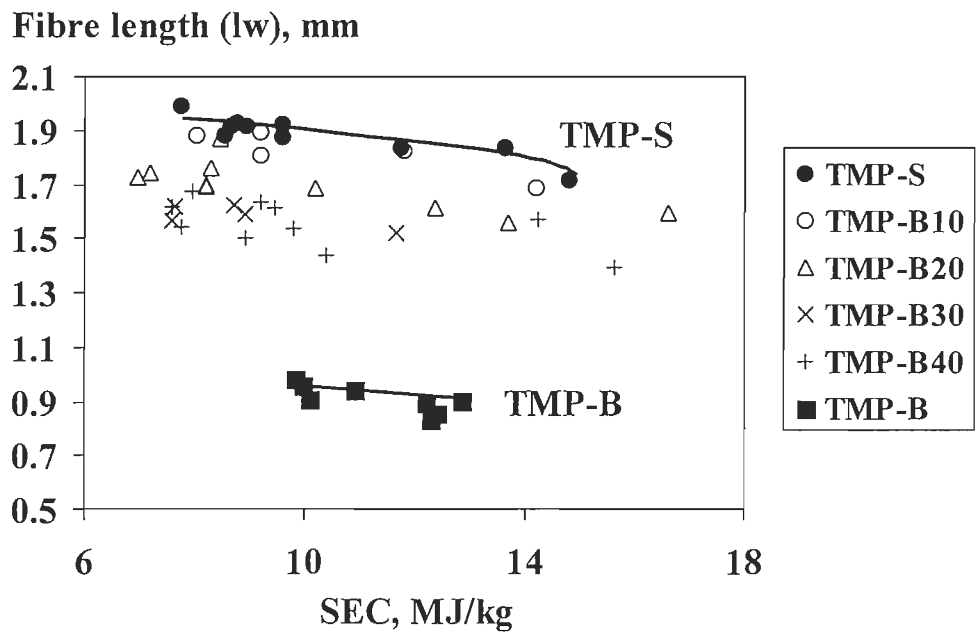


Figure 6.7 Fibre length (lw) of the TMP pulps measured by FQA vs. SEC.

Fibre coarseness

For all the samples, the coarseness of the whole pulp decreased gradually as the SEC increased (Figure 6.8). Due to its original lower coarseness, the TMP-B had lower coarseness than the TMP-S at a given SEC. Using white birch in chip mixtures decreased slightly the coarseness compared to that of the TMP-S.

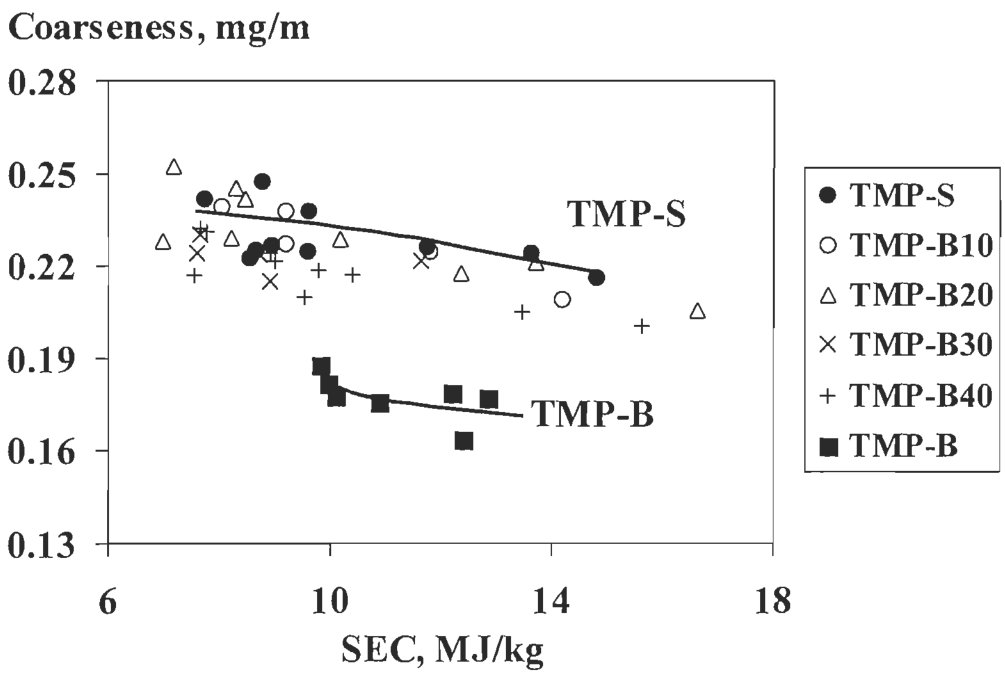


Figure 6.8 Fibre coarseness of the whole TMP pulp vs. SEC.

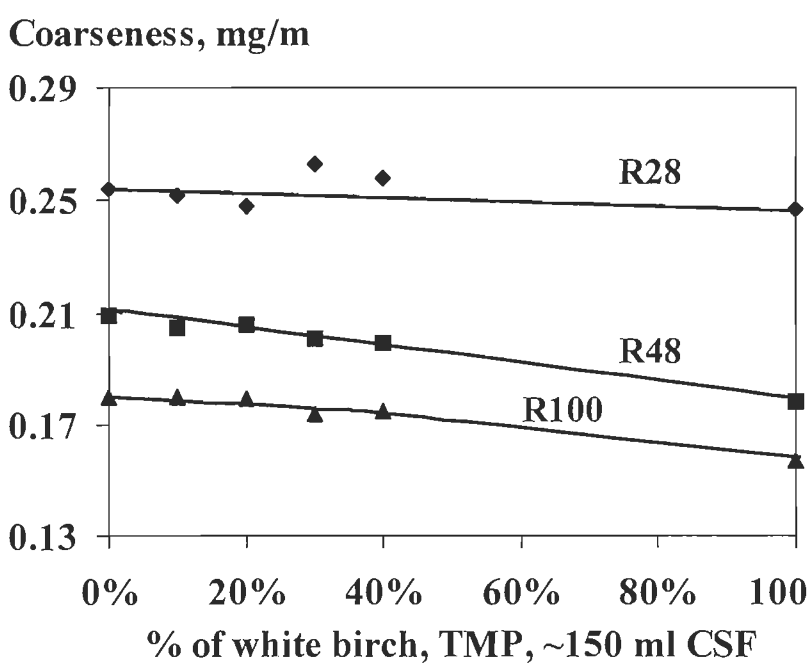


Figure 6.9 Effect of using white birch on fibre coarseness of the TMP fractions.

Fractions of R28, R48 and R100 of the pulps which had a freeness about 150 ml, were also chosen for coarseness analyses, in order to understand better the influence of the use of white birch (Figure 6.9). The coarseness of R200 was not measured since the fibres of this fraction are too short and contains lots of fines, such as fibrils, which will induce errors in the coarseness measurements by FQA. The fraction R28 of all the pulps had a similar coarseness. For the fractions R48 and R100, the coarseness of the TMP-B was lower than that of the TMP-S. The use of white birch decreased somewhat the coarseness in these two fractions. When compared to the TMP-B, the TMP-S had higher R28 (30% vs. 10%) and lower short-fibre content (R48+R100) (25% vs. 50%). For this difference, the whole pulp of the TMP-S had higher coarseness than that of the TMP-B. Figure 6.9 shows also that for all the pulps the fibre coarseness decreased as the fibre length decreased. This indicates that the degree of removal of cell wall due to peeling effect is higher for short-fibre fraction than that of long-fibre fraction. Observations by light microscopy showed that the R100 contained shorter fibres and much more ribbon-like cell wall lamellae while the R28 and R48 fibres were longer, stiffer and less delaminated (Figures 6.16, 6.17 and 6.18). Similar studies by Law [65] indicated also that the coarseness decreases with decreasing the length of the fibres for TMP. Considering the coarseness of its fibres in wood, the white birch fibres had a coarseness 30% lower than that of black spruce fibres. After refining, the difference in fibre coarseness between TMP-S and TMP-B decreased to approximately 20% for the whole pulp and 15% for the short-fibre fractions. This can be explained by the poorer development of white birch fibres during refining than that of black spruce fibres.

Flexibility (WFF) and RBA

Flexibility of the R28, R48 and R100 fractions of the pulps which had a freeness about of 150 ml were measured. The flexibility of R200 was not analysed because the fibres of this fraction were too short and contained fibrils and ray cells. As shown in Figure 6.10, the R100 had a higher flexibility than those of R28 and R48 for all the pulps except the TMP-B. For the TMP-S, the flexibility of R100 was much higher than those of the R28 and R48. But for the TMP-B, little difference was found among the R28, R48 and R100 fractions, probably due to the original highly rigid fibre structure and low degree of delamination of the fibres during refining. It shows again that the white birch fibres have a poorer development during refining compared to the black spruce fibres, which causes partly the poorer physical properties of the TMP-B. As the proportion of white birch in chip mixtures increased, the flexibility of the R28 and R48 changed slightly, but that of the R100 was more evident.

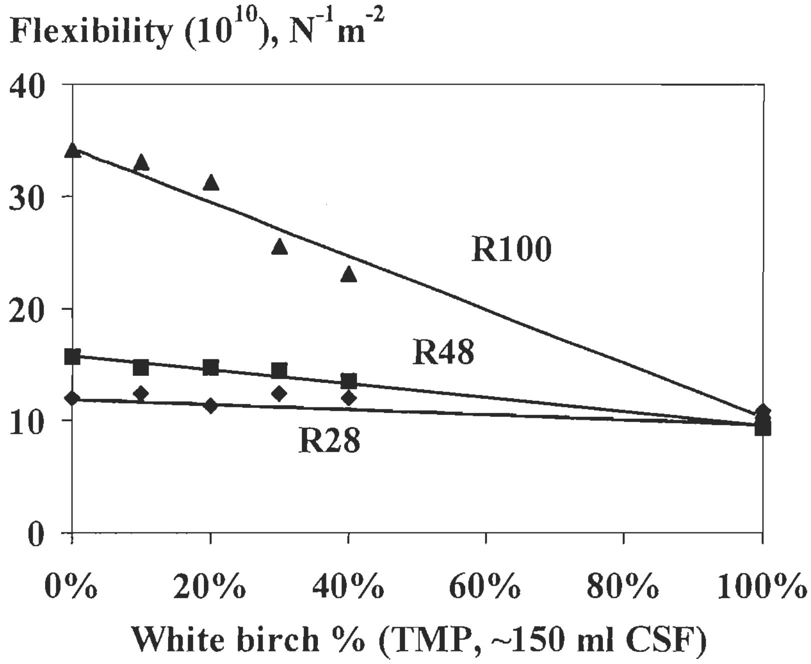


Figure 6.10 Effect of using white birch on fibre flexibility of the TMP pulps.

According to Equation 5.2, the flexibility of fibre depends on the fibre diameter and the unbonded span between the fibre and the glass. The decrease in coarseness with decreasing fibre length indicates that the fibre diameter decreases as the fibres are shorter due to the partial removing of cell wall. Theoretically, the flexibility increases with decreasing coarseness. This explains well for all the pulps except the TMP-B, as shown in Figure 6.11. Lots of fibres of R48+R100 of TMP-B keep their rigid characteristics as dose the R28, as observed by light microscopy. In view of this point, the white birch fibres behave similarly to the latewood fibres of black spruce in the TMP process. It seems that, for white birch, there is a limitation to increasing the fibre flexibility by mechanically delamination without chemicals.

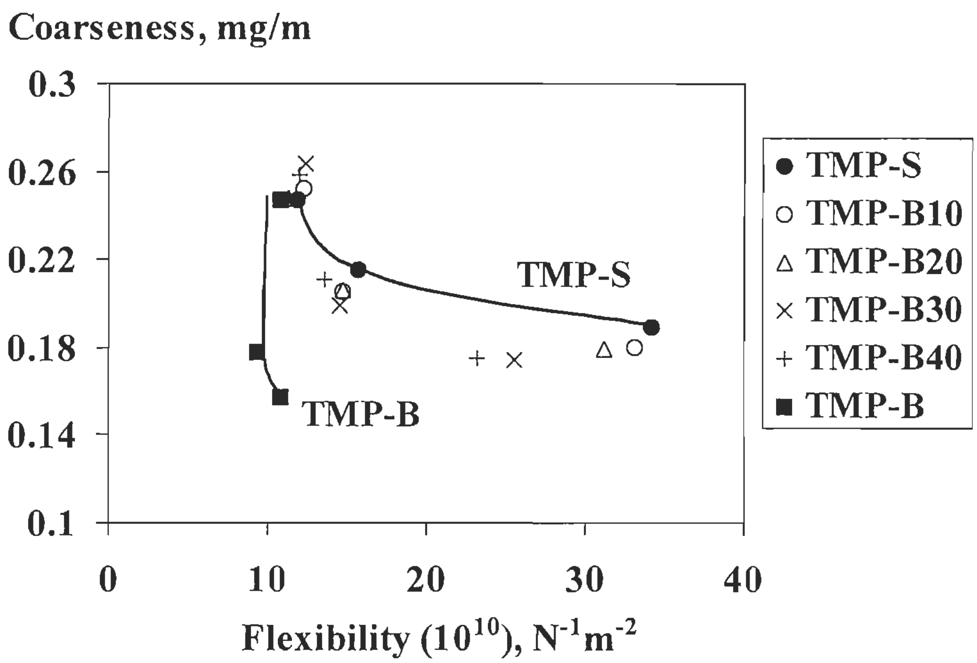


Figure 6.11 Relationship between fibre coarseness and flexibility.

RBA is an indicator of the fibre bonding potential which is measured by the percentage of fibre area made available for bonding to other fibres. A comparison of the RBA of the R48, R100 and R200 showed that the R200 had a RBA substantially higher than those of R48 and R100 for all the pulps except the TMP-B (Figure 6.12). Apparently, the R200 had a good fibre-bonding property observed for all the samples except the TMP-B. For the TMP-B, the R48 and R100 had a similar RBA, while a slightly improved RBA was observed for the R200. This again indicates the poor fibre development (e.g. fibrillation) in refining for white birch. However, the presence of vessel fragments in the R200 can affect negatively the pulp quality. Replacement of black spruce by white birch in chip mixtures decreased gradually the RBA of the R48 and R100 fractions but had little effect on the R200. This is probably for small quantity of vessel fragments affects slightly the liaison between the fibres. In view of this point, the advantage exists certainly in using white birch in mixing with black spruce for mechanical pulping. A good relationship was found between the flexibility and the RBA for the R48 as shown in Figure 6.13.

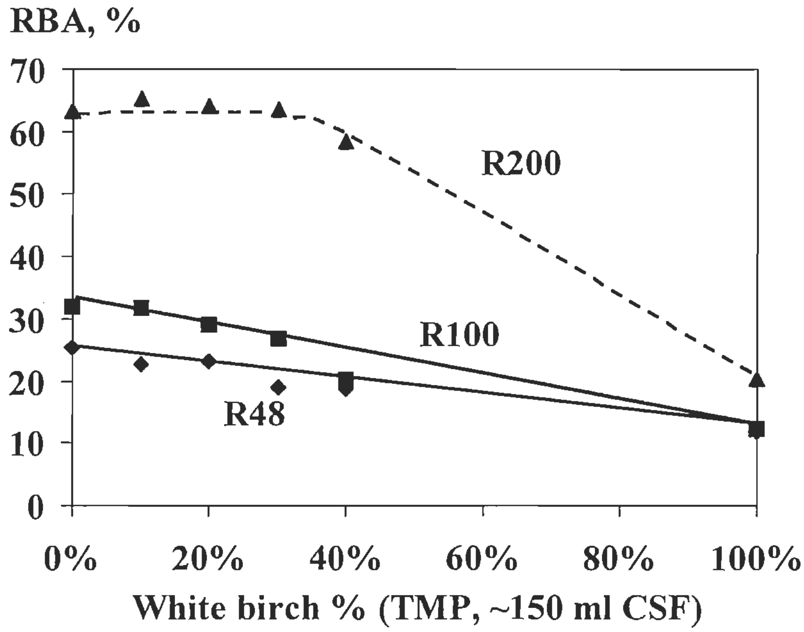


Figure 6.12 Effect of using white birch on the RBA of TMP.

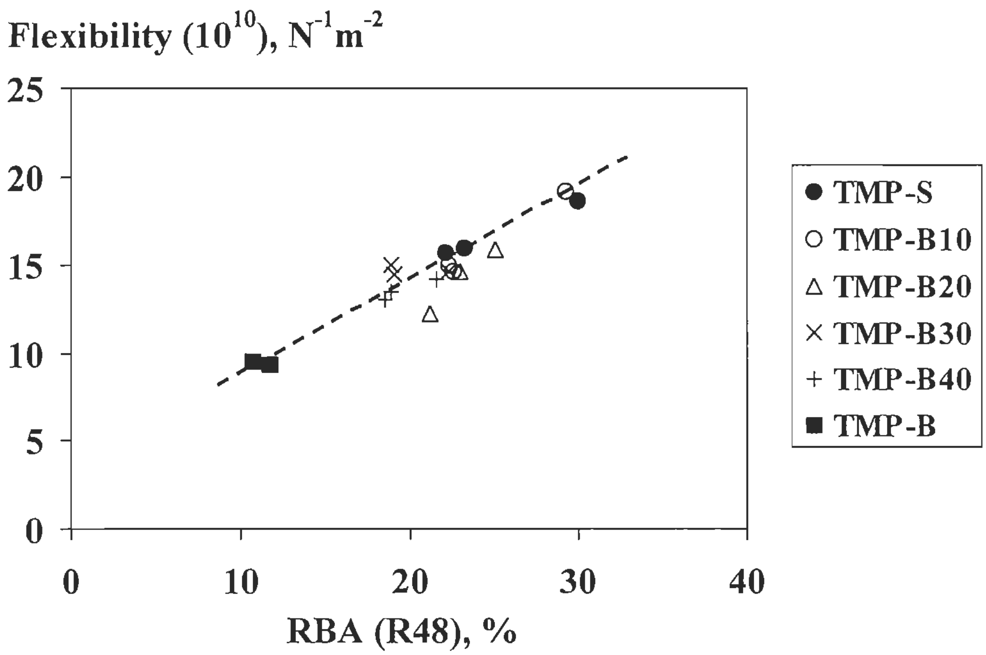


Figure 6.13 Relationship between fibre flexibility and RBA of TMP.

Hydrodynamic specific volume (HSV)

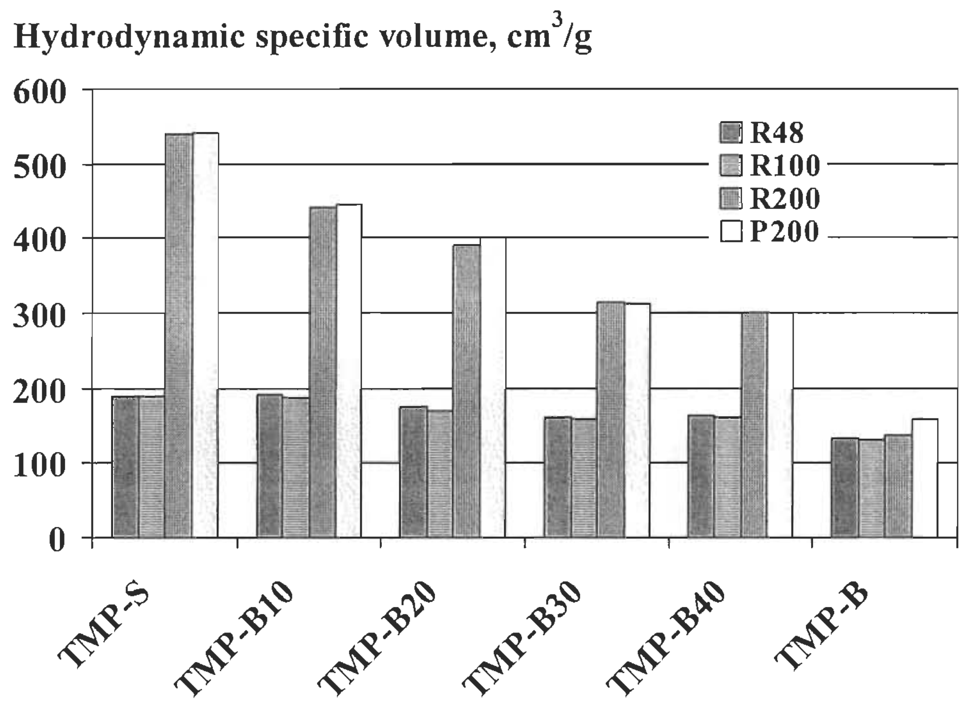


Figure 6.14 Hydrodynamic specific volume of fibre and fines of TMP.

The HSV of the R48, R100, R200 and P200 fractions was measured according to the method described by Matron and Robie [112] and Luukko [113]. Their studies showed that good relationship between the HSV and fibrillation of fibres existed and correlated well with the tensile index of paper sheet made from fines [113]. As shown in Figure 6.14, the R200 and P200 fractions had a much higher HSV than that of the R48 and R100 fractions for all the TMP except the TMP-B. It appears that the R200 and P200 have a degree of fibrillation higher than that of R48 and R100 for all the samples except the TMP-B, as indicated by microscopic observation (Figures 6.16, 6.17 and 6.18). The four fibre fractions of TMP-B had a similar HSV, which again indicates that the white birch fibre has a poor development in refining probably due to its low fibrillation. Compared to the R200 of TMP-S, the R200 of TMP-B is less fibril. In addition, the R200 of TMP-B is rich in vessel fragments while the P200 is rich in ray cells and their fragments, as observed by light microscopy (Figure 6.17). Both the vessel fragments and the ray cells have low specific surface. Augmenting the substitution of white birch for black spruce in the chip mixture had a slight effect on the HSV of the R48 and R100 fractions, but decreased gradually the HSV of the R200 and P200 fractions probably due to the presence of vessel fragments and ray cells, respectively.

Considering the large difference in HSV of the fines in the various pulps, it was decided to measure the trends of HSV of the R200 as a function of SEC. As shown in Figure 6.15, increasing the SEC augmented largely the HSV of this fraction for all the pulps except the TMP-B, which showed only slight improvement in HSV. This indicates that the black spruce fibres absorb energy more rapidly than the white birch fibres do. These characteristics maintained during co-refining.

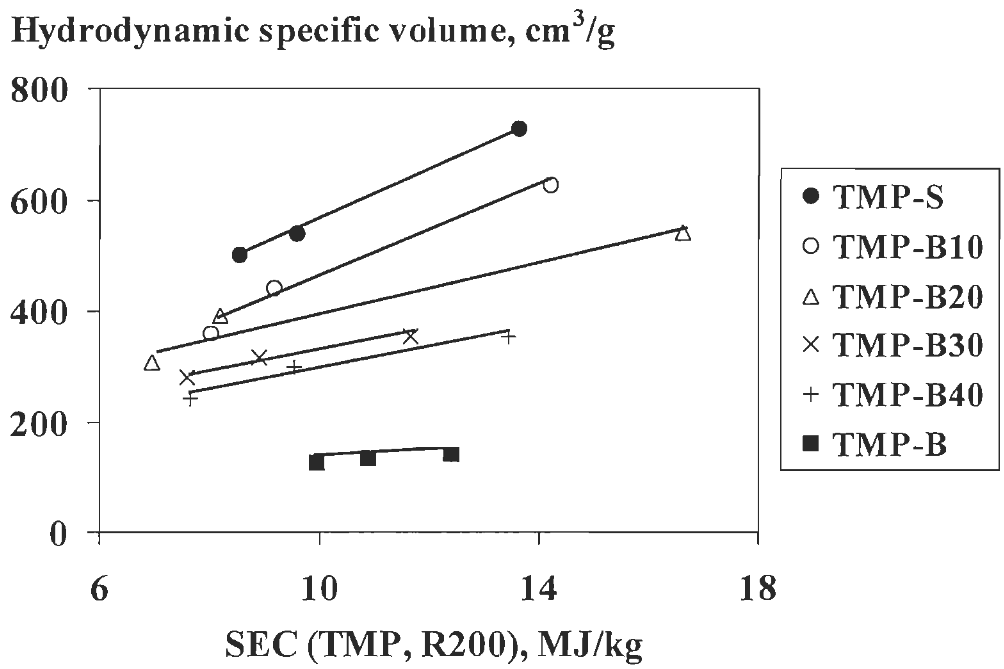


Figure 6.15 Hydrodynamic specific volume of R200 as a function of SEC.

Fibre surface characteristics (light microscopy and scanning electron microscopy)

In order to give a better interpretation of fibre and fines properties, the pulps were classified by a Bauer-McNett classifier and observed by using a microscope. It is recognized that fibre separation occurs principally somewhere at the interface between the middle lamellae and the main part of the fibre wall. The middle lamellae is then separated from both fibres or attached to one of them [114]. As the refining continues, part of the S_1 is removed and the S_2 is exposed. In this study, the R28, R48, R100, R200 and P200 were observed by means of an optical microscope. The R48 was chosen for the scanning electron microscope (SEM) observation of the fibre surface due to little difference in fibre characteristics of the long-fibre fraction between the pulps, as noted previously. For comparison, the TMP-S, TMP-B30 and TMP-B were chosen to be analyzed.

Visual inspection showed that the R28 contained lots of long and intact fibres for all the three samples (Figures 16, 17 and 18). However, partly exposed or all exposed S_2 can be observed on some fibres in the TMP-S and the TMP-B30. The intact fibres came mostly from spruce latewood and birch wood. The R28 of TMP-B showed also more fibre chunks than in the TMP-S and the TMP-B30. More ribbon like fibres were found in the R28 of TMP-S than in that of TMP-B. Other characteristics, such as cracks, splits at the end of fibres, low degree of fibrillation, and "rolled sleeve" can also be seen in this fraction. The fibres of black spruce and white birch exhibited similar characteristics in TMP-B30 as found in the TMP-B and the TMP-S.

Similar to the R28, the R48 consisted of lots of intact or partly intact but shorter fibres. The earlywood fibres appeared generally to be more flexible and had higher compressibility than latewood fibres and birch fibres, as shown in Figure 6.19: A. The paper strength and density will profit from these properties. A few latewood fibres had their S_2 completely exposed (Figure 6.19: B). The birch fibres showed more cracks across the cell wall in the S_2 helix direction (Figure 6.20). However, the latewood fibres of spruce and the birch fibres still seemed to be rigid. According to *Reme et al* [33], latewood fibres gained a larger reduction in wall thickness during refining than earlywood fibres. They indicated also that a reduction in wall thickness would raise the surface smoothness and light scattering coefficient. However, in our studies, it seems that partial removed cell wall does not improve the fibre flexibility of white birch. For the TMP-B30, much more birch fibres were observed in R48 than that in R28. Similar to the R28, the fibres of black spruce and white birch present exhibit characteristics in the TMP-B30 as seen in the TMP-B and the TMP-S (Figure 6.21).

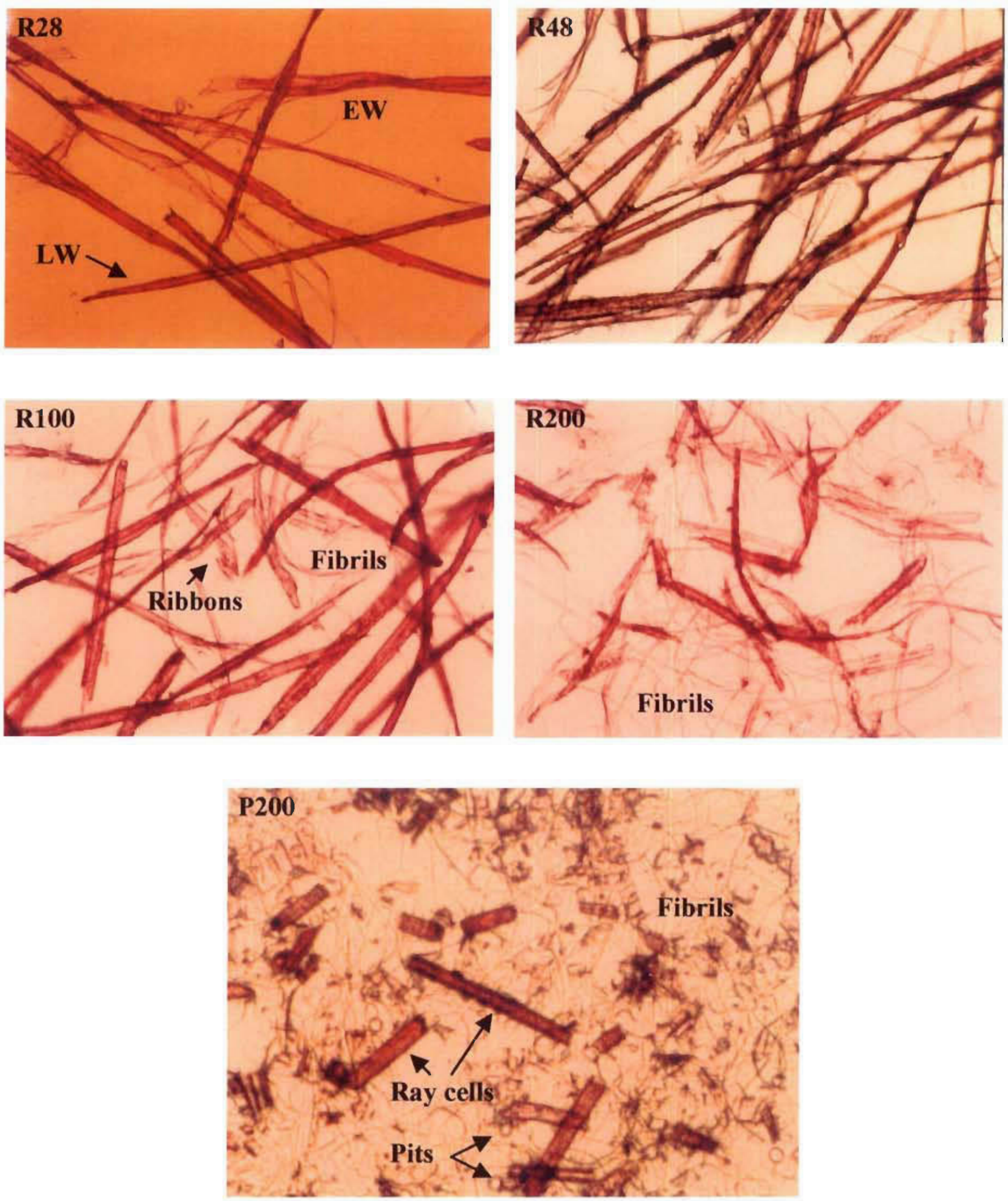


Figure 6.16 Light micrographs of the fractions of TMP-S, 40:1.

EW: earlywood of spruce; LW: latewood of spruce; EW fibres are flexible and most of them are in ribbon-like form. LW fibres are rigid.

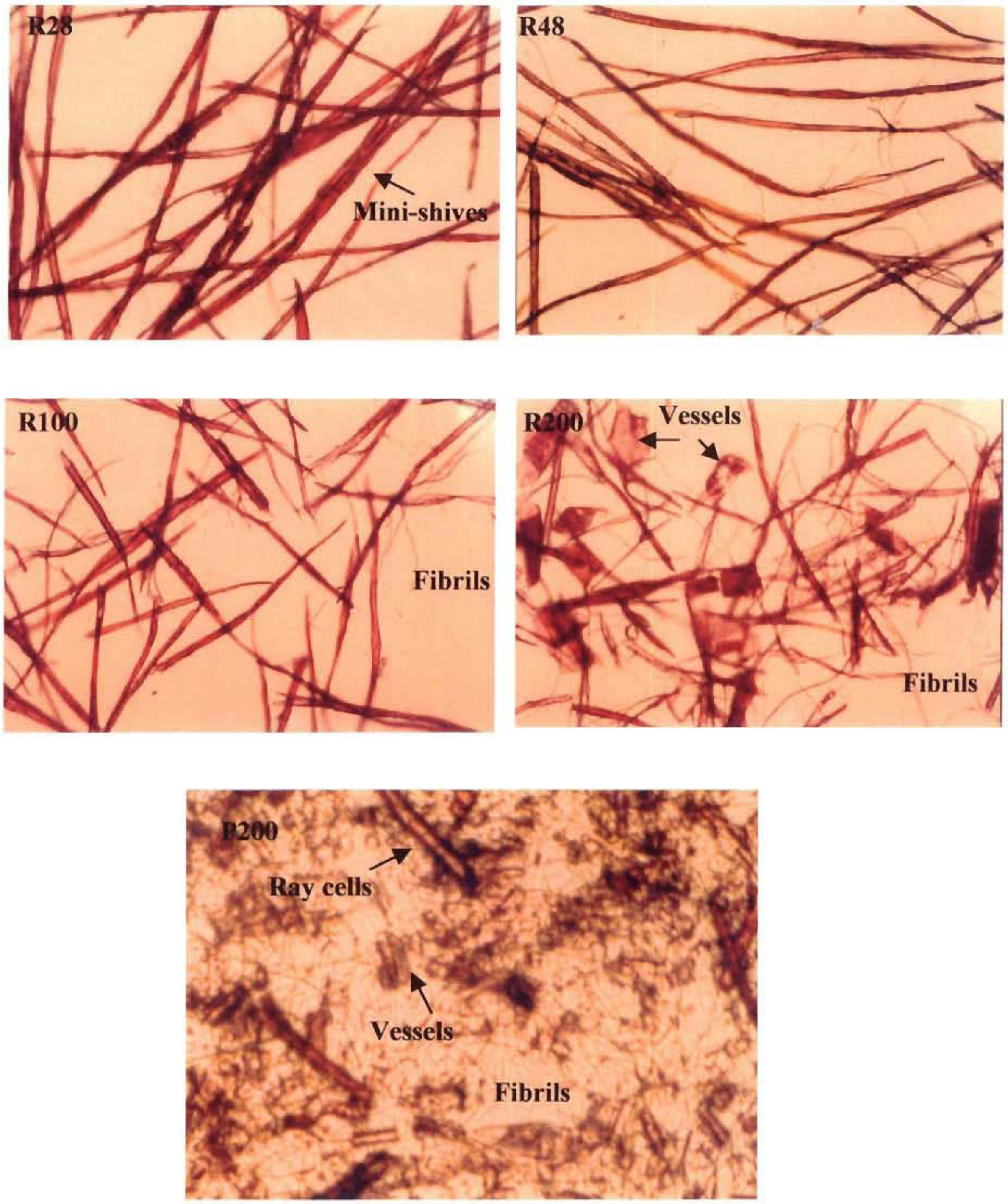


Figure 6.17 Light micrographs of the fractions of TMP-B, 40:1.

The R28 contains some mini-shives; Most of the vessels are found in the R200; and most of ray cells are remained in P200.

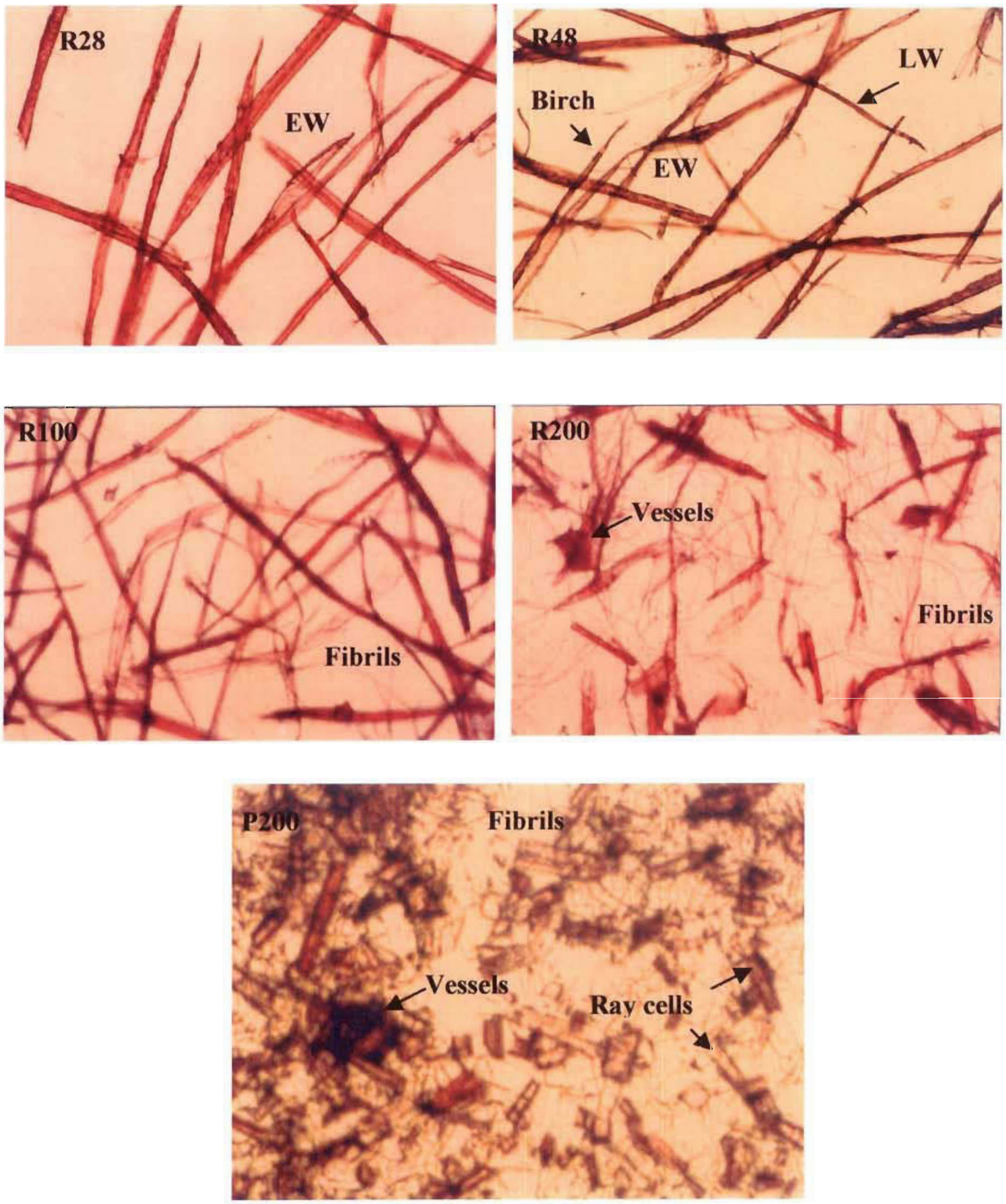


Figure 6.18 Light micrographs of the fractions of TMP-B30, 40:1.

EW: earlywood of spruce; LW: latewood of spruce.

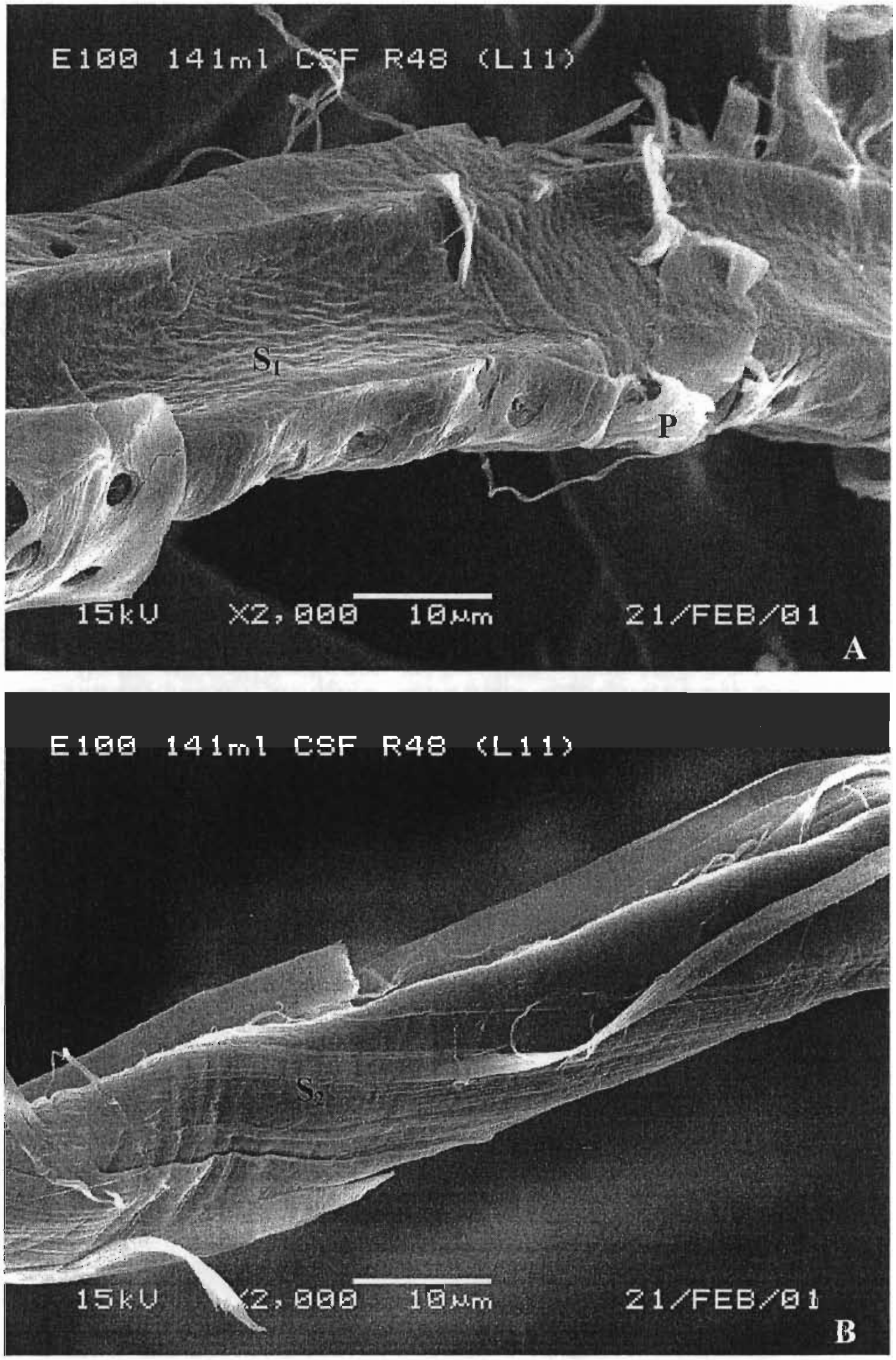


Figure 6.19 SEM micrographs showing the fibres of R48 of TMP-S.

A: a flexible earlywood fibre with S_1 exposed and remained debris of P;
B: a rigid latewood fibre with wholly exposed S_2.

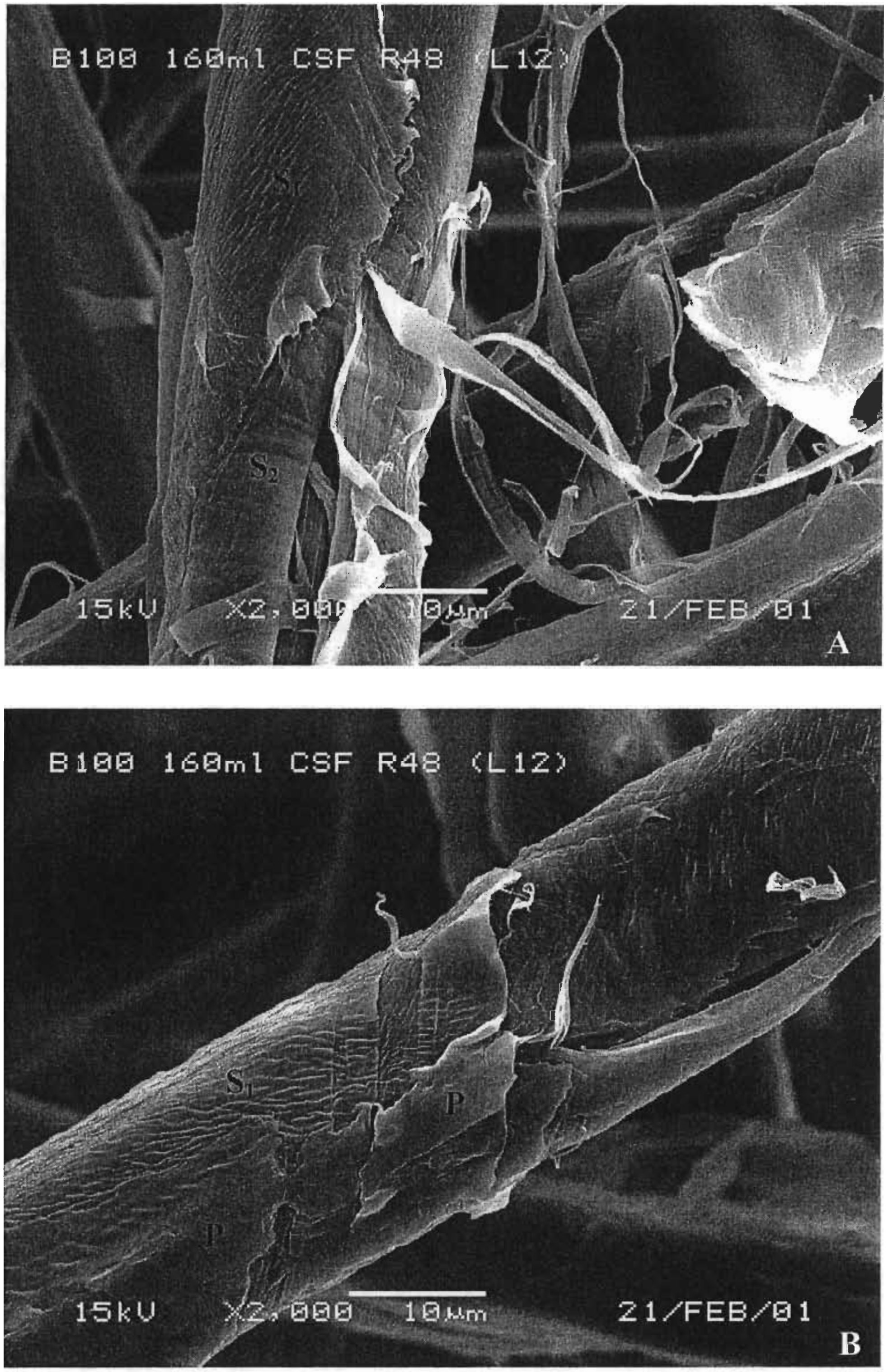
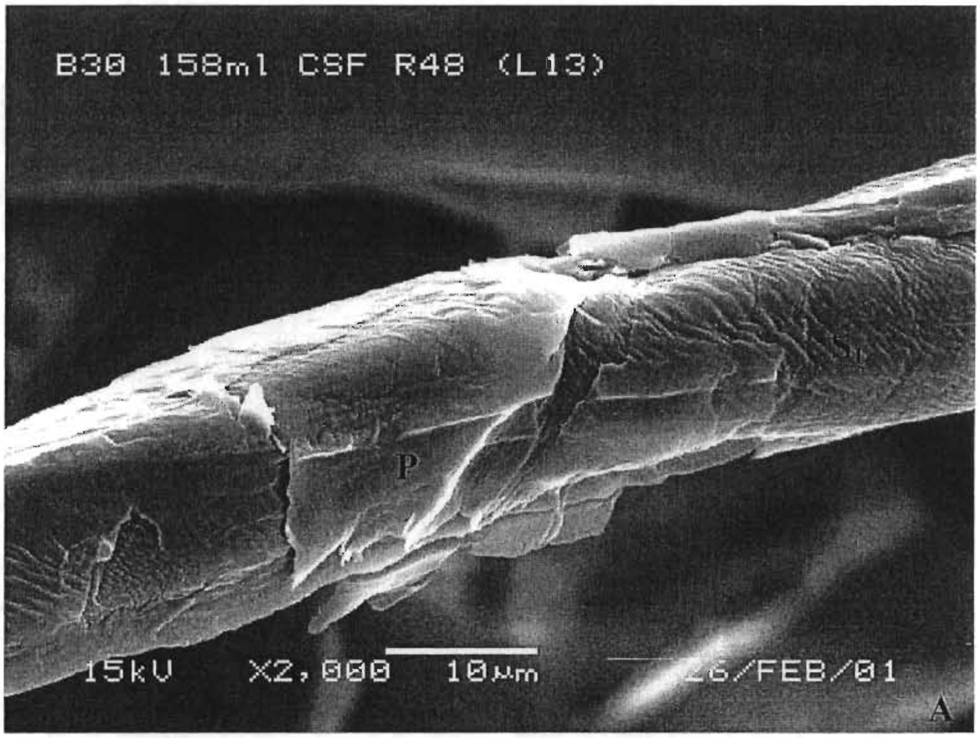
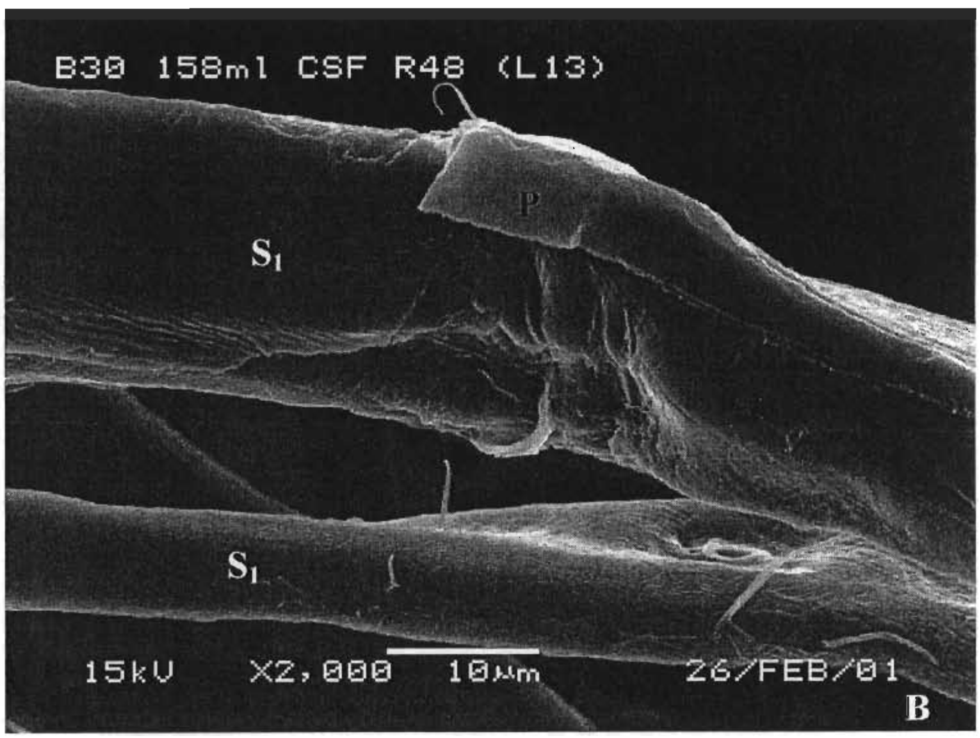


Figure 6.20 SEM micrographs showing the fibres of R48 of TMP-B.

A: a birch fibre with partially exposed S_2 and visible splits in the direction of S_2 helix;
B: a birch fibre with partially exposed S_1 and visible cracks in the direction of S_2 helix.


B30 158ml CSF R48 (L13)
P
15kU X2,000 10μm 26/FEB/01
A


B30 158ml CSF R48 (L13)
P
S1
S1
15kU X2,000 10μm 26/FEB/01
B

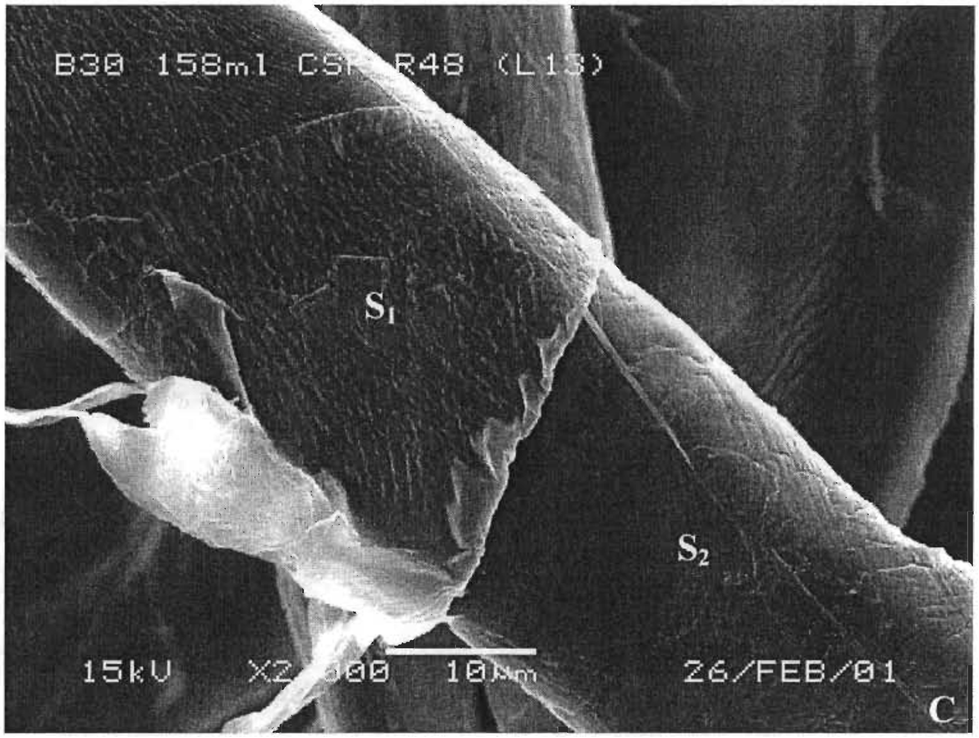


Figure 6.21 SEM micrographs showing the fibres of R48 of TMP-B30.

A: a rigid birch fibre with partially exposed S_1 and splits in the direction of S_2;
B: two flexible earlywood fibres of spruce with partially and wholly exposed S_1 respectively;
C: a rigid latewood fibre of spruce with partially exposed S_2.

The R100 composed mainly of short fibres and ribbon like cell wall lamellae (Figures 6.16, 6.17 and 6.18). In the TMP-S and TMP-B30, the R100 of TMP-S and TMP-B30 contained apparently much more ribbon-like cell wall lamellae and short fibres with higher flexibility, when compared to the R28 and the R48 of the same sample. For the TMP-B, the fibres of R100 were still in rigid structure as found in the R28 and R48 (Figure 6.17). Again, the intact fibres came almost from the spruce latewood and birch fibres. Some fibre chunks were still found in this fraction of the TMP-B. In addition, a few vessel fragments were found in this fraction of the TMP-B.

The R200 consisted mainly of short fibre fragments, fibrils and some ray cell (Figures 6.16, 6.17 and 6.18). The short fibre fragments with high fibrillation were observed in the R200 of the TMP-S and the TMP-B30. A few partially intact fibres found in this fraction came from spruce latewood or birch wood. The fibrillation was low for the R200 of TMP-B and lots of vessel fragments were found in this fraction. Some vessel fragments were also found in the R200 of the TMP-B30. It seems that these vessel fragments have a slight influence on the fibre-to-fibre bonding since high RBA was observed on the R200 of the TMP pulps from chip mixtures. The TMP-B also contained some short fibre chunks. These chunks were not found in the R200 of the TMP pulps from chip mixtures. Apparently, the separation and fibrillation of the white birch fibres is not so good as that of black spruce.

The P200 consisted mainly of flakes, fibrils and some very short fibre fragments (Figures 6.16, 6.17 and 6.18). The flakes are lignin-rich cell wall and middle lamella fragments as well as ray cells with a low swelling ability. On the other hands, the fibrils are cellulose-rich materials with a high specific area and swelling ability and are derived from the secondary layer, especially from S_2 layer. Again, the short fibre fragments in P200 of the TMP-B were less fibril than those of the TMP-S. In addition, the P200 of the TMP-B contained some of vessel fragments (the birch has 11% in volume of wood). It can be observed that the degree of fibre cutting was higher for the TMP-B than for the TMP-S due to the higher stiffness of white birch fibres. Hence, the P200 of the TMP-B had a poorer quality than that of the TMP-S. The visible inspection showed that the P200 of the TMP-B30 composed of the particles with the characteristics similar to that of the TMP-S except that some vessel fragments were found in the former.

Table 6.3 Fibre wall dimensions of spruce and birch fibres [27, 22, 75]

Fibre properties	**Black spruce**		**White birch**
	Earlywood	**Latewood**	
Length, mm	2-4 (3,5)		1,1-1,2
Width, μm	20-40		14-40
Thickness, μm	2-4 (1,52)*	4-8 (4,09)*	(1,74)*
S_1 Thickness, μm Lamellae Microfibril angle	0,13 3-4 Z helix or S helix 50-70°	0,18	0,21 (~2) Z helix or S helix 50-70°
S_2 Thickness, μm Lamellae Microfibril angle	1,26 30-40 10°	3,81 > 150 20-30°	1,44 - -
S_3 Thickness, μm Lamellae Microfibril angle	0,13 Several Z helix / S helix 50-90°	0,10	0,09 Several Z helix / S helix 50-90°

* ( ) Average thickness.

Generally speaking, the white birch has a poorer fibre development (such as delamination and fibrillation) in refining than that of black spruce due to the differences of the inherent fibre characteristics of these two species. The white birch fibres have a thicker S_1 layer than that of black spruce fibres (Table 6.3), which causes probably the lower delamination and fibrillation degree of white birch fibres, despite the exposition of the S_2 layer in white birch. Being the main portion of the cell wall, the S_2 layer (thickness, microfibrillar angle, etc.) has a decisive influence on the fibre stiffness and on the papermaking properties. Compared to the earlywood tracheids of softwood, the latewood tracheids of softwood and the libriform fibres of hardwoods have a high percentage of S_2, which may account for 90 % of the cell wall. As shown in Table 6.3, latewood tracheids of spruce have a S_2 with thicker wall and higher microfibril angle than that of earlywood tracheids. The S_2 layer of birch libriform fibres is also thicker than that of spruce earlywood tracheids but thinner than that of spruce latewood tracheids. Thus, the birch fibres could have still a higher stiffness although the S_2 of some birch fibres is exposed partly or completely, as showed by scanning electron microscopy. Koljonen *et al* [58] obtained similar results on latewood fibres of spruce. They studied the delamination of spruce fibres during refining and indicated that the stiffness of the earlywood fibres decreased during refining while that of the latewood fibres did not change.

Although little difference in fibrillation was noticed between the long-fibre fraction of the TMP-B and the TMP-S, the light microscopy observation showed that large improvement in the fibrils content can be found in the R200 and P200 of the TMP-S and the TMP-B30. But these fractions of the TMP-B have less fibril. These observations are in direct relationship with the fibre flexibility, HSV and RBA measurement of the fractions. It seems that the co-refining of chip mixtures does not change the refining behavious of white birch and black spruce fibre when compared to the refining of a single species. However, the undesirable effect of a small quantity of white birch fibres and vessel fragments can be compensated by the high quality spruce fibres and fines. There is a limitation beyond which the white birch fibre and fines quality cannot be improved by pure mechanical refining.

6.3 Pulp strength properties

Generally, the TMP is stronger than the other pure mechanical pulps, such as SGW and RMP, for its' high long-fibre content when compared to the pure mechanical pulps. In most cases, the TMP substitutes for SGW to produce news-grade papers to decrease the use of the expensive chemical pulp. In the following, the effect of using white birch on the tear, tensile and burst strength will be discussed in detail.

Tear strength

Black spruce produced TMP with higher tear strength than the white birch (Figure 6.22). Adding 20% white birch chips in spruce chips did not impair the tear strength relative to that of the TMP-S. But at 30-40% substitution the tear index decreased to lower than 8,0 mN*m^2/g. This is because of an important drop in as a result of the addition of birch.. This also caused a decrease in the average fibre length. There is a good relationship between the tear index and the long-fibre content of the pulps (Figure 6.23). As discussed previously, the fibres of birch are shorter than those of spruce. In addition, they have a rigid structure even when part of S_2 layer is exposed. Co-refining of birch with spruce decreased the average fibre length of the pulp and also introduced the rigid birch fibres, thus the tear strength of the pulp decreased remarkably when more than 20% birch are added in the chip mixtures compared to the TMP-S. Note that the TMP-B had the lowest tear index due to its lowest long-fibre content and the less flexible fibres.

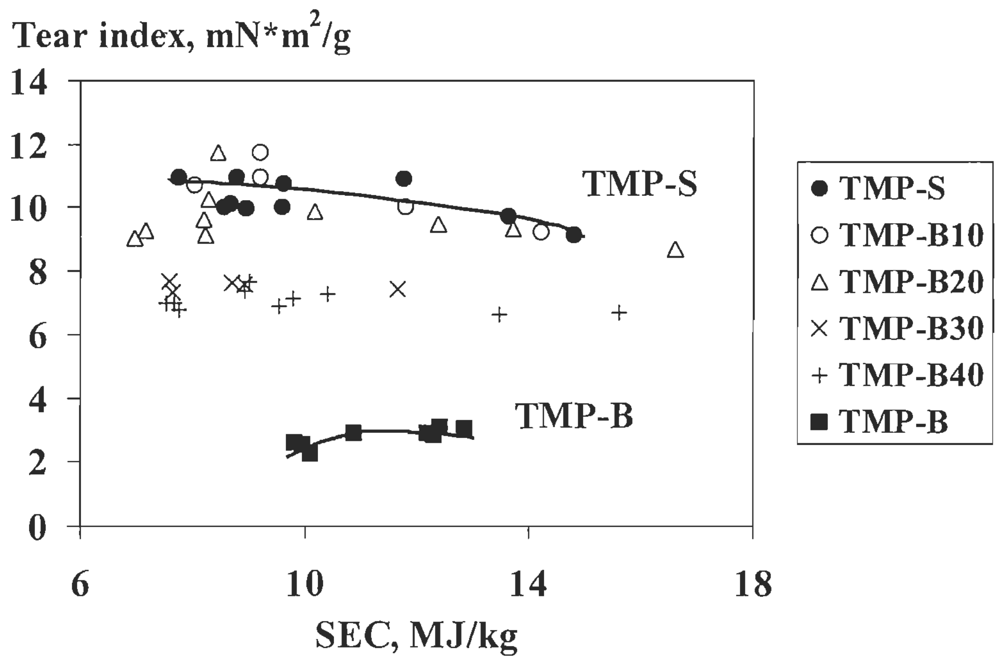


Figure 6.22 Tear index of the TMPs as a function of SEC.

Tensile strength

For all the pulps except the TMP- B, the tensile strength increased with increasing SEC, as shown in Figure 6.24. The tensile index slightly decreased when 20% of spruce was replaced with birch. The chip mixtures containing up to 30-40% white birch suffered a large decrease in tensile index, which was below 40 N*m/g. Obviously, these pulps do not meet a quality specification value of 42 N*m/g for the production of newsprint [115].

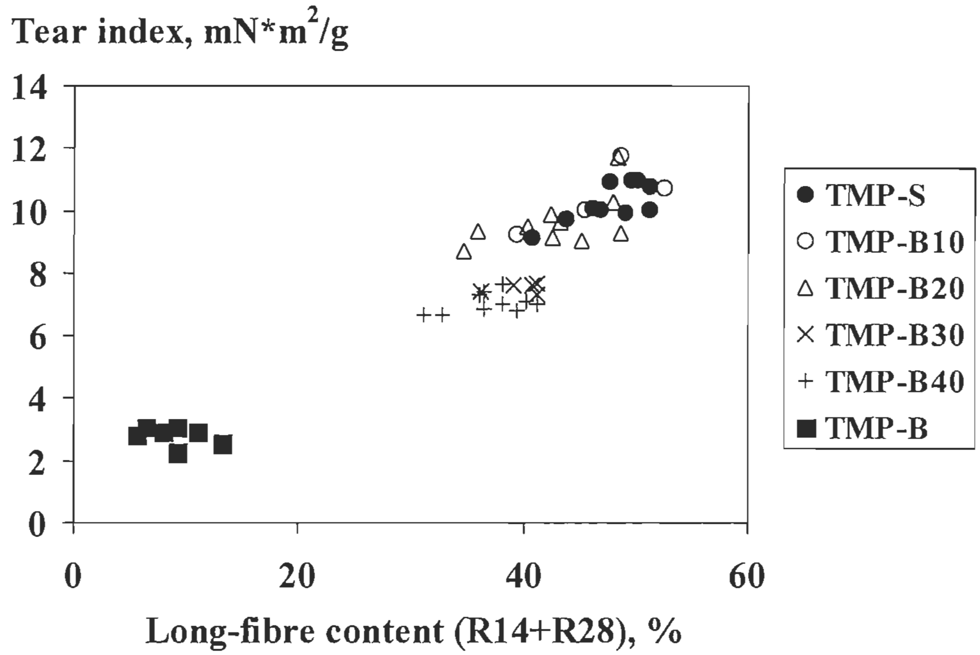


Figure 6.23 Relationship between the tear index and the long-fibre content for TMP.

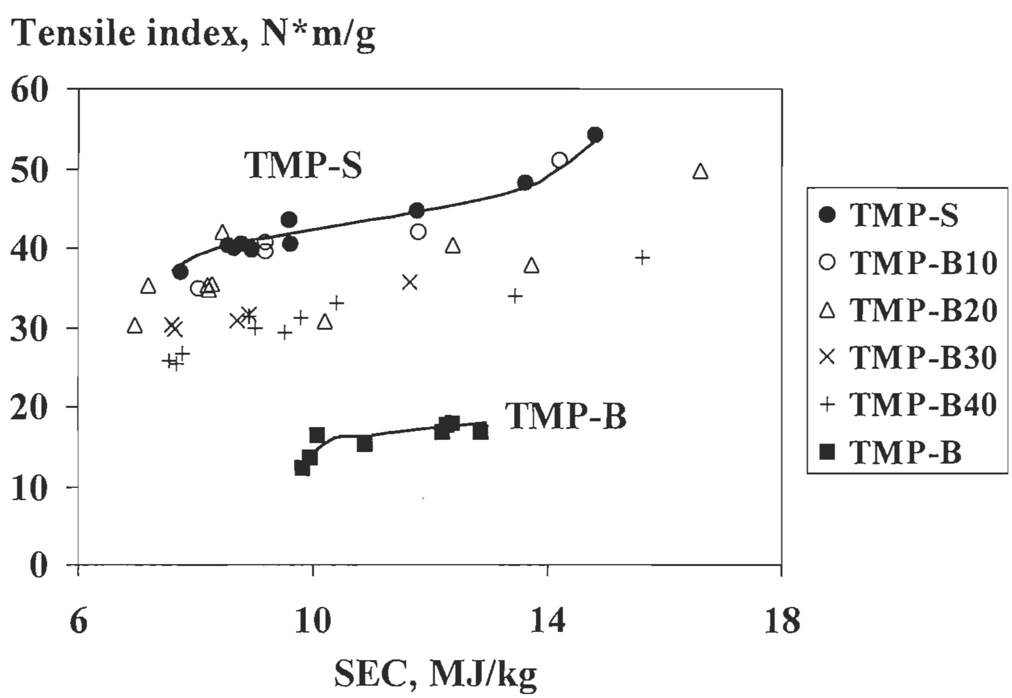


Figure 6.24 Tensile index of the TMPs as a function of SEC.

Burst strength

Increasing SEC increased the burst strength for all the pulps except the TMP-B (Figure 6.25). As expected, the TMP-B had the lowest burst strength and the TMP-S had superior burst strength. The chip mixtures containing 10-20% white birch affected slightly burst strength compared to TMP-S. Increasing the substitution of white birch in the chip mixtures decreased the burst index. For pulps produced from chip mixtures containing 30-40% of white birch, the bust index was lower than 2,0 kPa*m^2/g, for a freeness below 100 ml.

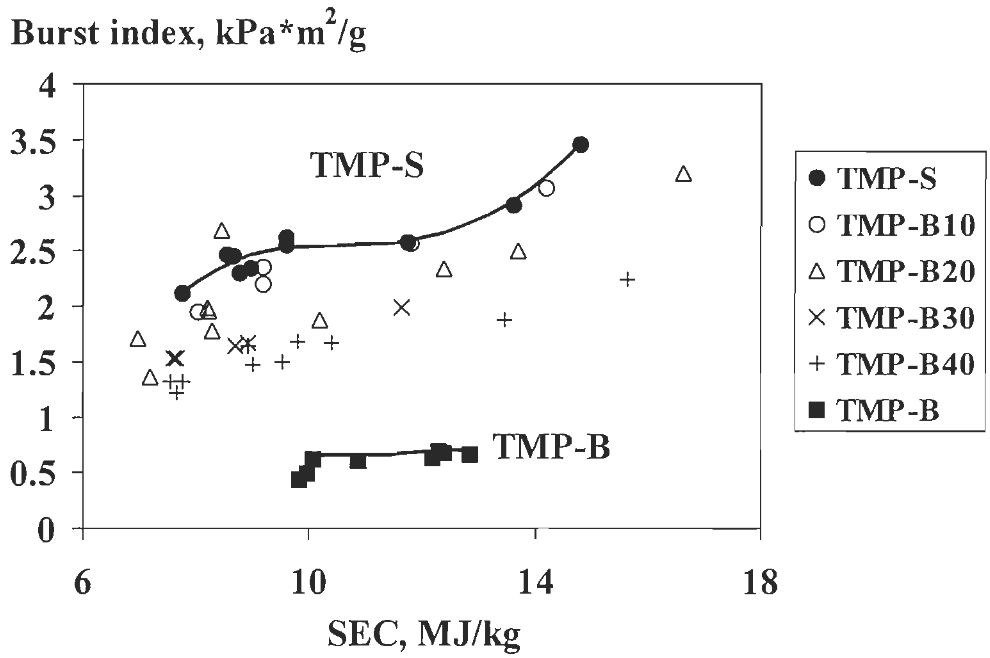


Figure 6.25 Burst index of the TMPs as a function of SEC.

6.4 Pulp optical properties

As a main newsprint furnish, the thermomechanical pulps have generally good optical properties due to their high fines content compared to chemical pulp and some high yield pulp (e.g. CTMP, APMP, CMP, etc.). The optical properties determined in this study include the light scattering coefficient, light absorption coefficient, and brightness. The relationships of these parameters are shown in Figures 6.26 to 6.28.

Light scattering coefficient and light absorption coefficient

For all the pulps, the light scattering coefficient increased with increasing refining energy input, as shown in Figure 6.26. Using white birch in the chip mixtures increased somewhat the light scattering coefficient at high refining energy input compared to the TMP-S. An increase of short-fibre fraction contributed also to augment the light scattering coefficient due to the increase in specific surface area and the introduction of flake-like fines from white birch [67]. The TMP-B had a light scattering coefficient superior to that of the other pulps due its high short-fibre and fines with low specific surface. In addition, the fines of the TMP-B consist mainly of flake-like particles and have low HSV, as discussed previously. Therefore, the fines of TMP-B behave like fillers and contribute to light scattering coefficient. Figure 6.27 shows the tendency of light absorption coefficient of the pulps as a function of SEC. Using up to 20% of white birch influenced slightly the light absorption coefficient. As the substitution of white birch was increased to 40% the light absorption coefficient increased somewhat.

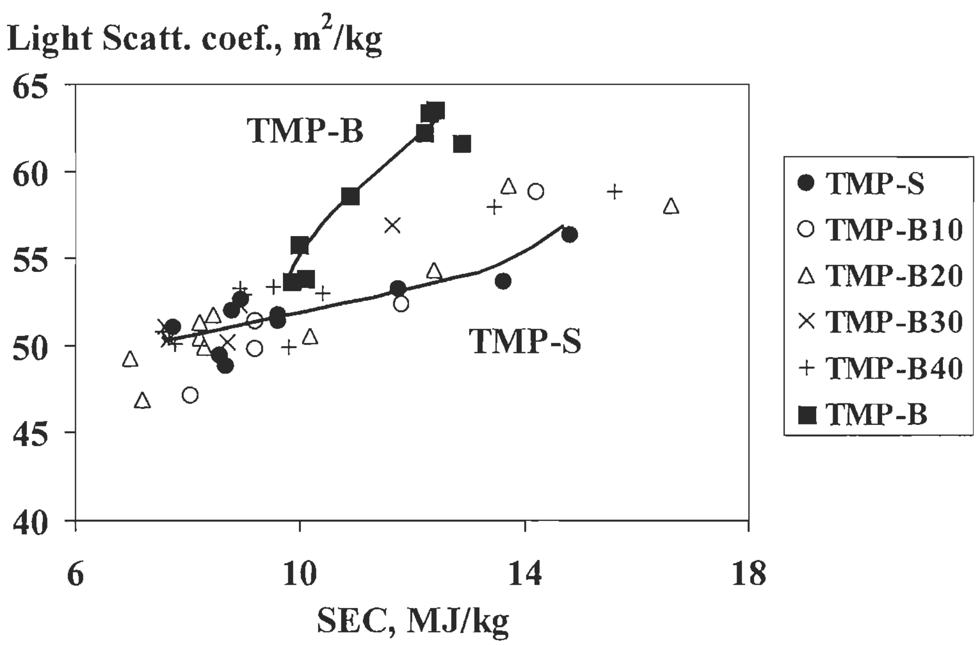


Figure 6.26 Light scattering coefficient of the TMP pulps as a function of SEC.

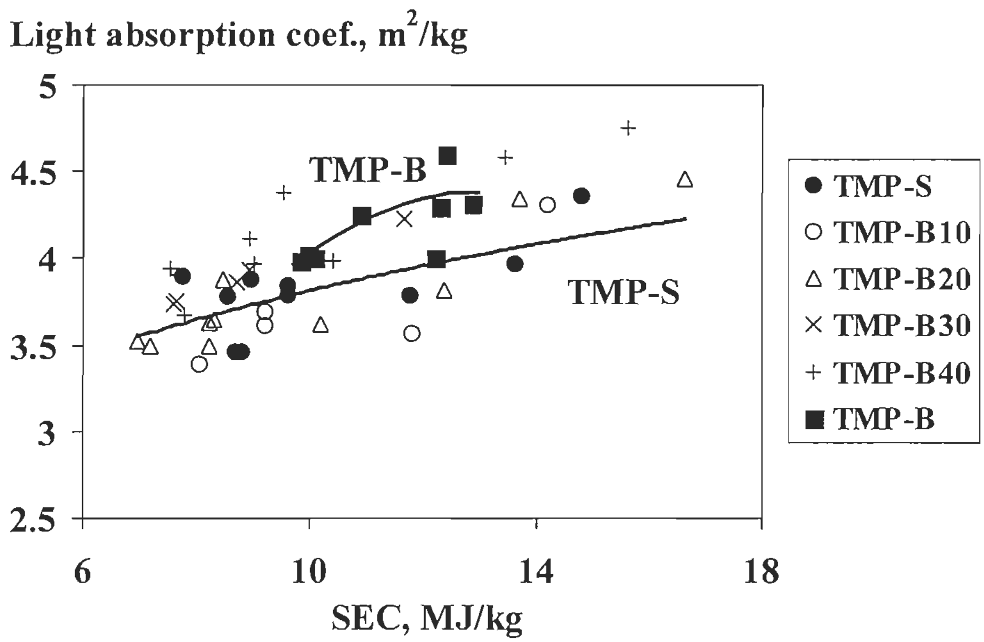


Figure 6.27 Light absorption coefficient of the TMP pulps as a function of SEC.

Brightness

The brightness of pulp depends on the fibre composition as well as the quality and quantity of the fines on top of the original brightness of the wood species. Although the wood of black spruce is much brighter than that of white birch, the TMP-B had brightness higher than that of the TMP-S at a given SEC (see Figure 6.28). Mixing of white birch with black spruce improved slightly the brightness of the pulps compared to the TMP-S.

6.5 Sheet structure properties

Sheet density is a useful indirect measure of the fibre flexibility and inter-fibre bonding ability. As shown in Figure 6.29, the TMP-S had the highest sheet density compared to the other pulps. Adding white birch in the mixtures decreased proportionally the sheet density.

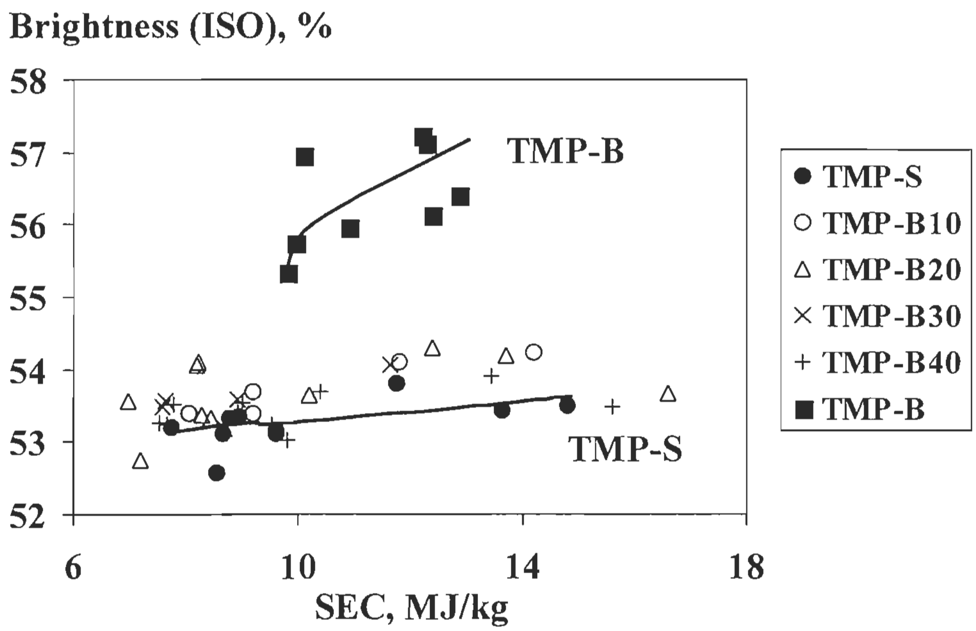


Figure 6.28 Brightness of the TMP pulps as a function of SEC.

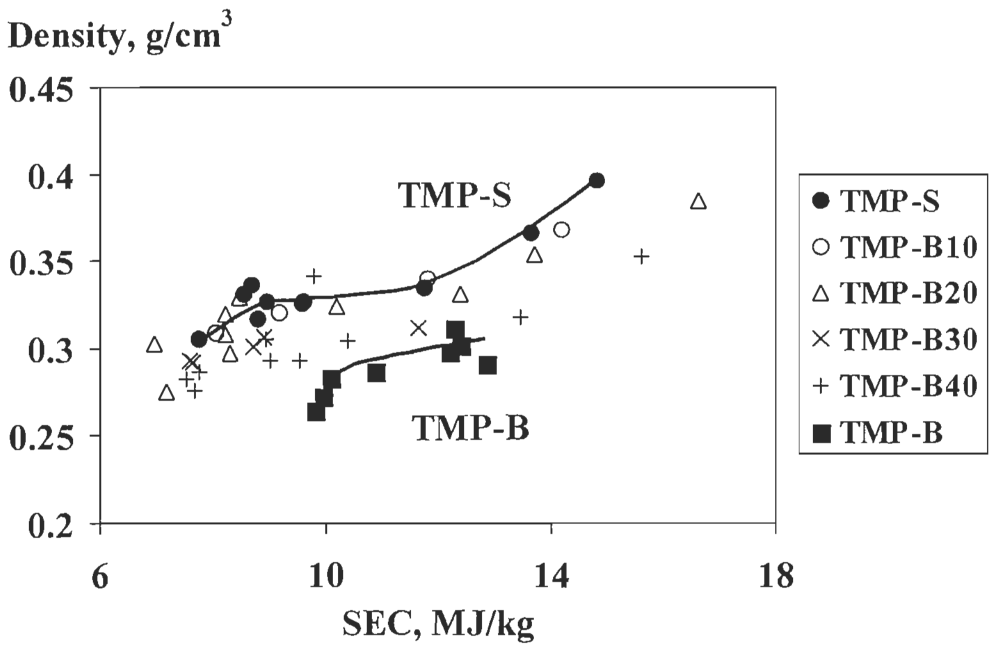


Figure 6.29 Density as a function of SEC.

Generally, good smoothness or low roughness of paper surface along with low porosity are two important properties required for good printability of newsprint furnishes. In mechanical pulp, high fines content contributes not only to good formation and opacity, but also to high smoothness and low porosity. As shown in Figure 6.30, the handsheet of the TMP-B had the highest porosity while the TMP-S gave the lowest for a given SEC. This indicates again that the flake-like fines of the TMP-B behave as fillers and have less effect on reinforcing the fibre-to-fibre bonding potential compared to the fines of TMP-S. Increasing the white birch substitution in the chip mixtures increased proportionally the porosity of sheet probably due to the introduction of stiff fibres of white birch.

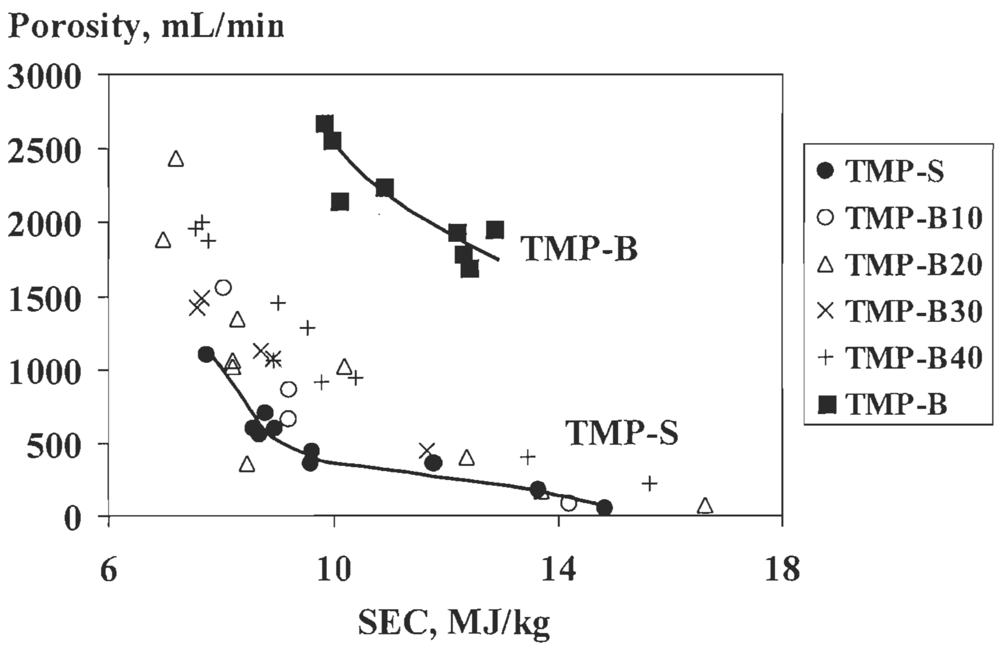


Figure 6.30 Porosity of the TMP pulps as a function of SEC.

At low levels of SEC (<12 MJ/kg), the TMP-B had roughness higher than that of TMP-S. But the difference between them decreased with increasing refining energy input (Fig.6.31). Increasing the white birch addition in the chip mixtures increased marginally the roughness.

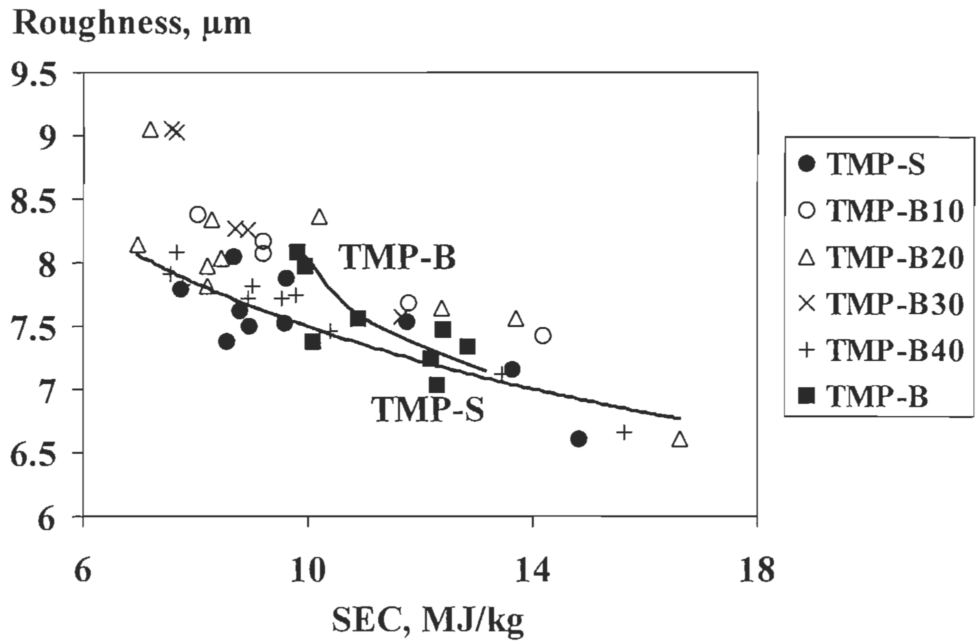


Figure 6.31 Roughness of the TMP pulps as a function of SEC.

6.6 Linting propensity

The handsheets made from the TMP-S and from mixture of chips (10-40 and 100% birch) were analysed by a RNA-52 Printability Tester (Research North America Inc.). The collected lint materials were analysed by FQA and the detail results are found in Appendix A. According to the *CPPA useful method L.5U* designed by Paprican, for most newsprints, the fraction of long fibres (L > 1,35 mm) is less than 5% of the total number of fibres removed during printing. In pilot scale studies by Mangin [116], the proportion of fibres longer than 1,35 mm was usually below 2%. In this test, all samples have less than 3% of long fibres fraction and more than 90% of fines fraction, except for TMP-B. This indicates that the conditions chosen in our studies for analysing the linting propensity of papers by RNA-52 Printability Tester is proper.

As shown in the Figures 6.32 and 6.33, more than 2000 fibres per 65 cm^2 or more than 150 m/m^2 cumulated fibres length were removed during the printing test for the TMP-B, while less than 580 fibres per 65 cm^2 or less than 30 m/m^2 cumulated fibres length were removed for the TMP-S and the other TMP pulps made from the chip mixtures. It may appear that the use of TMP-B could develop a serious linting problem. Figures 6.32 and 6.33 also show that the increase of refining energy input can only decrease somewhat the linting propensity of the TMP-B. Using of white birch in the chip mixtures increased very slightly the number of fibres removed and the cumulated fibres length in comparison to the TMP-S. As discussed previously, a superior RBA of the R200 fraction was observed in the TMP pulps of the chip mixtures. It may help reinforce fibre-to-fibre bonding, thus producing sheets with low linting propensity. Moreover, the negative effect of the small amount of vessel fragments can be compensated by the fibres with high quality. As a consequence, their influence on the linting propensity in the pulps of chip mixtures is slight.

The analyses by FQA showed that the increased refining energy input influenced slightly the removed fibres distribution of linting propensity test. The average long- and short-fibre percentages of the removed particles are shown in Figure 6.34. The remainders of the materials are the fines. All the TMP pulps from the chip mixtures had similar removed particles distribution compared to the TMP-S. The TMP-B had higher long- and short-fibre content and relatively lower fines content compared to the TMP-S. In fact, the TMP-B had a higher number of removed fibres and a longer cumulated (removed) fibres length in all the three fractions compared to the other pulps. This finding corresponds well with the previous discussion in that the TMP-B fibres showed higher stiffness while the fines had lower specific surface than the other pulps. These properties caused the low strength and serious linting problem of the sheet made from the TMP-B.

Light microscope showed that the main lint materials in all samples composed of short fibre fragments, ray cells and some long intact fibres. Vessel fragments and shives are also presented in the removed materials of the TMP-B and the other TMP of chip mixtures.

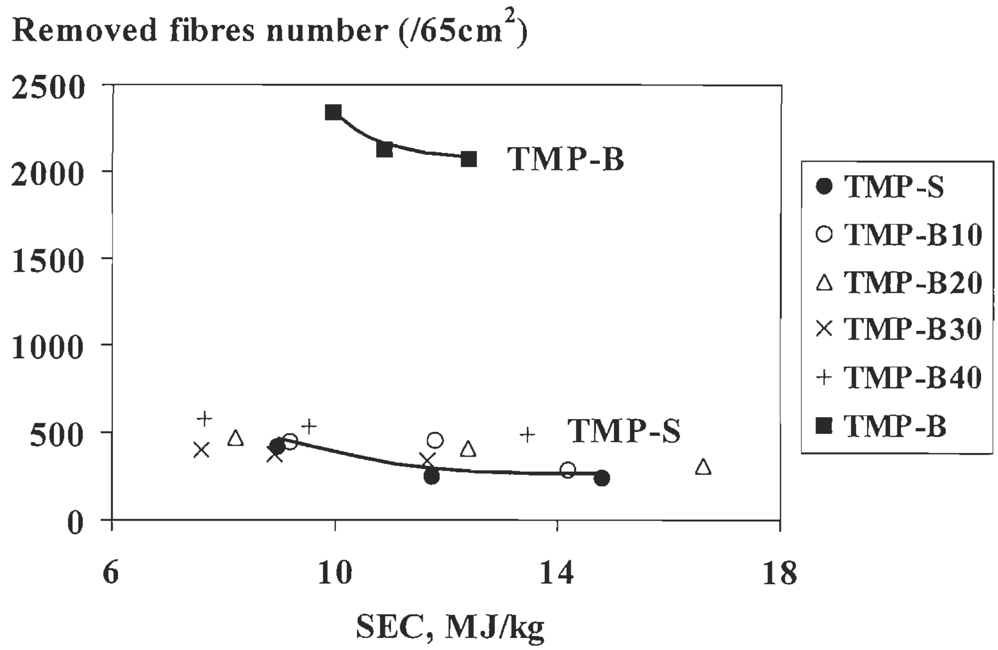


Figure 6.32 Removed fibres number during linting propensity test vs. SEC.

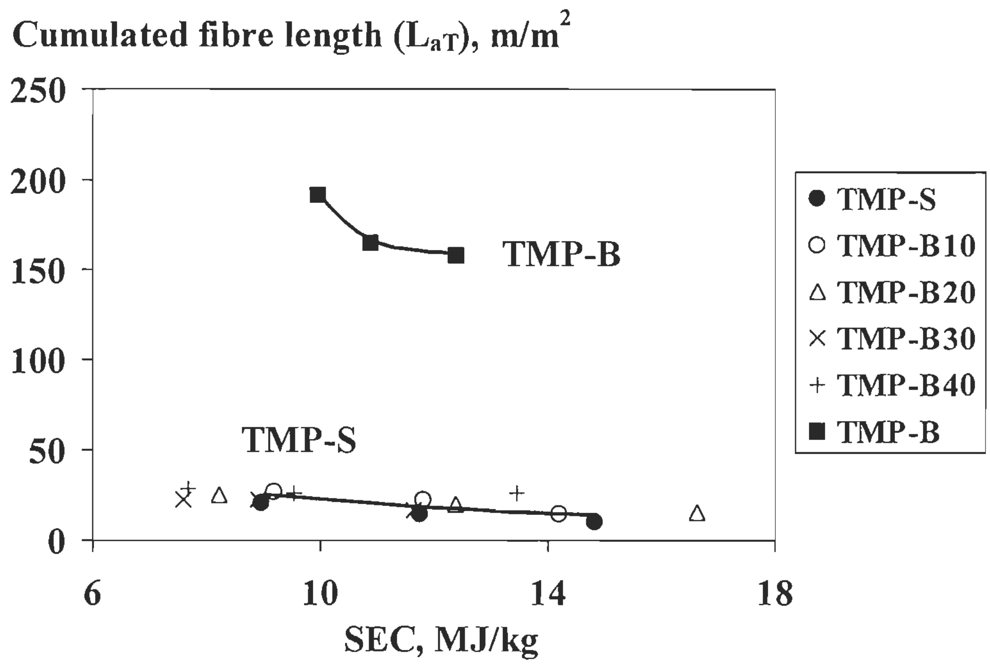


Figure 6.33 Cumulated fibres length during linting propensity test vs. SEC.

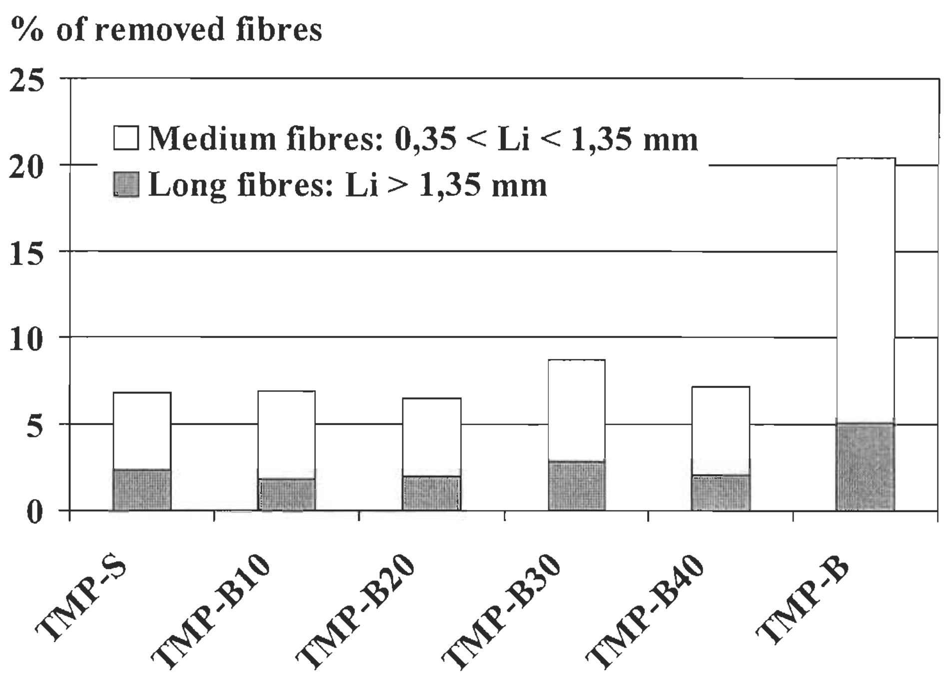


Figure 6.34 Removed fibres distribution of linting propensity test.

6.7 Chemical pre-treatment of white birch

As discussed previously, a limitation of improving the white birch fibre qualities can not be improved by using mechanical refining or co-refining with black spruce in the absence of chemicals. To increase the quality of birch fibres, a chemical pre-treatment may be necessary. Johal and Hatton [16] tried to improve the strength of the pulps made from chip mixtures by refining the chemical pre-treated aspen with untreated spruce chips together, but did not succeeded. They found the aspen refined more easily than the spruce probably due to the severe chemical treatment condition. In this section, to explore the possibility of improving white birch fibre qualities in co-refining, a mild chemical condition was chosen for pre-treating white birch before mixing it with untreated black spruce followed by co-refining.

Specific energy consumption

Previous studies showed that the use of sodium sulfite reduced the refining energy of hardwood pulps but had no effect on the strength properties [12]. On the other hand, alkaline treatment improved significantly the strength of hardwood pulps but also increased the refining energy. When a low alkali charge (only 1,5% NaOH) was utilised in the TMP-Bt30, a slight increase in SEC was noted compared to the TMP-B30 at a given freeness (Figure 6.35).

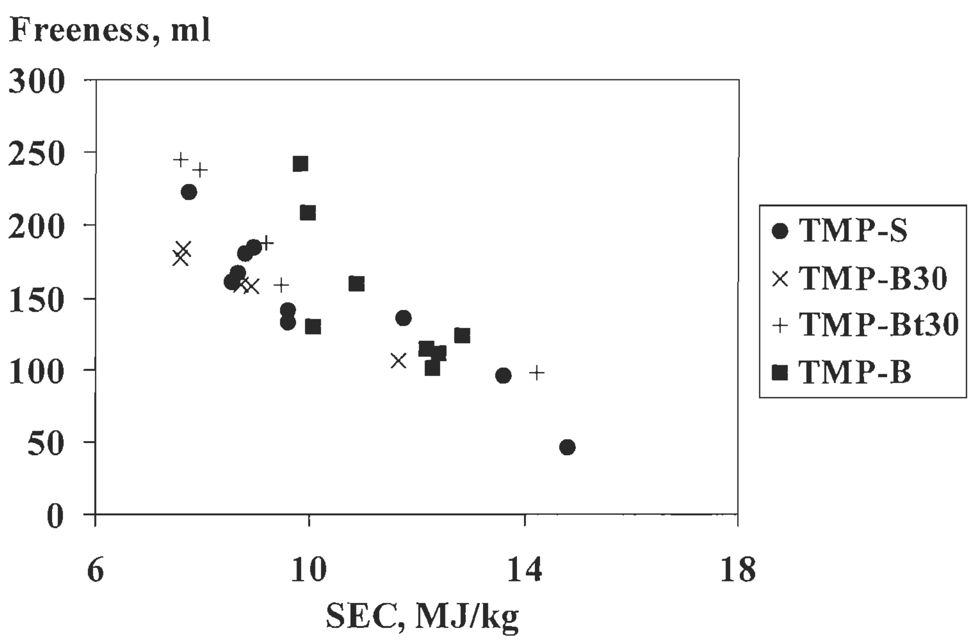


Figure 6. 35 Effect of chemical pre-treatment of white birch on SEC in co-refining.

Shives

The TMP-Bt30 contained less rejects than the TMP-B30. The amount of rejects was, however, similar to that of the TMP-S. This indicates the benefits of the chemical pre-treatment of white birch prior to mixing with black spruce in co-refining (Figure 6.36).

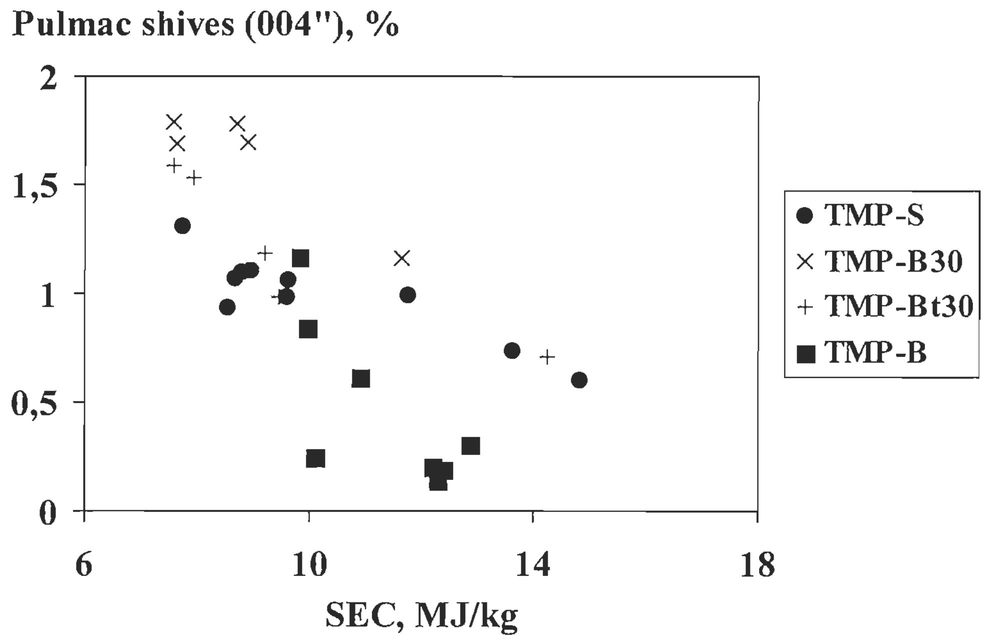


Figure 6. 36 Effect of chemical pre-treatment of white birch on rejects content.

Fibre properties

The variation of long and short-fibre and fines contents, as a function of SEC, are presented in Figures 6.37, 6.38 and 6.39 for the TMP-B30 and the TMP-Bt30. The long- and short-fibre contents were slightly higher for the TMP-Bt30 than for the TMP-B30. This suggests that the alkaline sulfite improves fibre separation and reduces the fibre cutting during co-refining. Moreover, the chemical pre-treatment decreases probably also the degree of delamination of the white birch fibres, as observed by Cisneros et al. [55]. They compared the fibre surface properties of birch TMP and CTMP by cross-section analyses. Higher proportions of exposed S_2 layer were found in the TMP fibres than in that of CTMP fibres. They proposed that pulp strength was not dependent on the degree of exposure of the S_2 layer but largely related to the fibre flexibility due to the chemical treatment in CTMP process.

Pulp strength and optical properties

Alkaline sulfite pre-treatment of white birch chips before having mixed with black spruce chips improved substantially the tear index but it had little effect on the tensile and burst indices when compared to the TMP-B30 (Figure 6.40, 6.41 and 6.42). With a similar long-fibre content, the TMP-Bt30 had a tear index higher than that of the TMP-B30 (Figure 6.43). This may be the present of chemical pre-treatment of white birch chips which improved the fibre-bonding potential due to the increased fibre flexibility.

Compared to the TMP-B30, the TMP-Bt30 had a lower light scattering coefficient, which was also lower than that of the TMP-S (Figure 6.44).

Figure 6.45 shows that the brightness changes marginally when the TMP-Bt30 is compared to the TMP-B30. Since the alkali charge of 1,5% on o.d. wood is relative low, the alkaline darkening may counter-balanced be compensated by the bleaching effect of the sulfonation on the lignin.

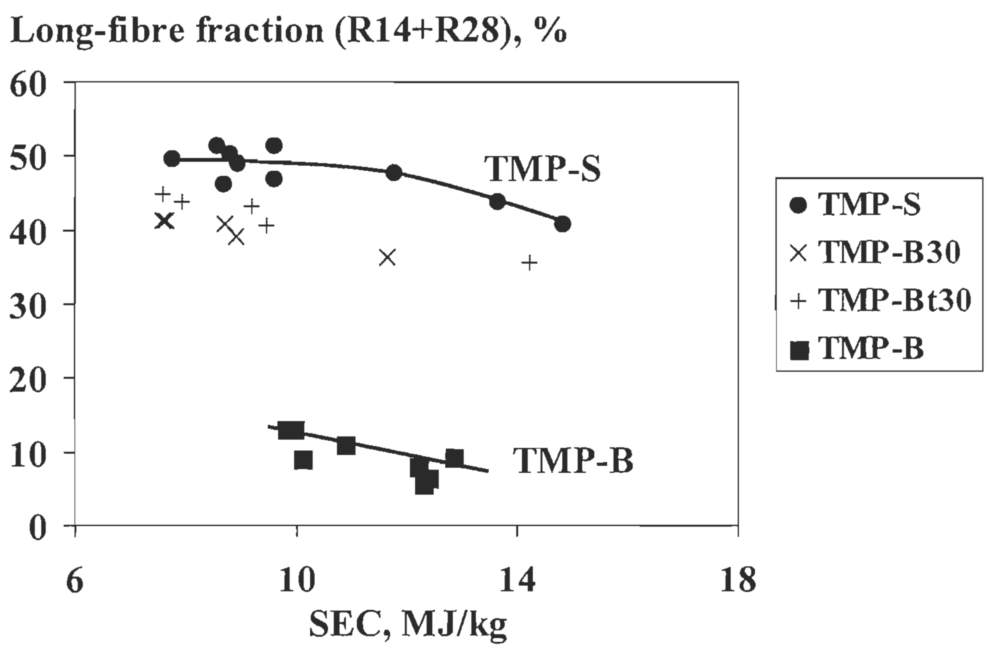


Figure 6. 37 Effect of chemical pre-treatment of white birch on long-fibre content.

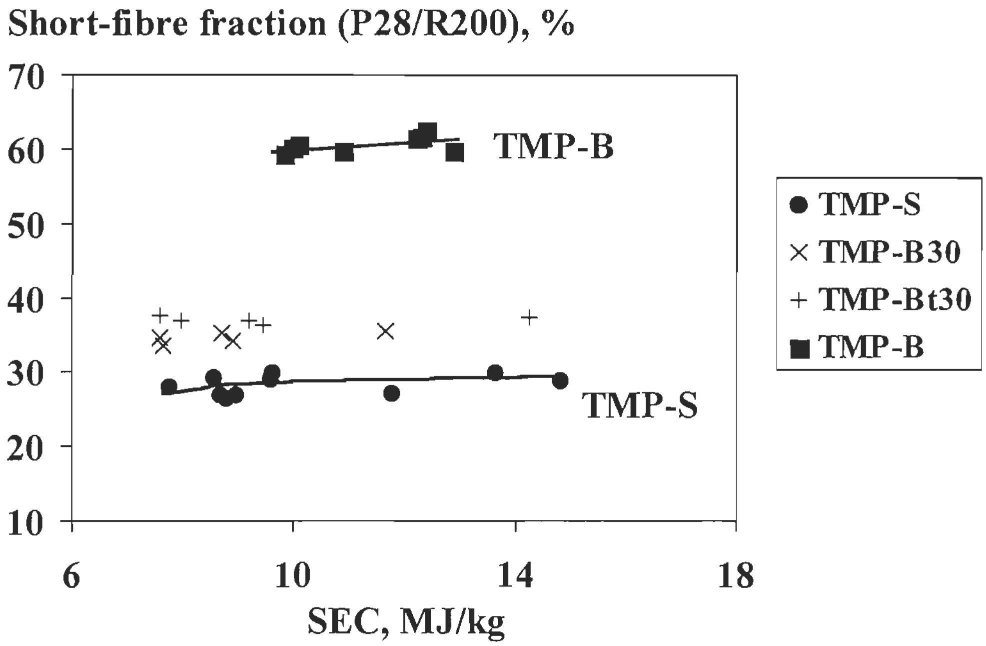


Figure 6. 38 Effect of chemical pre-treatment of white birch on short-fibre content.

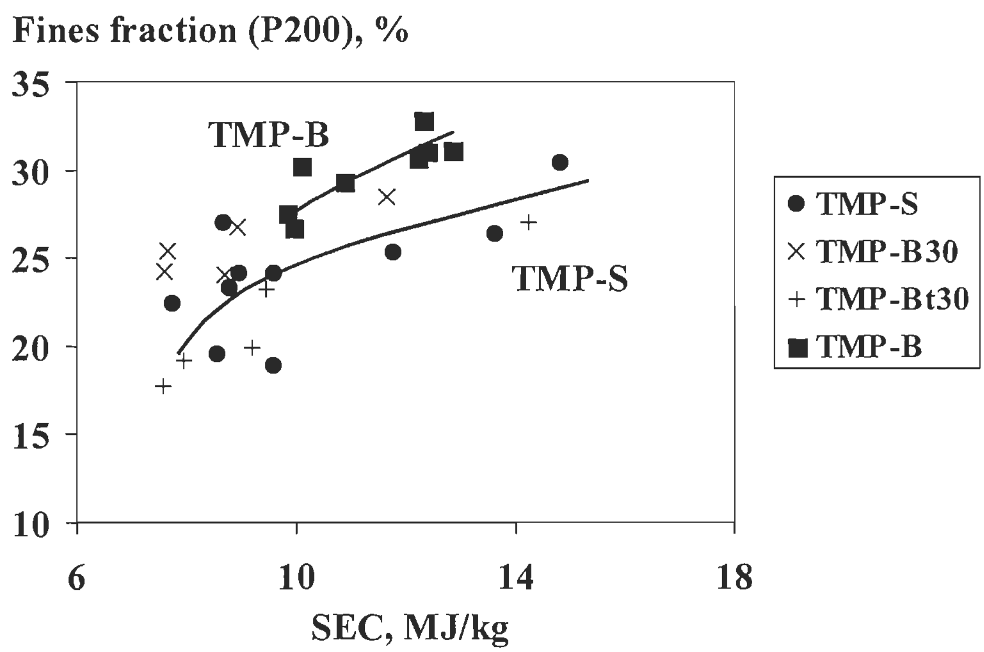


Figure 6. 39 Effect of chemical pre-treatment of white birch on fines content.

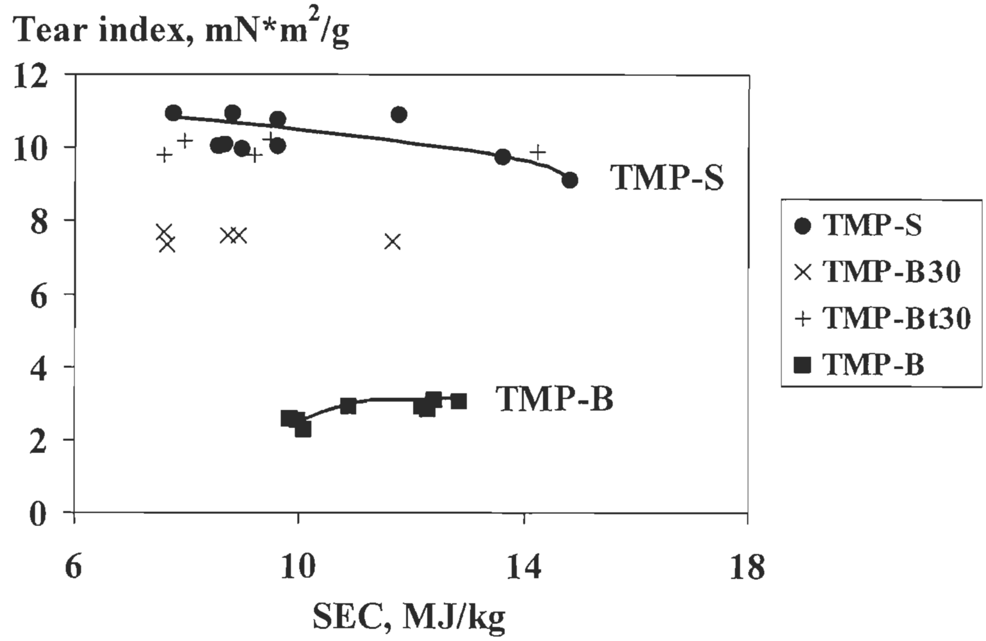


Figure 6. 40 Effect of chemical pre-treatment of white birch on tear index.

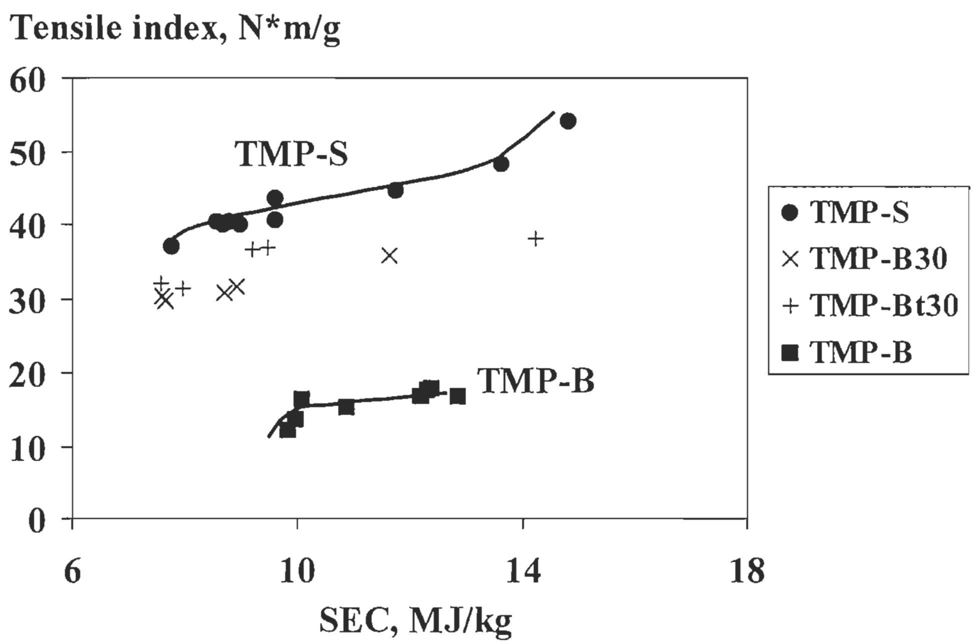


Figure 6. 41 Effect of chemical pre-treatment of white birch on tensile index.

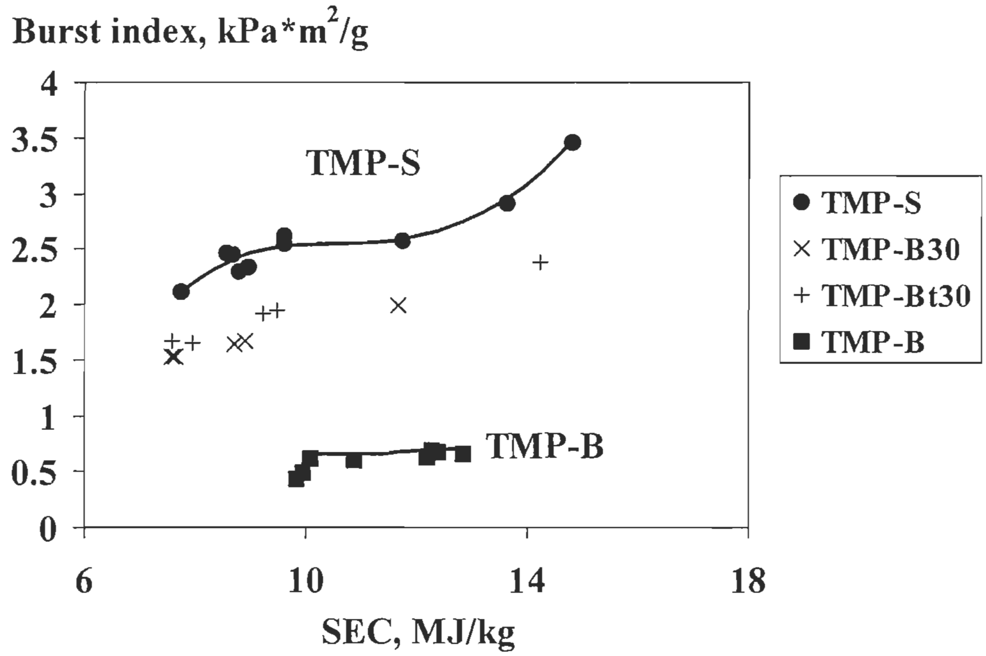


Figure 6. 42 Effect of chemical pre-treatment of white birch on burst index.

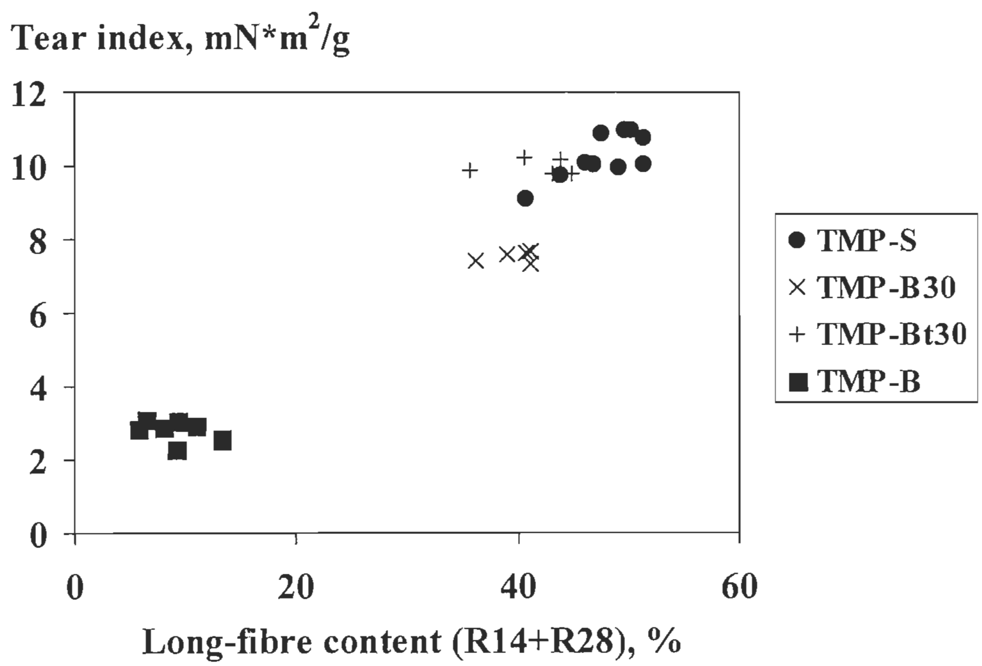


Figure 6. 43 Relationship between tear index and long-fibre content.

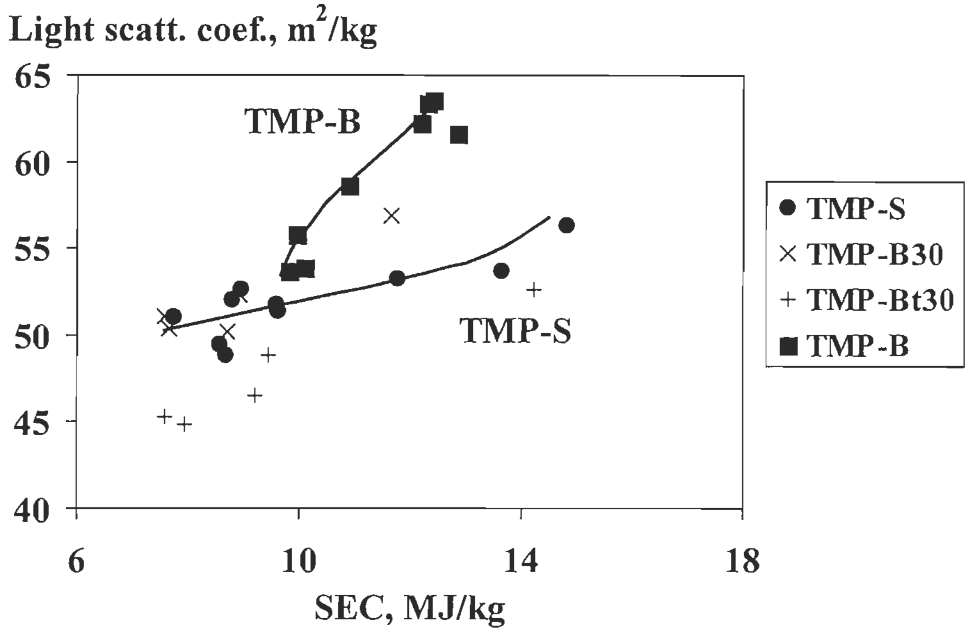


Figure 6. 44 Effect of chemical pre-treatment of white birch on light scattering coefficient.

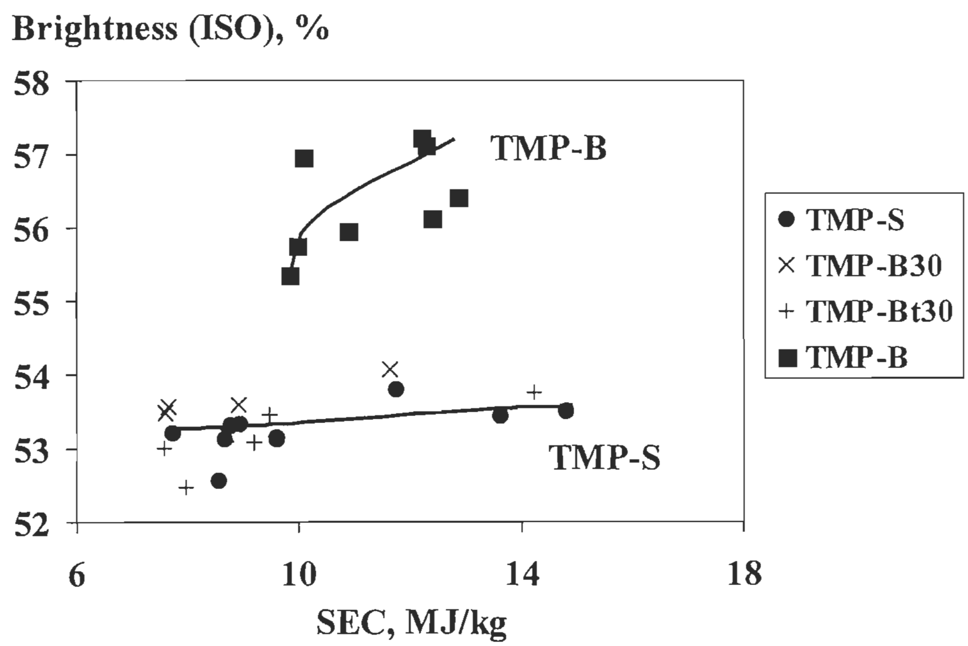


Figure 6. 45 Effect of chemical pre-treatment of white birch on brightness.

6.8 Conclusion

Generally speaking, substituting white birch for black spruce in the production of TMP had little influence on the long fibre qualities. However, the flexibility and hydrodynamic specific volume of the short fibre and especially the fines were significantly reduced by the presence of birch. These findings were supported by the microscopic observations. It seems that, in co-refining, the birch and spruce are acting independently in terms of fibre development. However, high quality spruce fibres and fines can compensate the effect of a small quantity of white birch fibres and vessel fragments. Hence, the use of white birch in black spruce influenced slightly the linting propensity compared to the TMP-S. The quality of the white birch fibre and fines quality cannot be improved by mechanical refining alone.

The chemical pre-treatment of white birch by alkaline sulfite before being mixed with black spruce improved the strength properties. Continuing research is necessary to further investigate the effect of chemical pre-treatment of white birch prior to blending with black spruce in co-refining.

Chapter 7 - RESULTS & DISCUSSION (2)

Part 2: CHEMITHERMOMECHANICAL PULPING

The results of the first part of this work showed that chemical pre-treatment of white birch improved the shear properties, except for the light scattering. In the second part, efforts were made to modify the fibre properties of white birch during co-refining. The purpose is to increase the substitution of white birch for black spruce while trying to maintain the balance of pulp quality. More specifically, the influence of white birch on fibre and pulp properties of black spruce CTMP was studied. Also, a theoretical mechanism of co-refining was elaborated by studying the effect of refining on the fibre morphologies.

The chip mixing and refining conditions were shown in Tables 5.2 and 5.4 (Chapter 5). Eight pulps were produced by a Sunds Defibrator (Metso) CD300. For the sake of simplicity, the CTMP of 100% white birch and the CTMP of 100% black spruce are designated as CTMP-B and CTMP-S, respectively. The CTMP from chip mixtures containing 30% and 60% white birch are designated as CTMP-B30 and CTMP-B60, respectively. The CTMP-Bn30 stands the CTMP made from chips mixture containing 30% white birch which was pre-treated with alkali prior to mixing with untreated spruce, while the CTMP-Bns30 stands for the CTMP made from chips mixture containing 30% white birch which was pre-treated with a combination of alkali and sulfite prior to mixing with untreated spruce. In the following analyses, we use the TMP of 100% black spruce (TMP-S) as a reference pulp for comparison. Black spruce is one of the ideal species for the production of TMP for newsprint making which has been accepted by most of the newsprint industry. All the data in this study can be found in Appendix A.

7.1 Specific energy consumption (SEC)

The CTMP-S required higher refining energy when compared to the CTMP-B at a given freeness, as shown in Figure 7.1. Co-refining of white birch with black spruce had a slight effect on the SEC compared to the CTMP-S. For the same substitution of 30% white birch, the CTMP-Bns30 required lower SEC to reach the same freeness compared to the CTMP-Bn30 and the CTMP-B30. This is probably because neither alkali nor sodium sulfite is used during refining for the CTMP-Bns30; thus there is no chemical treatment on black spruce. Obviously, alkaline sulfite pre-treatment of white birch prior to blending with untreated black spruce followed refining without chemicals is beneficial to avoid the increases in refining energy consumption. Compared to TMP-S, higher SEC was observed for all the CTMP pulps. The reason is that the alkali swells the chips. The swelled chips need higher SEC to be refined to a given freeness compared to the untreated chips.

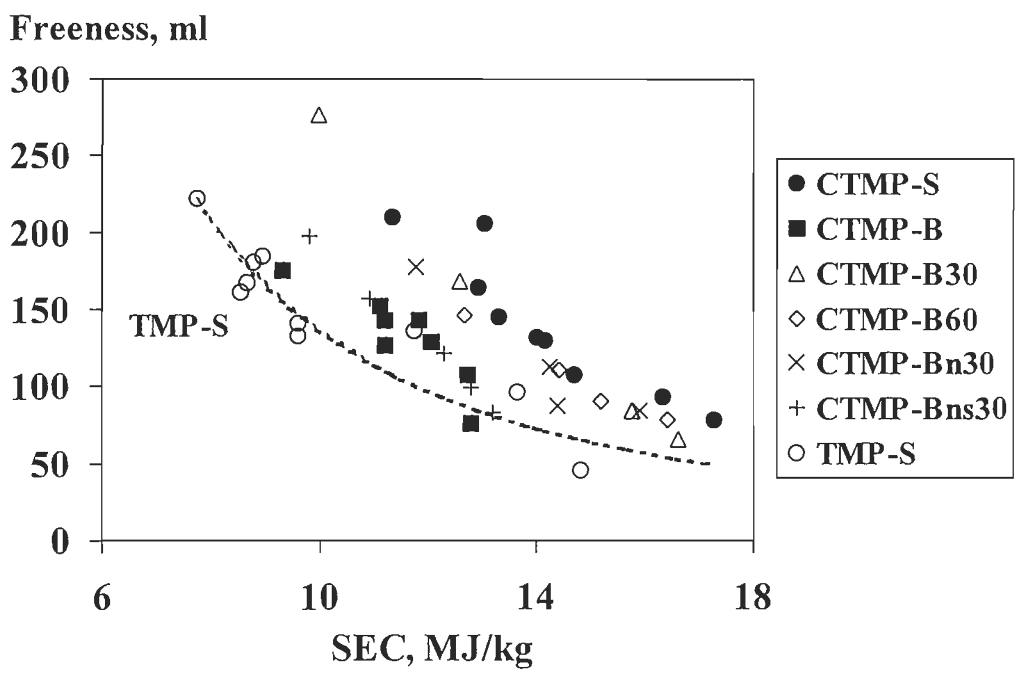


Figure 7.1 Specific energy consumption of the CTMPs vs. freeness.

7.2 Fibre properties

Shives content

As shown in Figure 7.2, both the CTMP-B and the CTMP-S had the lowest shives content than the other pulps. The substitution of black spruce by white birch increased the rejects content compared to the refining of single species only. The CTMP-Bn30

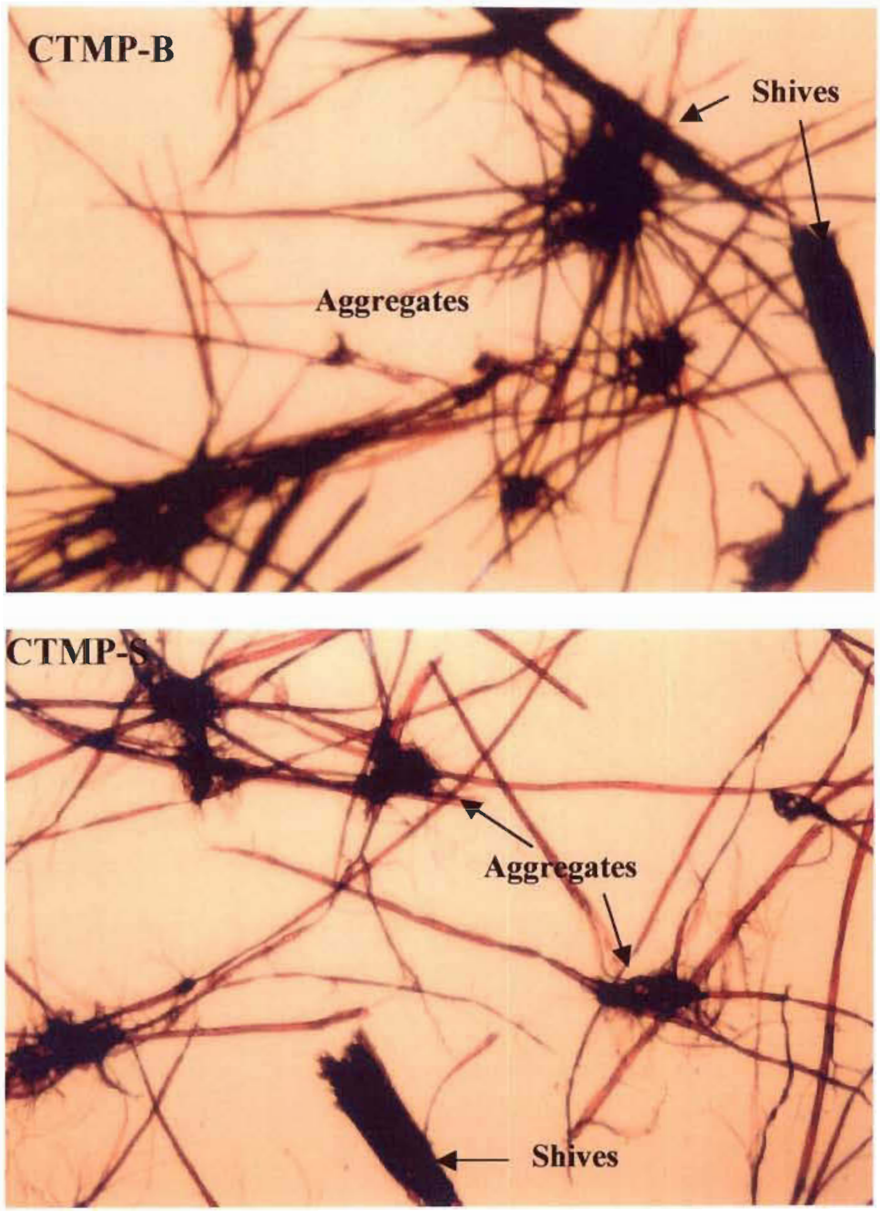


Figure 7.3 Light micrographs of the rejects of the CTMP-B and CTMP-S, 16:1.

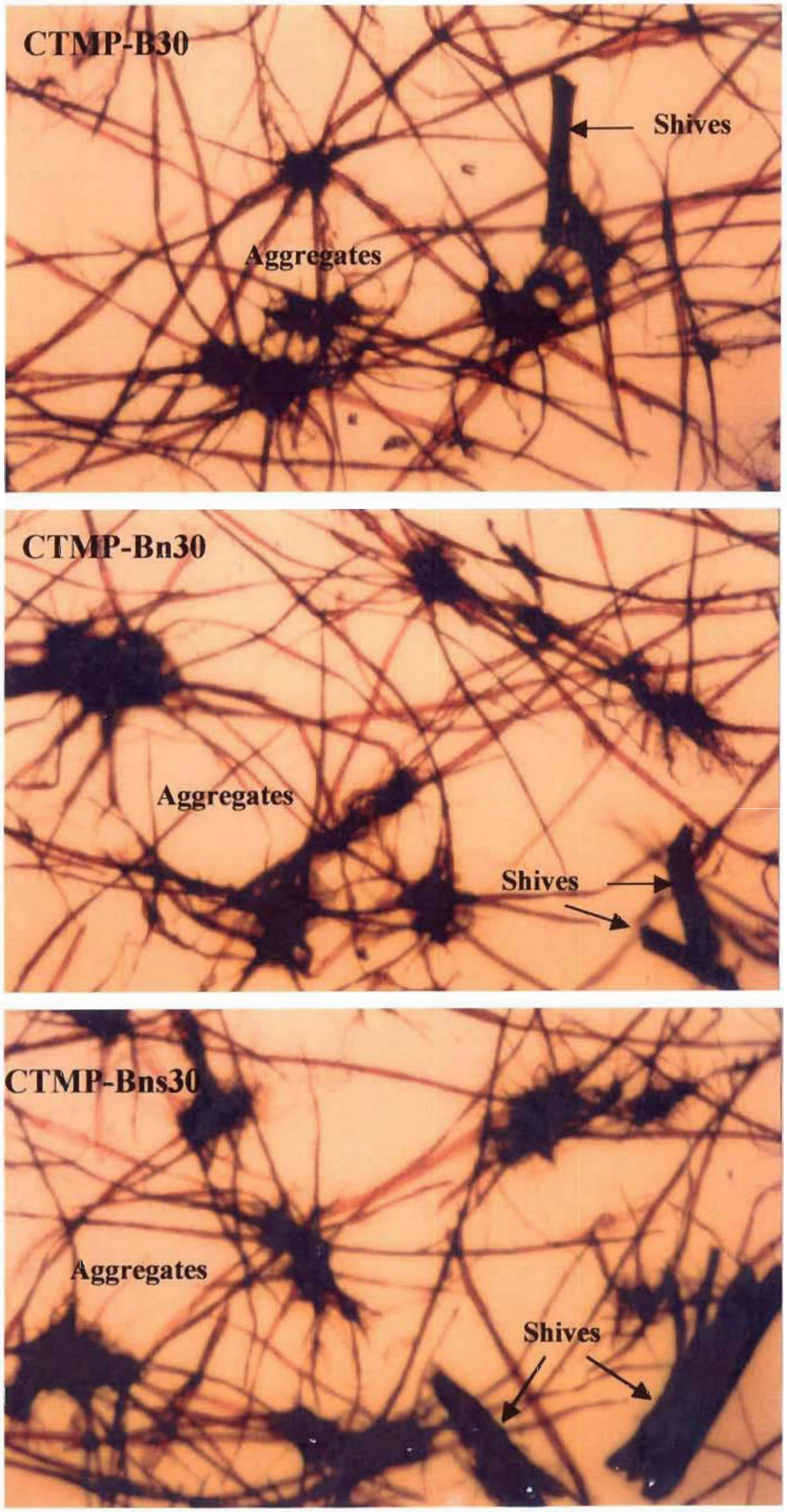


Figure 7.4 Light micrographs of the rejects of CTMPs from the B/S mixtures, 16:1.

contained lower rejects content than the CTMP-Bns30 and the CTMP-B30, which illustrated that alkali swelled and softened well the white birch chips prior to mixing with black spruce. Compared to the TMP-S, all the CTMP pulps had somewhat lower rejects content. It is reasonable for the application of alkali-sulfite that swells the wood chips. It also introduces sulfonic groups that increase the hydrophilicity of lignin, which softens the wood chips and facilitates the fibres separation compared to the thermomechanical pulping which uses only steaming.

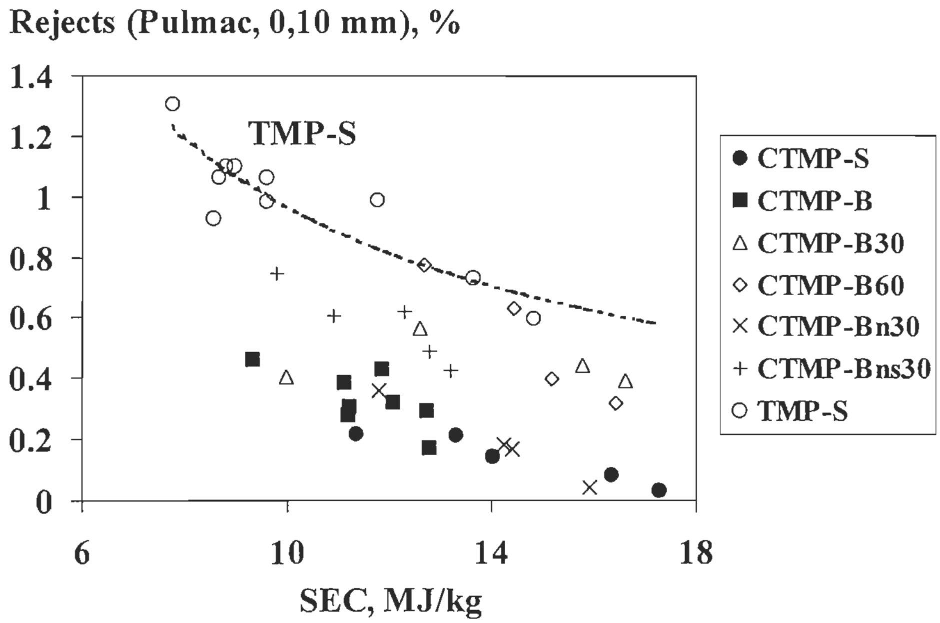


Figure 7.2 Rejects content of the CTMP pulps vs. SEC

The microscopic observation showed that the rejects of CTMP also composed of shives and aggregates (Figures 7.3 and 7.4). The shives accounted for about 75% of the rejects of CTMP-B. Compared to the TMP-B, both the total amount of rejects and the relative amount of shives decreased for the CTMP-B due to the chemical treatement. On the other hand, the shives accounted for about 83% of the rejects of CTMP-S. Compared to the TMP-S, the total amount of rejects decreased but the relative amount of shives increased slightly for the CTMP-S. The probable reason is that the earlywood of spruce absorbs the chemicals easier than the latewood of spruce. The use of birch increased somewhat the relative amount of shives in the rejects (Table 7.1).

Table 7.1 Rejects composition of the CTMPs.

Sample *	Shives **, %	Aggregates **, %	Total ***, %
CTMP-S	~17	~83	0,217
CTMP-B	~ 25	~ 75	0,389
CTMP-B30	~ 20	~ 80	0,564
CTMP-B60	~ 20	~ 80	0,775
CTMP-Bn30	~ 25	~ 75	0,360
CTMP-Bns30	~ 25	~ 75	0,606

* The pulps have a freeness of ~150 ml;
** The percentage of the total number of shives and aggregates;
*** The percentage of the whole pulp.

Fibre classification

For each Bauer-McNett fraction, the pulps from chip mixtures had a content of the fraction increasing or reducing with the use of white birch, as shown in Figure 7.5. When the pulps from chip mixtures were compared to those of single species, drops in R14 and increases in R48 and R100 were observed. Small variations in the rest fractions were observed. The substitution degree (30% to 60%) and the chemical pre-treatment of white birch had little influence in fibre distribution (Figures 7.5 and 7.6).

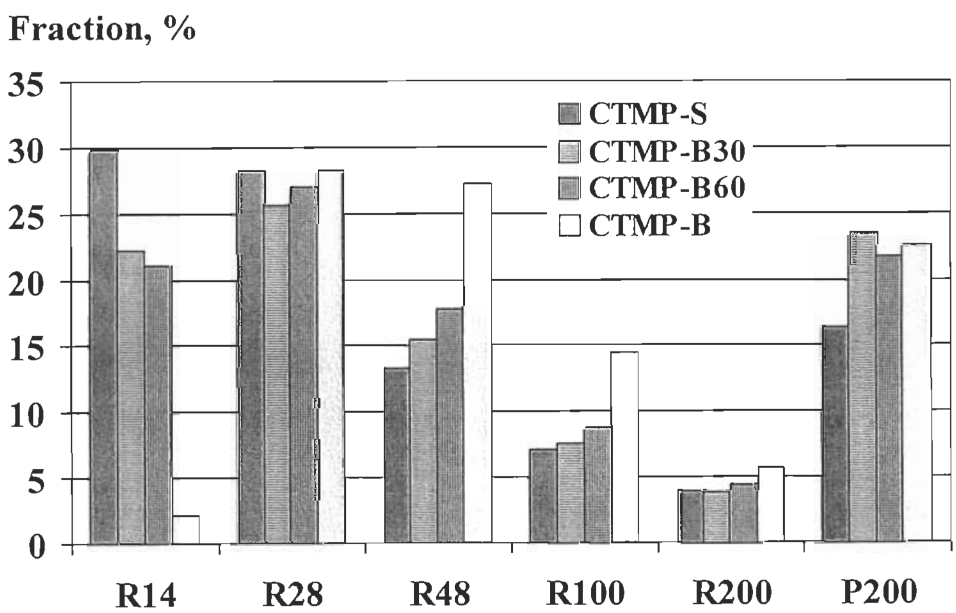


Figure 7.5 Bauer-McNett fractions of the CTMP at 150 ml CSF.

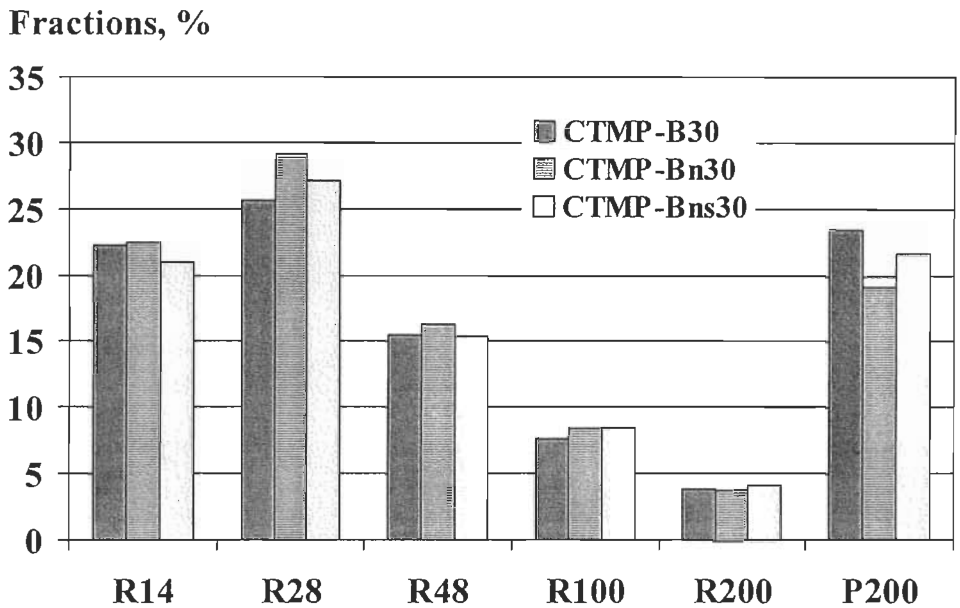


Figure 7.6 Bauer-McNett fractions of the CTMP at 150 ml CSF.

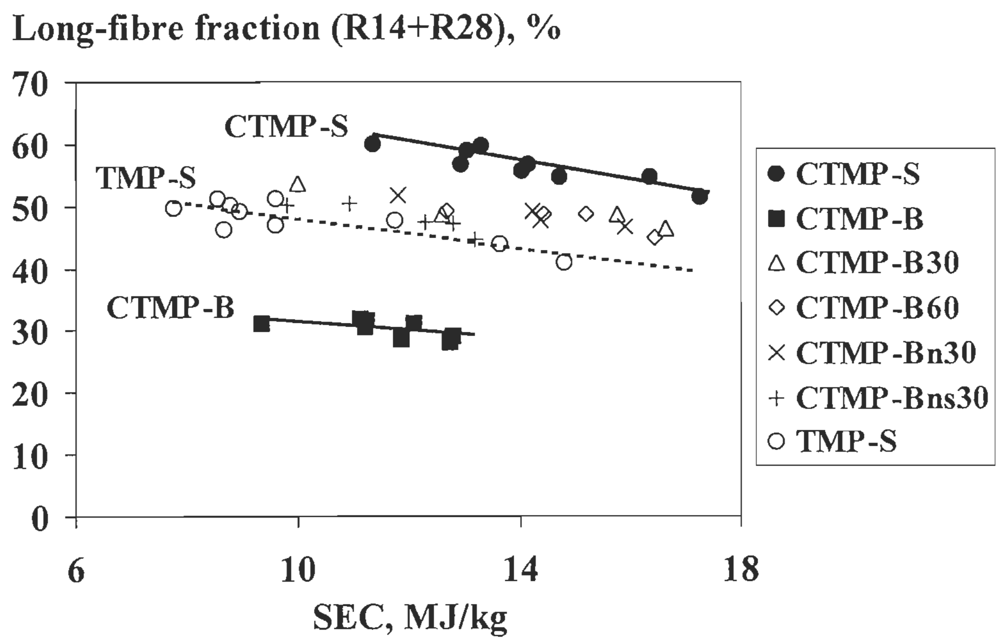


Figure 7.7 Long-fibre content of the CTMP measured by Bauer-McNett.

As expected, the CTMP-S had the highest long-fibre content (R14+R28) while the CTMP-B had the lowest (Figure 7.7). All the CTMP from chip mixtures had similar long-fibre content, which was situated between those of the CTMP-S and the CTMP-B, and slightly higher than that of the TMP-S. This suggests that using white birch reduced the long-fibre content to a certain degree, and then neither the substitution degree (30 to 60%) nor the chemical pre-treatment of white birch prior to mixing with black spruce affected the degree of fibre cutting. Apparently, the alkali-sulphite treatment swells well the chips and the lignin is slightly sulfonated, both of them modify the separation of fibres with less cutting during refining, and finally produces pulps with a relative high long-fibre content.

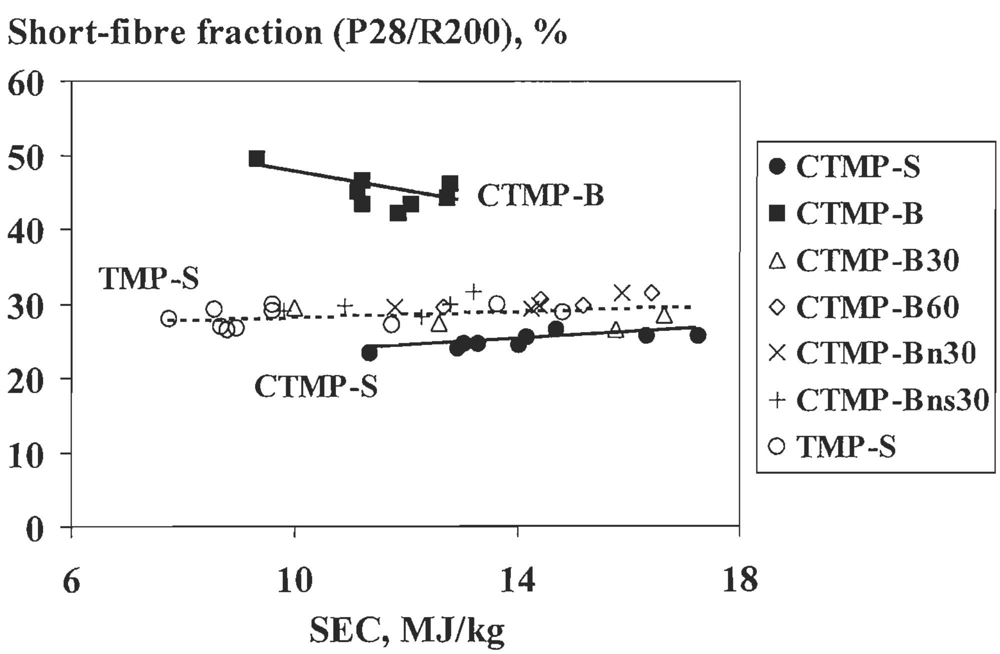


Figure 7.8 Short-fibre content of the CTMP measured by Bauer-McNett.

Figure 7.8 shows the variation of the short-fibre contents of the pulps as a function of SEC. The CTMP-B had a short-fibre content much higher than those of the other pulps, due to the shorts fibres of white birch. As a result, the pulps from chip mixtures had a short-fibre content similar to that of the TMP-S, and were somewhat higher than that of the CTMP-S. However, the short-fibre content of the pulps from chip mixtures was not affected by the substitution degree (30% to 60%) of white birch and by the chemical pre-treatment of white birch.

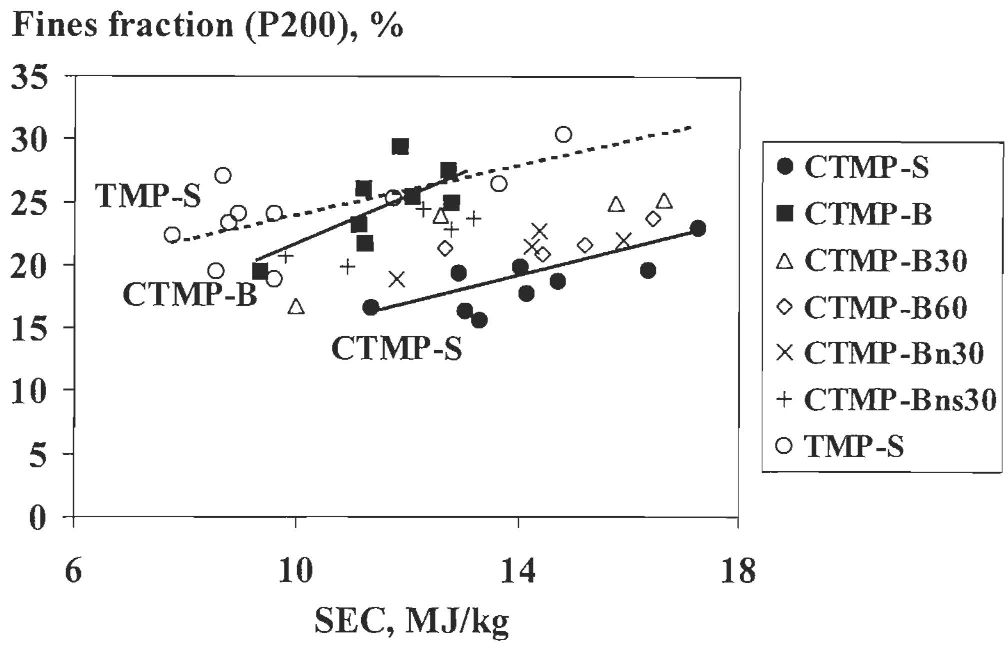


Figure 7.9 Fines content of the CTMP measured by Bauer-McNett.

The fines from a Bauer-McNett classifier consist mostly of parenchyma cells, flake-like fragments from middle lamella and fibrillar fragments from secondary wall [76]. For white birch, fragments of vessels were also found in the fines fraction, as shown by microscopic observation (Figure 7.22). The CTMP-B contained more fines than the CTMP-S and slightly less than the TMP-S at a given SEC, as shown in Figure 7.9. The CTMP from chip mixtures had more fines than that of the CTMP-S, but less than that of the CTMP-B. The CTMP-Bns30 had a fines content slightly lower than that of the CTMP-B, but higher than those of the CTMP-Bn30 and the CTMP-B30. This is possible because there was no chemical effect on black spruce during the co-refining process of the CTMP-Bns30 compared to that of CTMP-Bn30. So more fines were possibly produced from the black spruce due to a higher proportion of exposed S_2 layers [55]. The higher fines content of the CTMP-Bns30 induces higher light scattering coefficient compared to the CTMP-B30, which will be discussed later.

Average fibre length (lw)

The CTMP-B had the shortest average fibre length while the CTMP-S had the longest (Figure 7.10). All the pulps from chip mixtures had a average fibre length similar to that of the TMP-S, which was located between the CTMP-B and the CTMP-S. The results showed that both the substitution degree (30-60%) of white birch and the chemical pre-treatment of white birch influenced marginally the average fibre length. This is confirmed by the fibre distribution measured by the Bauer-McNett classifier as discussed previously. According to the results presented in Chapter 6, the average fibre length of TMP decreased proportionately with the increase of white birch in the chip mixtures. This indicated that the white birch and the black spruce fibres are acting independently during co-refining. Apparently, different from the TMP, the chemical treatment could maintain an average fibre length comparable to that of the TMP-S. There are two possible explanations: one is that black spruce fibres protect white birch fibres from fibre cutting during co-refining. The other is that the chemical treatment is much more efficient in swelling and sulfonating white birch than black spruce thus improving the fibre flexibility and decreasing the fibre-cutting during refining. Since the white birch and the black spruce fibres behave independently during co-refining of the process of TMP, the latter must be the possible explanation.

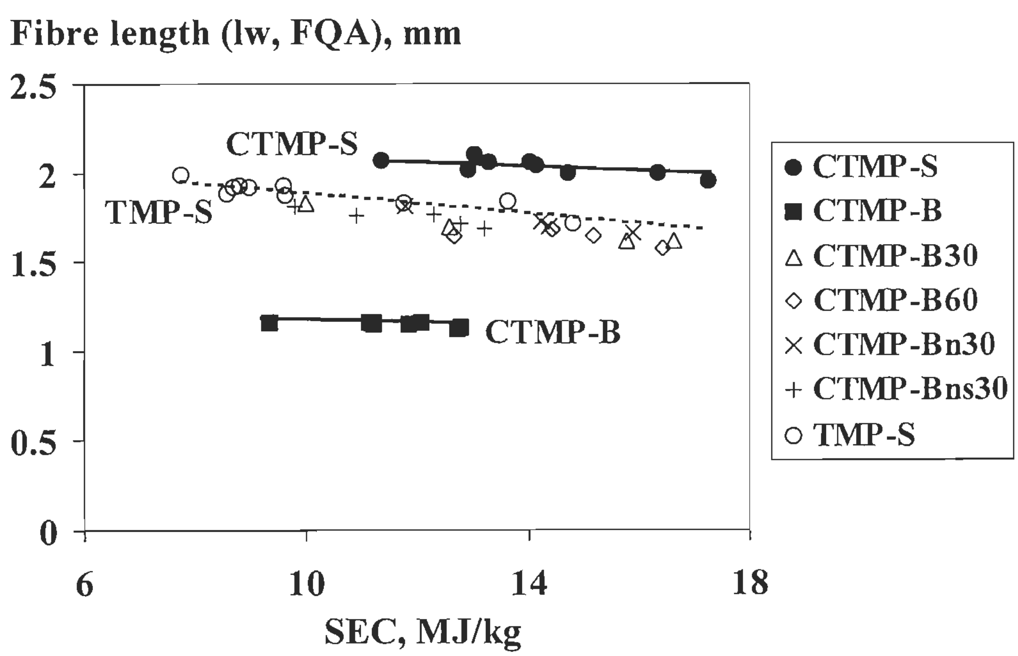


Figure 7.10 Fibre average length (lw) of the CTMP measured by FQA.

Water retention value

Water retention value (WRV) is considered as a useful test for evaluating the water holding capacity of the fibres [117]. A good correlation between the WRV and the tensile strength of handsheets was found over a wide range of beating. As shown in Figure 7.11, the CTMP-B had the highest WRV compared to the other pulps for its high quantity of fines as discussed previously. The pulps from the chip mixtures had a slightly higher WRV than the CTMP-S. Although the CTMP-S had the lowest WRV compared to the other pulps, but it produced handsheets with a tensile index much higher than that of the CTMP-B (Figure 7.12). Obviously, the flake-like fines produced from white birch have a poorer quality than that from black spruce. The pulps from the chip mixtures had a similar tensile index at the same WRV, which implies that the substitution degree of white birch and the chemical pre-treatment of white birch have almost no effect on the relationship between the tensile index and the WRV. In the following studies, because of the extreme heterogeneous fibre distribution and qualities of the pulps from different species, the pulps were separated by a Bauer-McNett classifier into long-fibre, short-fibre and fines fractions. The coarseness, hydrodynamic specific volume, flexibility and the RBA of these fractions were evaluated.

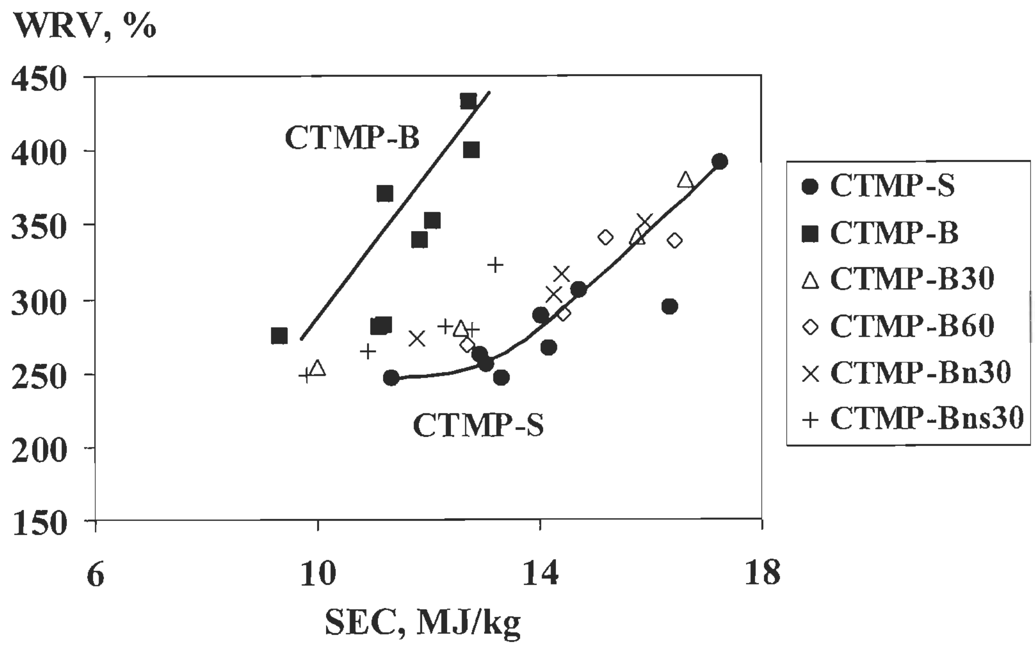


Figure 7.11 Water retention value of the CTMP pulps vs. SEC.

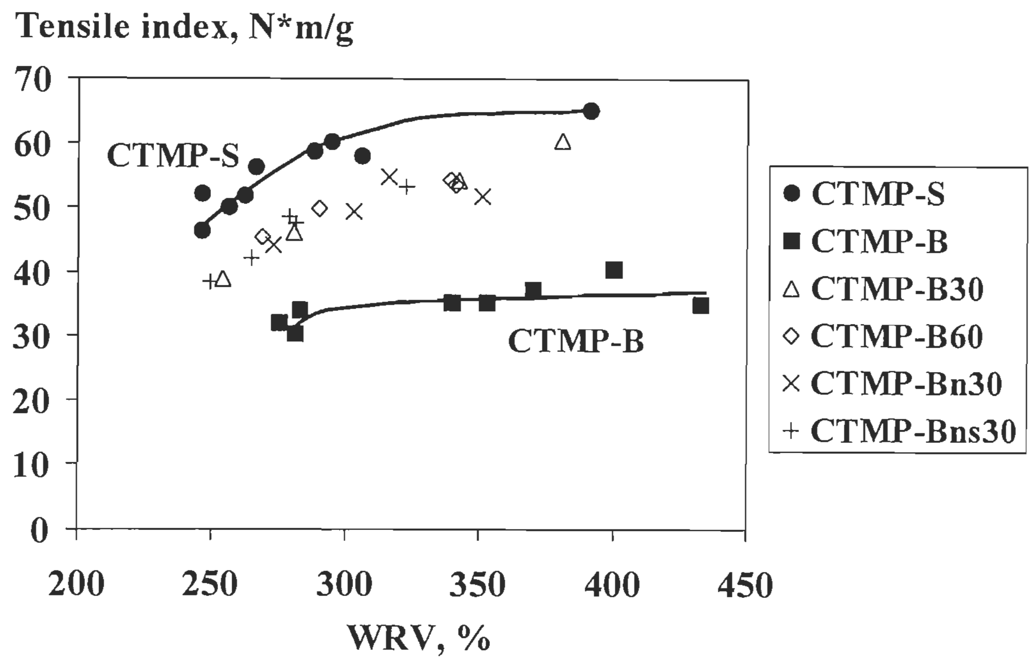


Figure 7.12 Relationship between tensile index and WRV of the CTMP.

Coarseness

The R28, R48 and R100 fractions of the pulps having a freeness of 150 ml, were chosen for analyses of coarseness. Similar to the TMP, the fibre coarseness decreased with decreasing fibre length (Figure 7.13). This indicates again that the degrees of cell wall removing are higher for short-fibre fraction than for the long-fibre fraction. The R28 of the CTMP-B had a coarseness substantially higher than that of the R28 of the other pulps. This is probably due to a certain quantity of flocs existed in this fraction according to the observation by light microscope (Figures 7.14 to 7.16: light microscopy photos of R28 of CTMP-S, CTMP-B and CTMP-B30). Several fibres formed a floc and were counted once as a fibre during the coarseness test, thus the measured coarseness was higher than the real value. Another possibility is that the external delamination degree of white birch fibres in the process of CTMP was lower than that in the process of TMP, as already indicated by Cisneros [55]. The use of white birch in the chip mixtures did not change the fibre coarseness of the same fractions compared to the CTMP-S. Neither the substitution percentage nor the chemical pre-treatment of white birch had an effect on fibre coarseness. Obviously, the fibre coarseness is not adequate for evaluating the fibre development during co-refining since fibres with different cell wall thickness and fibre diameter could have similar coarseness [118].

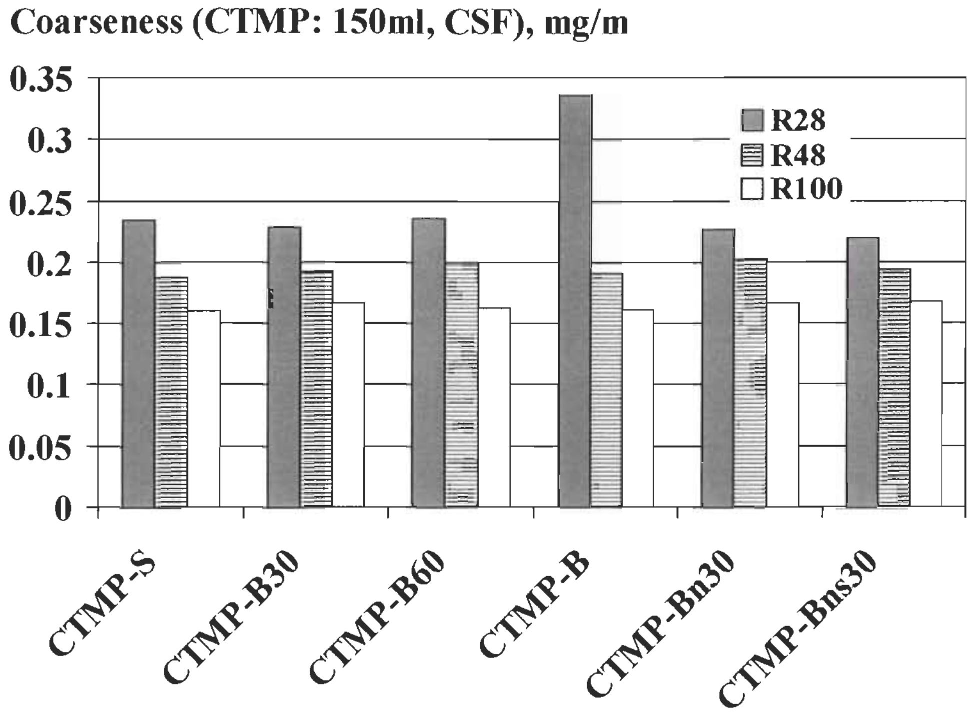


Figure 7.13 Effect of using white birch on fibre coarseness of the CTMP fractions.

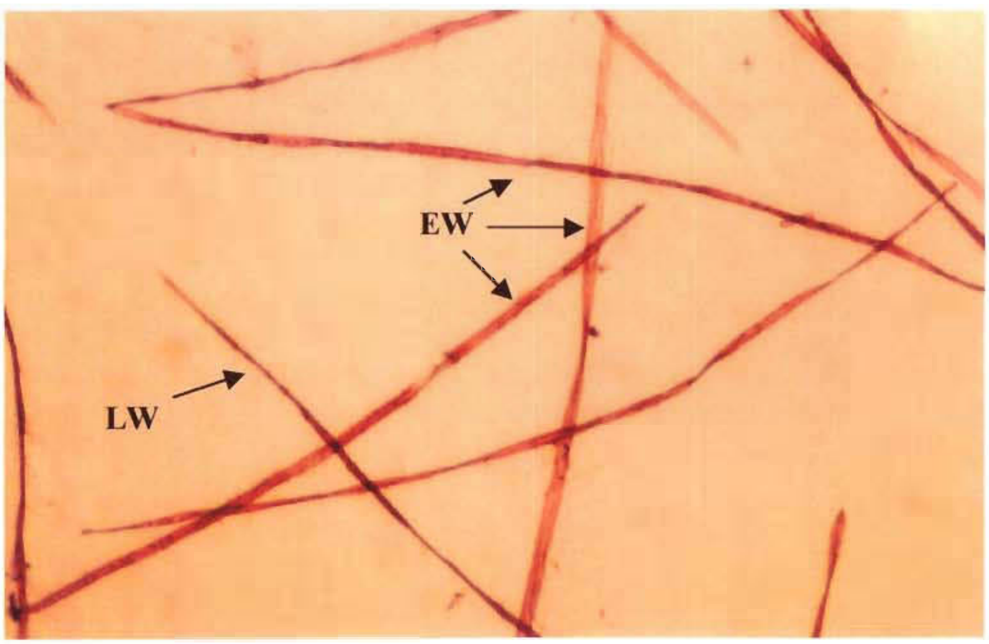
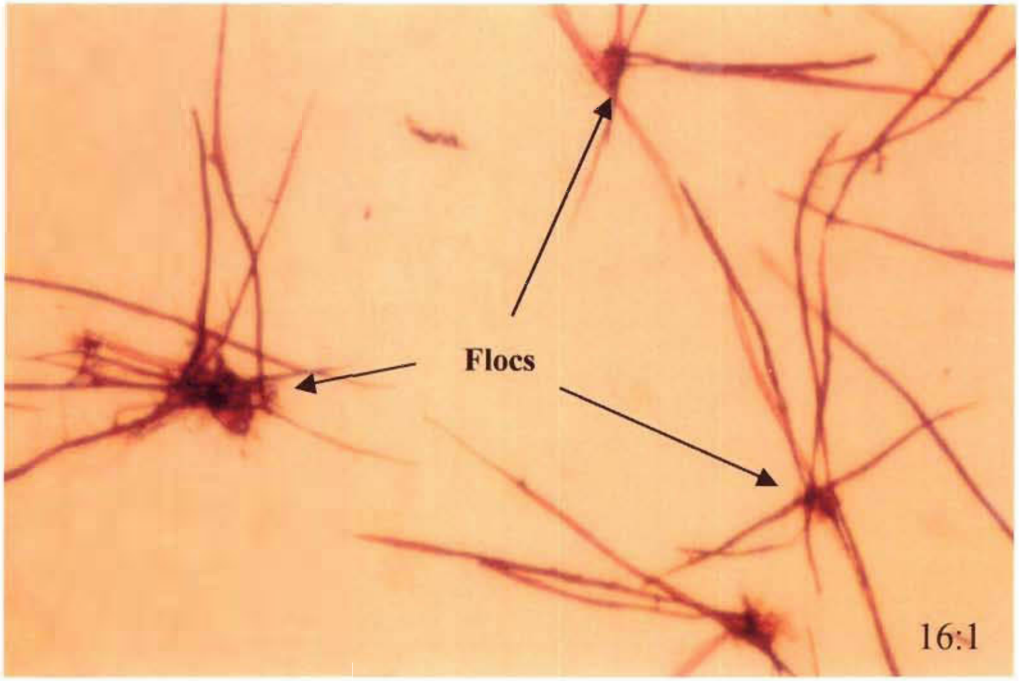


Figure 7.14 Light micrographs of the R28 fraction of CTMP-S, 16:1.

EW: earlywood fibres; LW: latewood fibres.



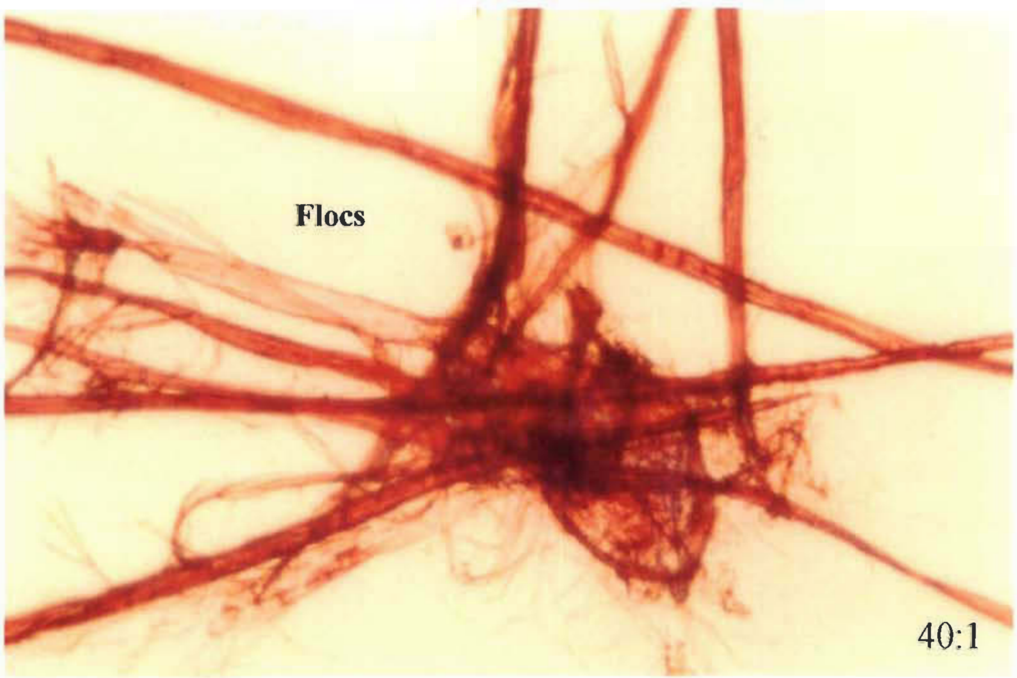


Figure 7.15 Light micrographs of the R28 fraction of CTMP-B.

The birch fibres formed flocs in the refining.

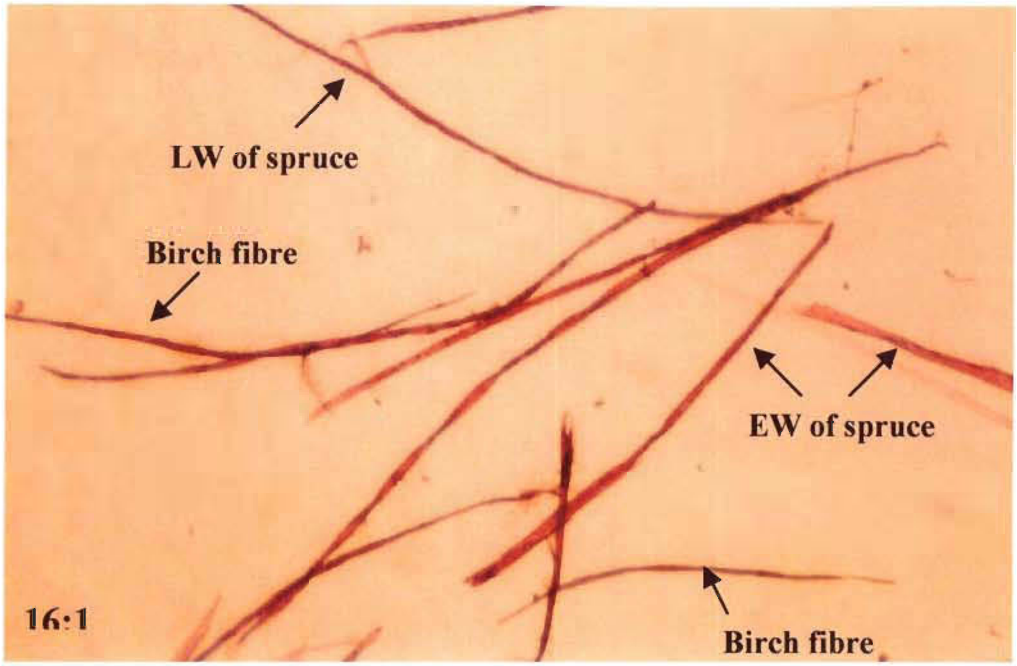


Figure 7.16 Light micrographs of the R28 fraction of CTMP-B30, 16:1.
EW: earlywood; LW: latewood.

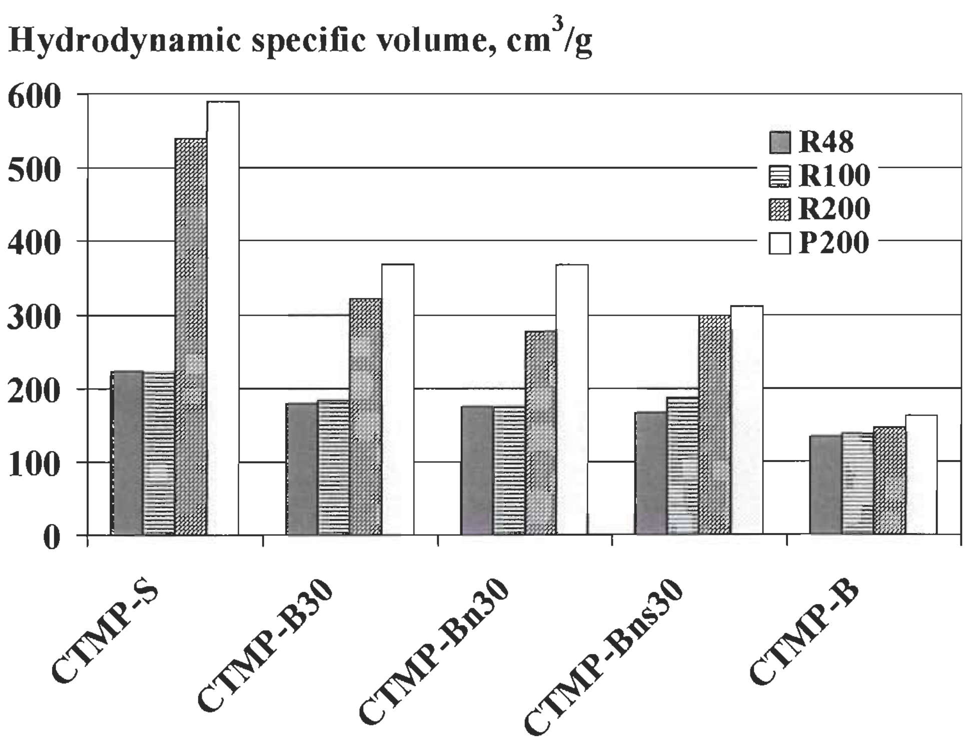


Figure 7.17 Fibre and fines hydrodynamic specific volume of CTMP.

Hydrodynamic specific volume (HSV)

The HSV distributions of the CTMP fractions had a tendency similar to those of the TMP pulps. As shown in Figure 7.17, the P200 and R200 fractions had a HSV substantially higher than the R48 and R100 fractions for all the pulps except for the CTMP-B. Note that the fines fraction had a higher degree of fibrillation than that of fibres fraction, as observed by light microscopy. Similar to the TMP-B, only slight differences of HSV existed among the fractions of the CTMP-B. The use of white birch decreased slightly the HSV of the R48 and R100, but largely those of the R200 and P200. The chemical pre-treatment of white birch had little influence on the HSV of the fibre fractions.

Comparing the CTMP to the TMP of the same species or from the chip mixtures, only slight differences in the HSV were illustrated. This suggests that the chemical treatment does not improve the fibrillation of the fibres and the fines, which corresponds to the visual inspection by light microscopy. Cisneros *et al* [55] compared the fibre surface characteristics of the TMP and the CTMP from hardwood. They also focused that chemical treatment of chips did not improve fibre surface quality (such as the exposure degree of the S_2 layer and fibre fibrillation) in comparison with the TMP process. They indicated that the pulp strength was not related to the exposure degree of S_2 layer but rather closely associated with the fibre flexibility. Figure 7.17 shows that the HSV measured by settling method is more sensitive to the fines but less to the fibre fractions. In this case, the freeness, as one of the conventional tests, was measured for the fractions R48, R100 and R200.

Forgacs [119] indicated that the higher the specific surface was, the less sensitive the freeness was to the change in specific surface, since the fines has a high chance of passing through the screen plate and cause a "false freeness" reading. In addition, freeness test is limited to the coarse fibre fractions R14, R28 and R48 of all the pulps, all of which have a freeness higher than 700 ml (Table A.29). As shown in Figure 7.18, different relationships between HSV and freeness existed for different species and the chip mixtures. At the same freeness, the CTMP-S had a greater hydrodynamic specific volume than the other pulps. Using white birch reduced the hydrodynamic specific volume for a given freeness. This reduction was almost not affected by the chemical pre-treatment of white birch or non prior to mixing with untreated black spruce. However, freeness is much more useful to explain the increase of specific surface in CTMP-B since the flake-like fines must have a large specific surface than the long- and short-fibre fractions.

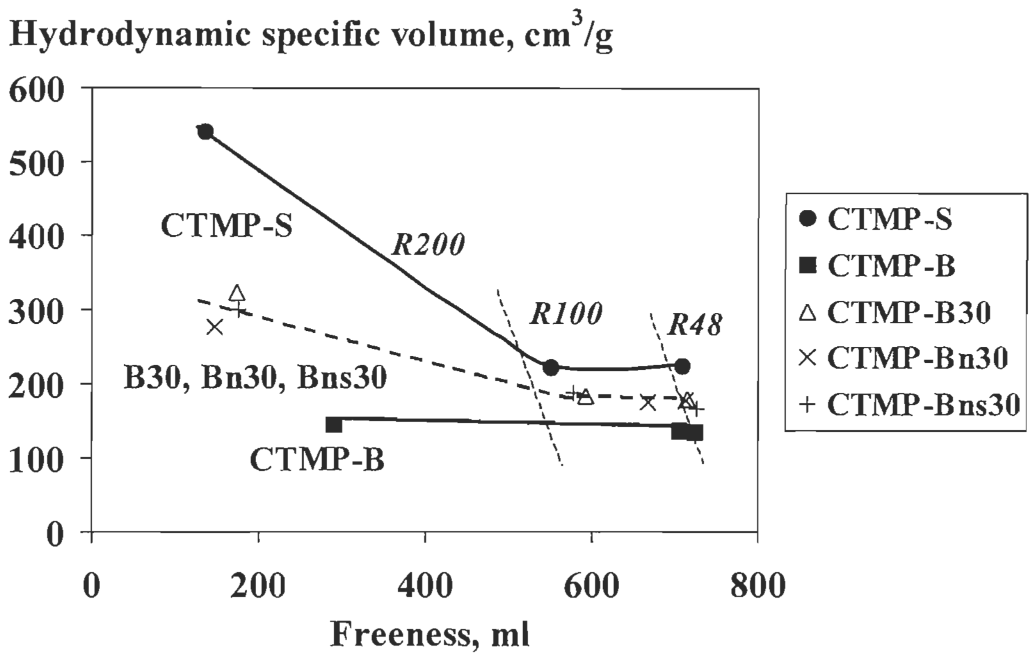


Figure 7.18 Relationship of hydrodynamic specific volume vs. freeness.

Flexibility (WFF) and RBA

The flexibility of the R28, R48 and R100 fractions of the CTMP with a freeness of 150 ml are shown in Figure 7.19. The CTMP-B had a lower fibre flexibility of these fractions than the CTMP-S, especially for the R100. The augmentation of white birch in the chip mixtures decreased the flexibility of the R100 while influencing slightly those of the R28 and R48 fractions. It seems that the substitution degree of white birch from 30% to 60% had little influence on the fibre flexibility. The fibres of the R100 of the CTMP-Bn30 and the CTMP-Bns30 had a higher flexibility than those of the CTMP-

B30., The fibre flexibility remained relatively unchanged for the R28 and R48 fractions of the CTMP-Bns30 and CTMP-Bn30 when compared to the CTMP-B30. Generally, the flexibility increased with decreasing of fibre length, which was noted for all the samples.

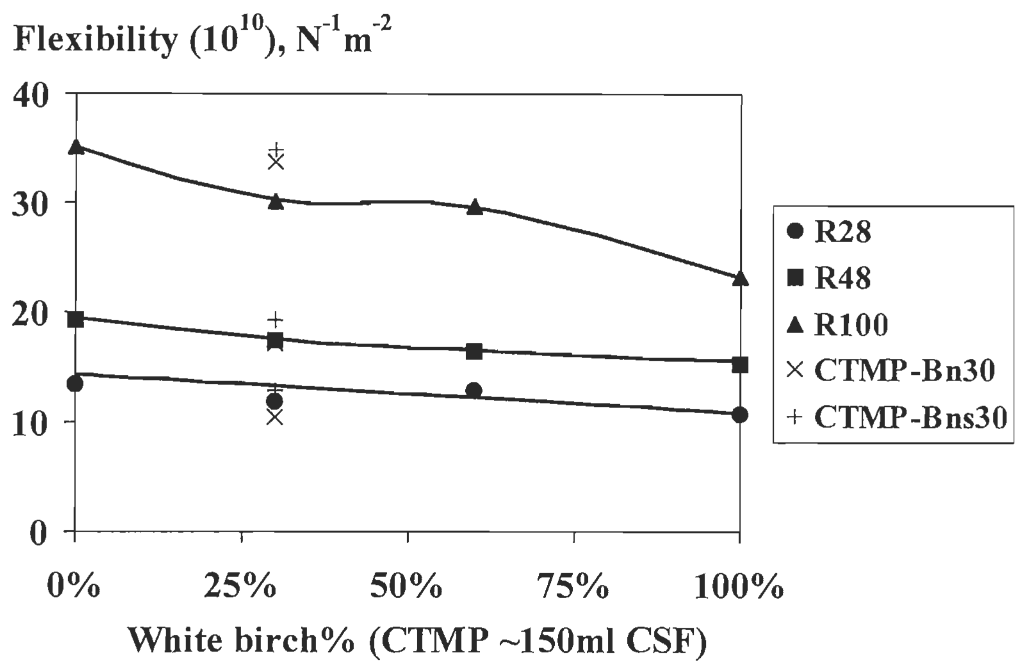


Figure 7.19 Effect of using white birch on fibre flexibility of the CTMP.

Similar to the TMP, the R200 fraction of all the CTMPs had a RBA substantially higher than those of the R48 and R100 fractions (Figure 7.20). Apparently, the RBA of the R200 of CTMP-B was improved when compared to that of the TMP-B. It shows that chemical treatment modifies not only the flexibility of short fibres but also the fines qualities thus improving the bonding potential of the fibres. Using white birch in the chip mixtures for producing CTMP decreased the RBA when compared to the CTMP-S. Similar to the case of fibre flexibility, this reduction was not affected by the substitution degree of white birch. Compared to the CTMP-B30, little modification of the RBA was observed with these three fractions of the CTMP-Bn30 and the CTMP-Bns30.

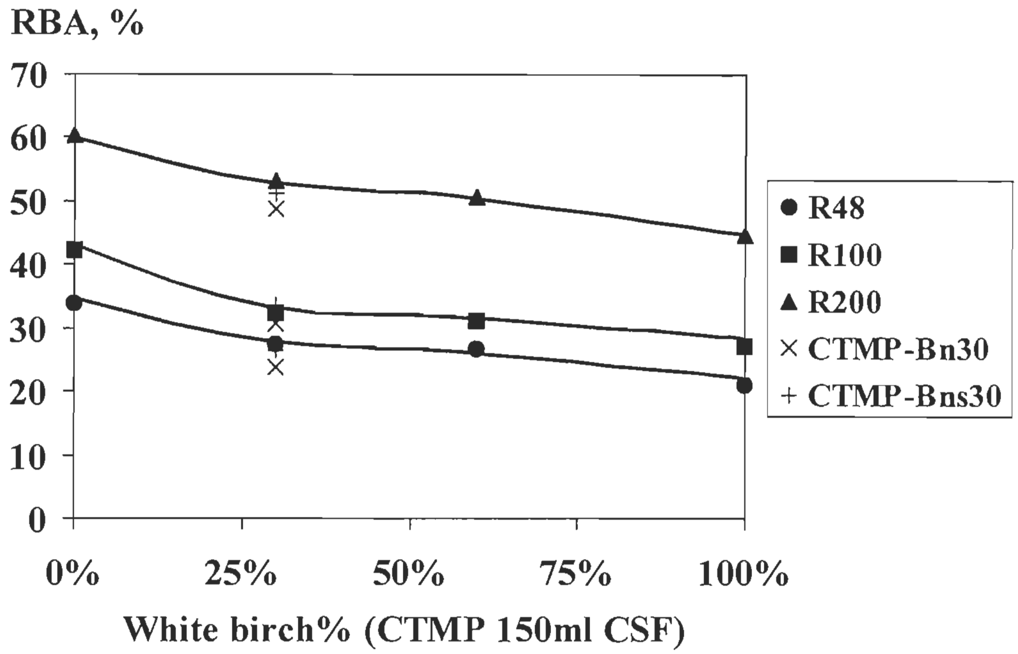


Figure 7.20 Effect of using white birch on RBA of the CTMP pulps.

Fibre surface characteristics (light and scanning electron microscopy)

In this section, the microscopic feature of the R28, R48, R100, R200 and P200 fractions was studied by means of a light microscope (Figures 7.21, 7.22 and 7.23). Additionally, the surface characteristics of the R48 were examined by using a scanning electron microscope (SEM). For comparison, the following pulps were used for the microscopic observation: the CTMP-S, -B30, -Bn30, -Bns30 and CTMP-B.

Similar to the TMP, considerable improvement in fibre fibrillation and delamination was found on the R200 compared to the R28 and R48 fractions for all the CTMPs except the CTMP-B. For the CTMP-B, only slight improvement of fibre fibrillation was noticed on R200 compared to R28, R48 and R100 (Figures 7.21, 7.22 and 7.23). Most of the ray cells and their fragments were found in the P200, while the vessel fragments were mainly concentrated in the R200. Visual inspection showed that the fractions of the pulps from the chip mixtures had similar tendency of improvement in fibre fibrillation and delamination when compared to the CTMP-S. In the CTMPs, both the fibres of black spruce and white birch became flexible due to the chemical treatment (SEM photos: Figures 7.24, 25 and 26). The chemical softening helps reduce the broken fibres and rejects in the long-fibre fractions of the CTMP. Cisneros *et al* [55] compared the hardwood CTMP properties to TMP by means of the SEM and also found that the CTMP fibres had a better collapsibility and produced sheet with a higher density as a result of alkali-sulfite.

In the characterisation of mechanical pulps, the measurements of WRV and coarseness are relatively inadequate. For this reason, additional tests, such as fibre flexibility and microscopy may be useful, especially when chemicals are used in the pulping. Generally, white birch gains more benefits of alkali-sulfite in improving fibre flexibility when compared to the black spruce. The increased flexibility combined with the possibility of lignin sulfonation is probably the main reason for the increase in fibre bonding potentials for the CTMPs. The substitution of white birch from 30% to 60% has little effect on the fibre qualities such as long-fibre content, average fibre length, flexibility and RBA etc. The co-refining of birch and spruce in a CTMP process appears to be an interesting approach to produce mechanical pulp for newsprint making.

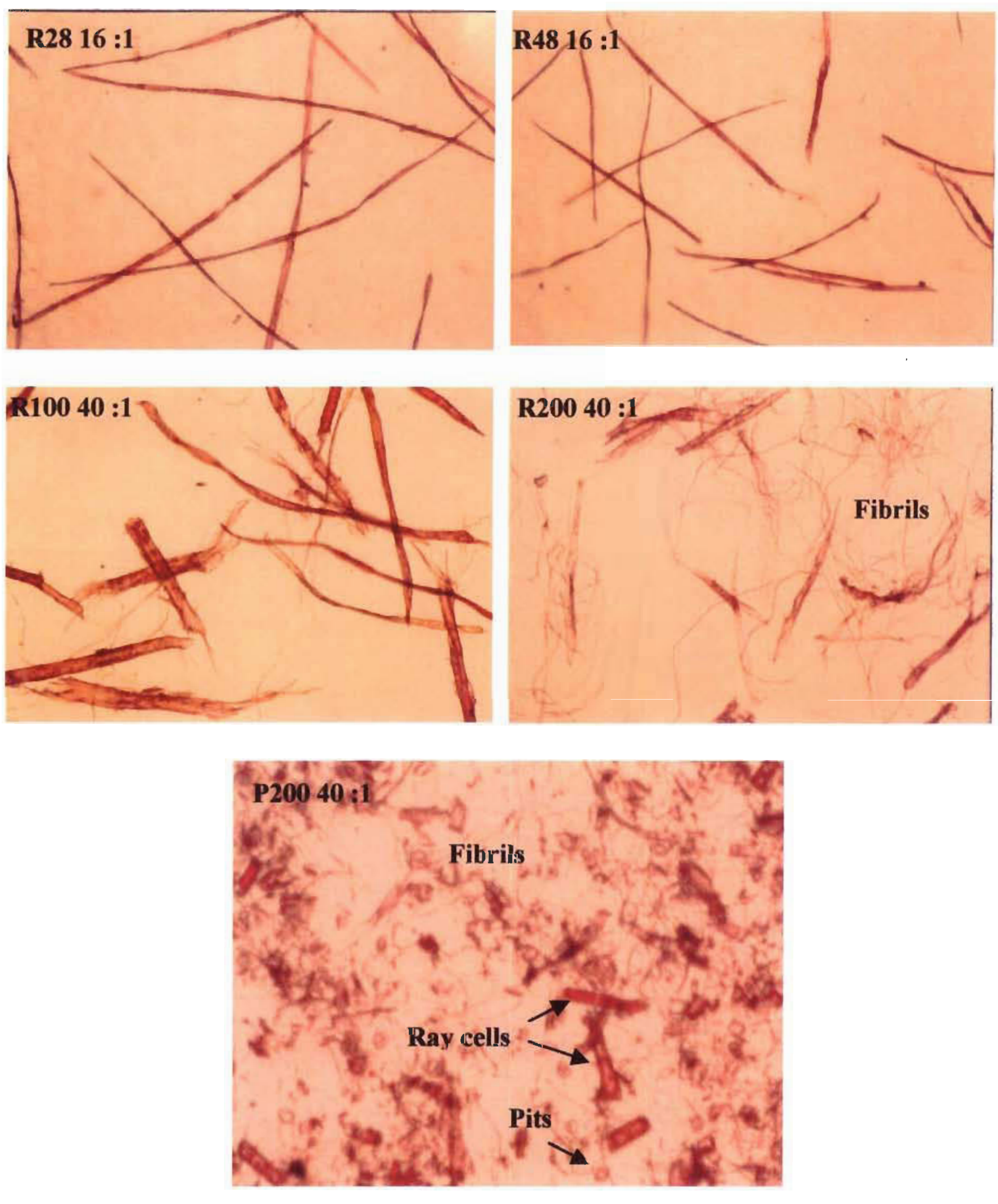


Figure 7.21 Light micrographs of the fractions of the CTMP-S.

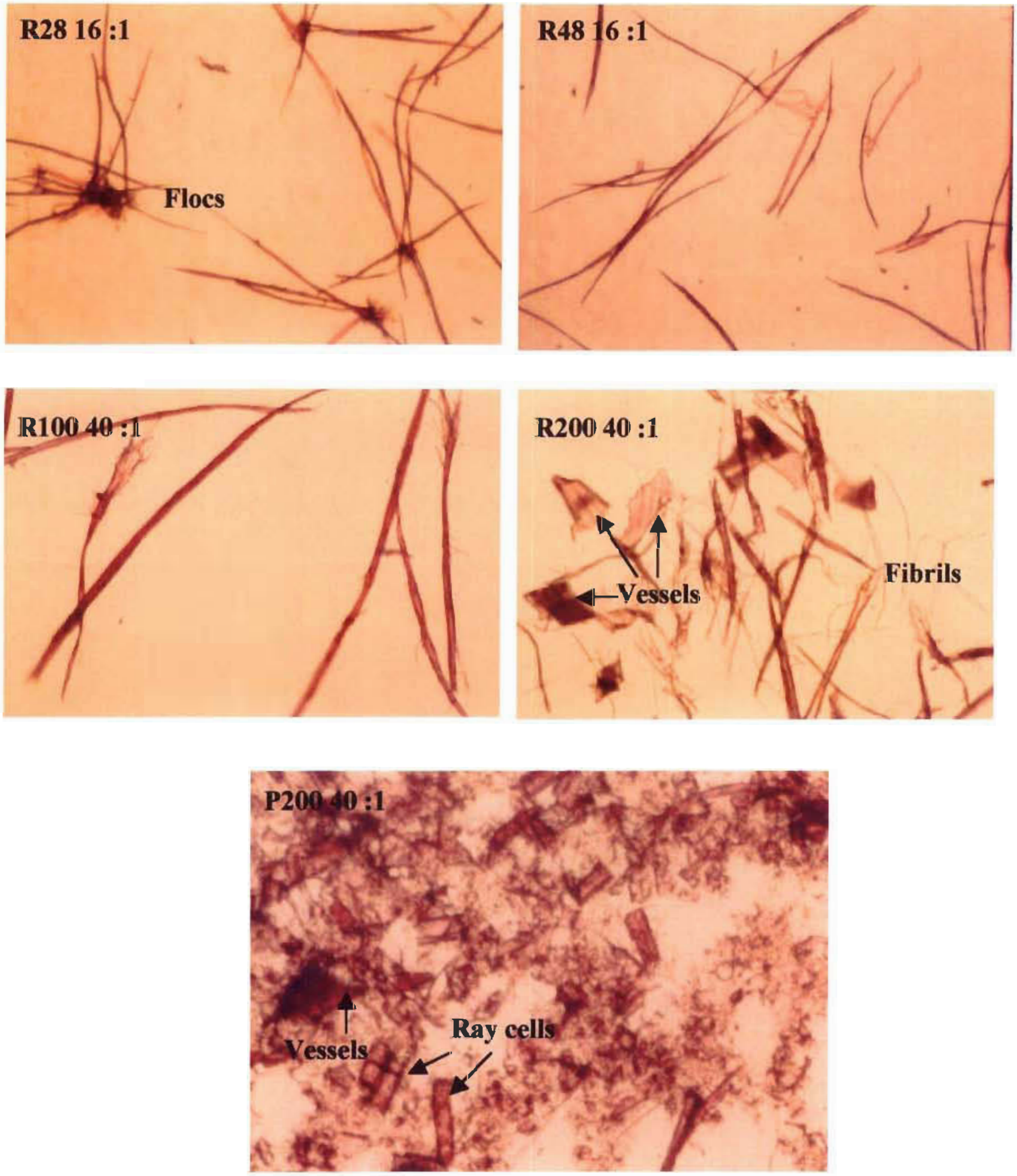


Figure 7.22 Light micrographs of the fractions of the CTMP-B.

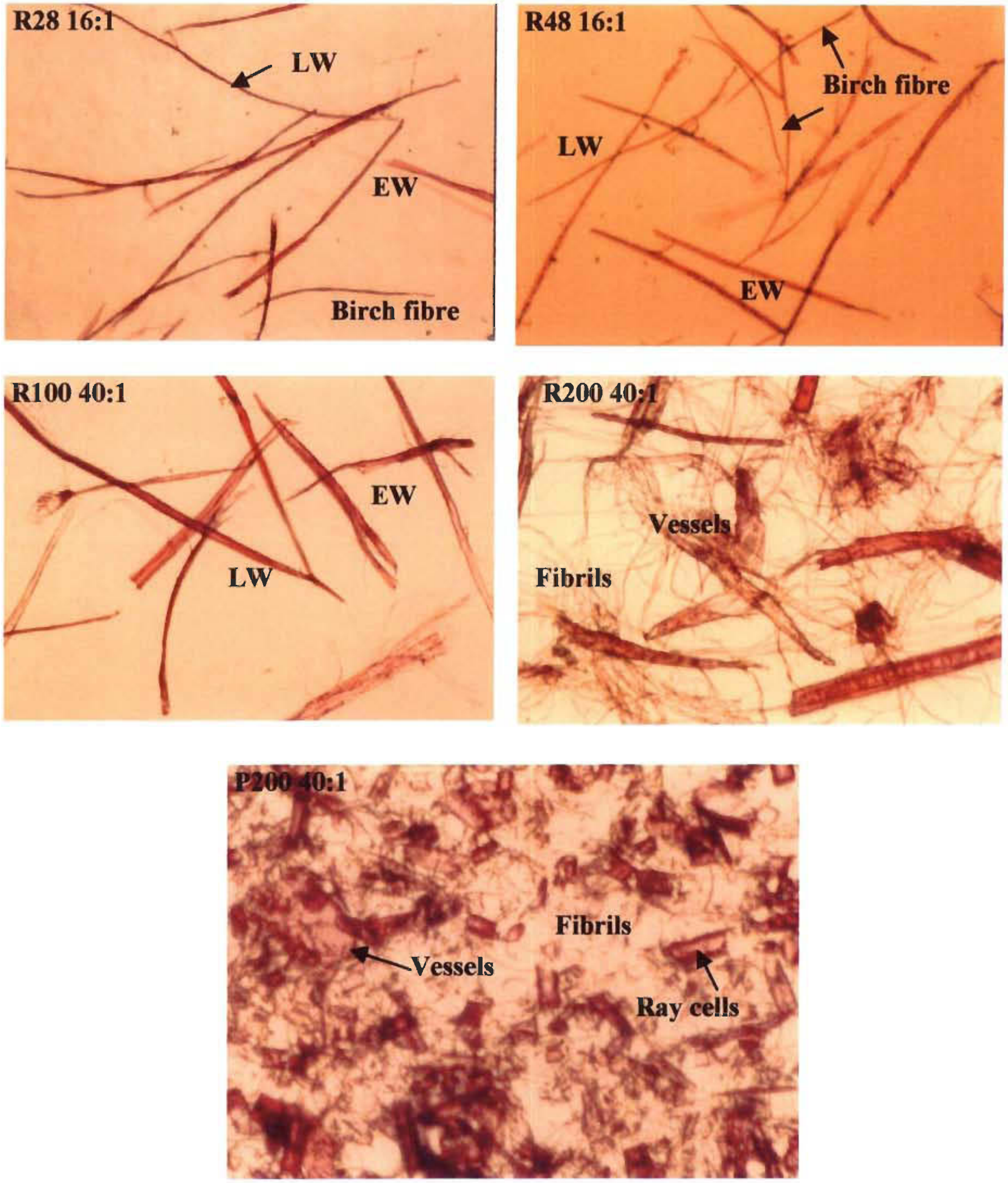


Figure 7.23 Light micrographs of the fractions of the CTMP-B30.

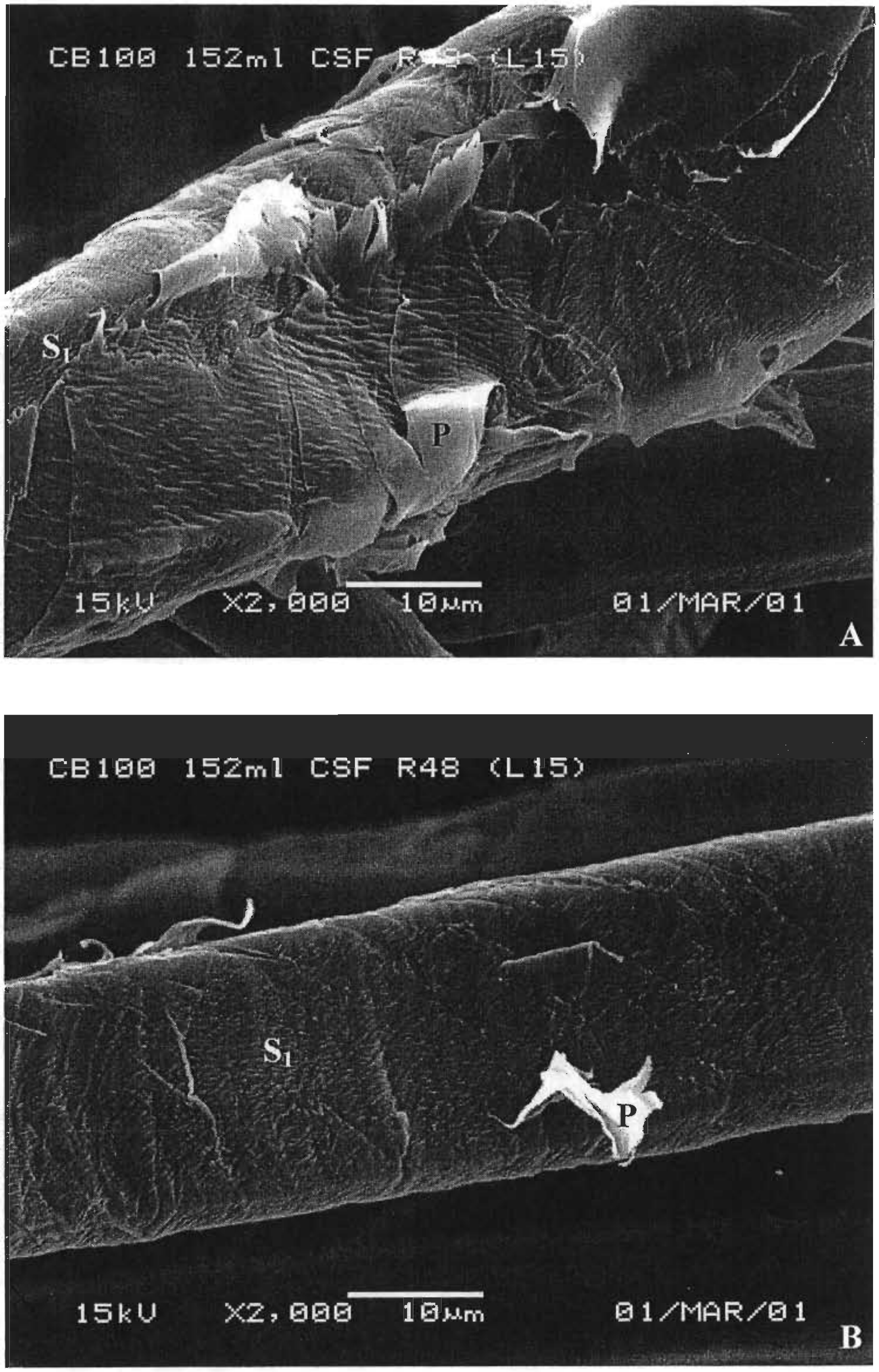


Figure 7.24 SEM micrographs showing the fibres of R48 of CTMP-B.

A: a birch fibre with partially exposed S_1;
B: a birch fibre with nearly wholly exposed S_1.

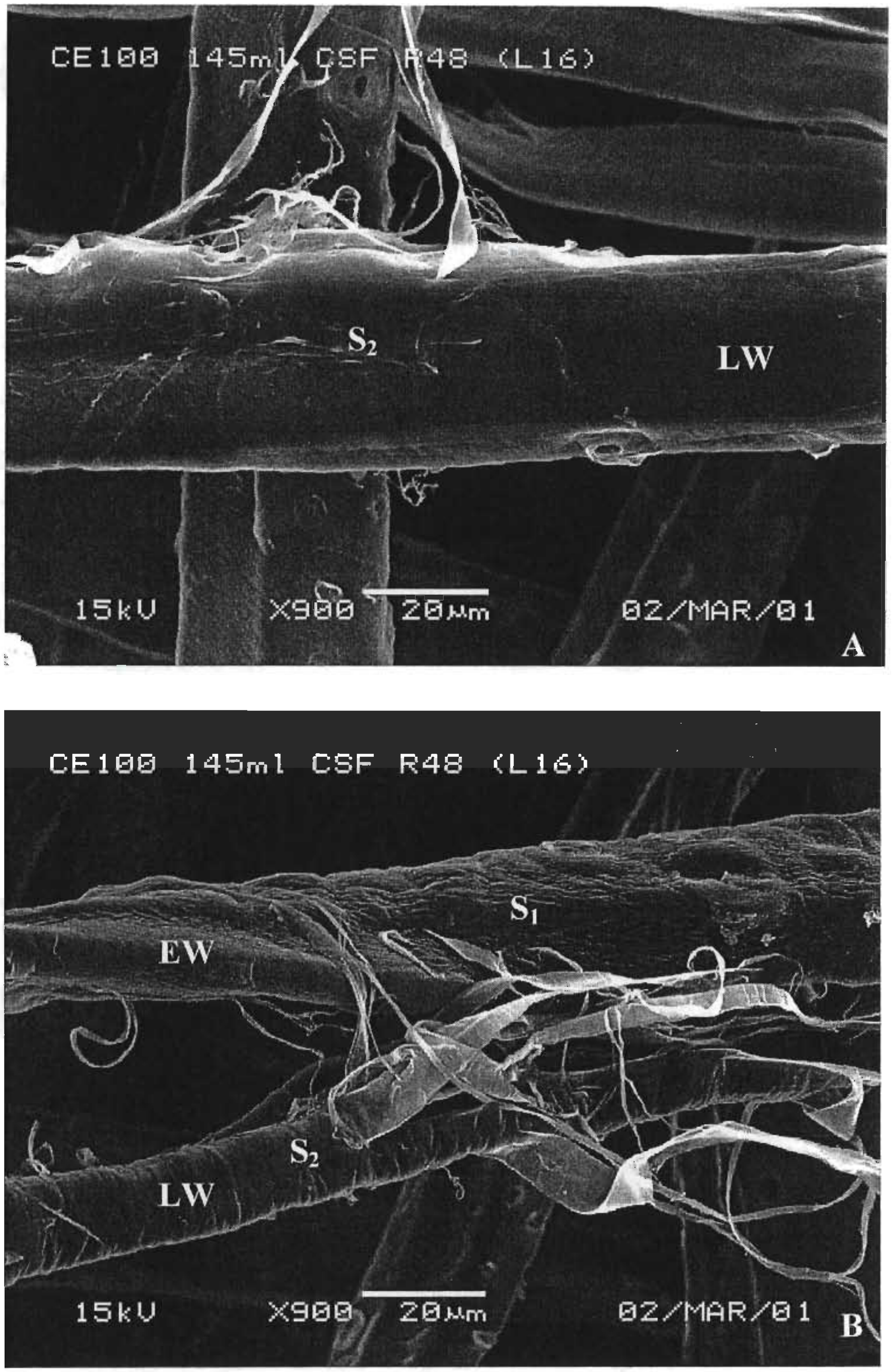
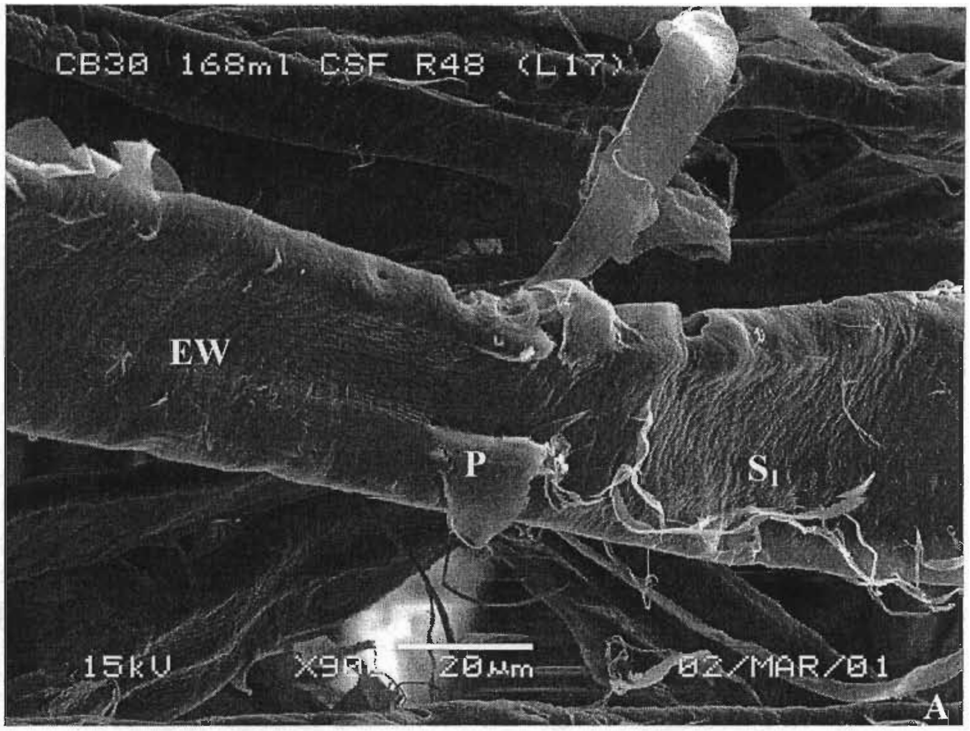


Figure 7.25 SEM micrographs showing the fibres of R48 of CTMP-S.

A: a latewood fibre (LW) with the exposed S_2;
B: an earlywood fibre (EW) with the exposed S_1 and a LW fibre with the exposed S_2.



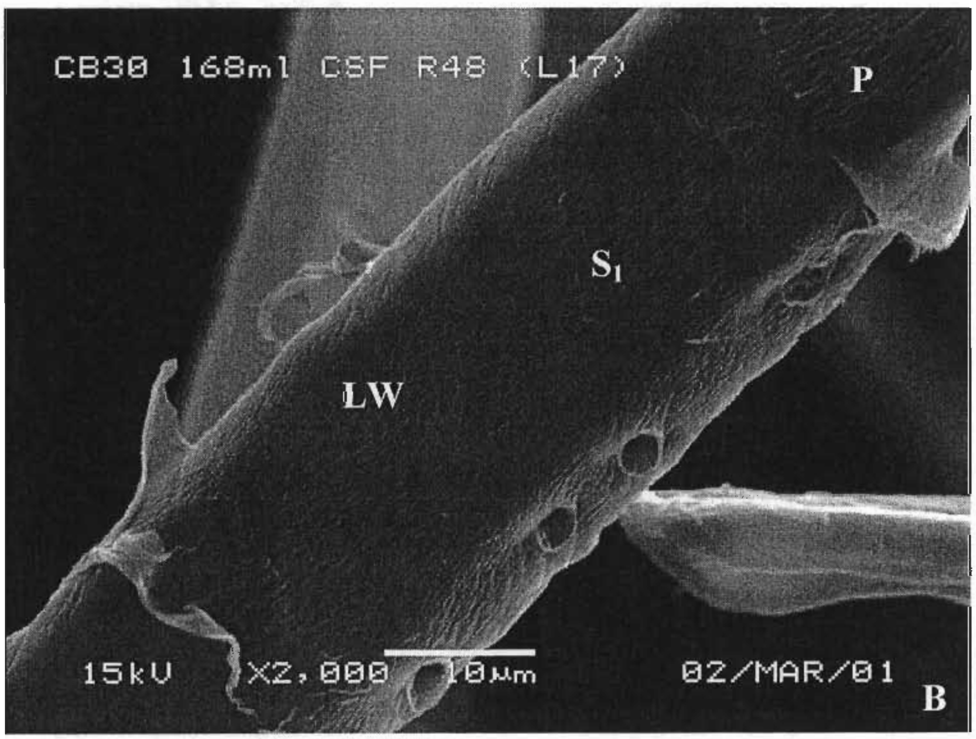


Figure 7.26 SEM micrographs showing the fibres of R48 of CTMP-B30.

A: a flexible earlywood fibre (EW) with the partially exposed S_1;
B: a latewood fibre (LW) with the partially exposed S_1.

7.3 Strength properties

Tear strength

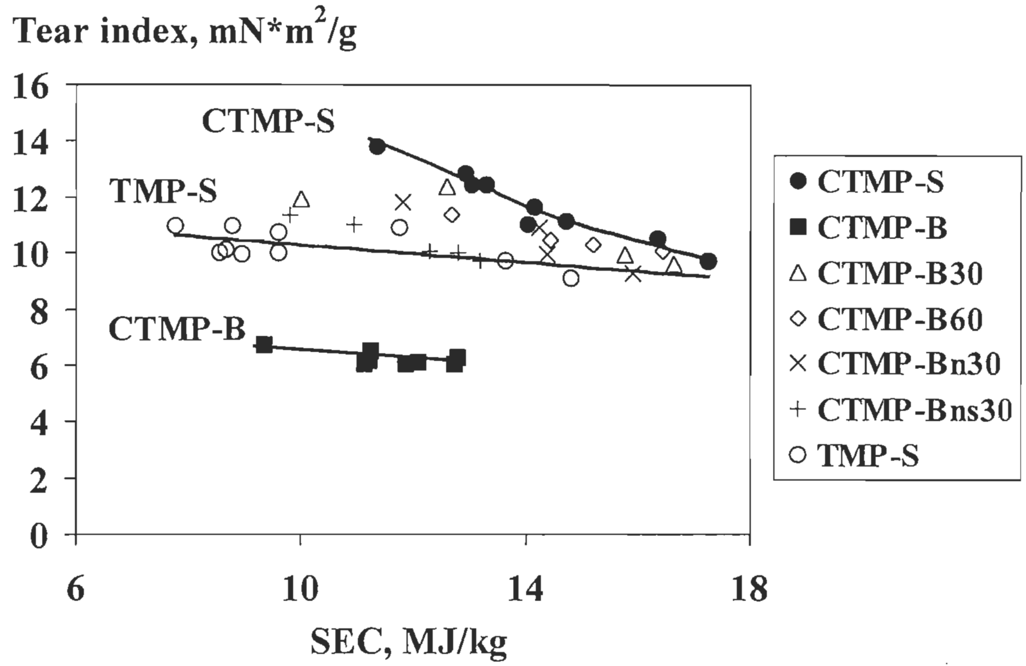


Figure 7.27 Tear index of the CTMP as a function of SEC.

For its high long-fibre content, the CTMP-S had the highest tear strength (Figure 7.27). On the other hand, the sheet of the CTMP-B had the lowest. As such the introduction of white birch in the chip mixtures decreased the tear strength. However, the tear index of the CTMP from the chip mixtures remains somewhat higher or equal to that of the TMP-S which was about 10 mN*m^2/g. Note that the difference in tear index between the CTMP-S and the TMP-S decreased gradually as the SEC increases. In general, the substitution degree of white birch (30-60%) had little effect on the long-fibre content and the tear strength of the pulps. Compared to the CTMP-B30, the CTMP-Bn30 had similar tear index and the CTMP-Bns30 had a slightly lower tear index. This suggests that alkali pre-treatment of white birch chips prior to mixing with black spruce chips following co-refining with adding sulfite is better in keeping the long-fibre content than that of alkali-sulfite pre-treatment of white birch chips prior to mixing with black spruce chips following co-refining without chemicals added. Probably, the sodium sulfite has a positive effect on both of white birch and black spruce.

Tensile strength

As shown in Figure 7.28, it is always that the CTMP-S had the highest tensile index while the CTMP-B had the lowest. Using up to 60% white birch in chip mixtures decreased slightly the tensile index compared to the CTMP-S but tensile strength still comparable to that of the TMP-S. Chemical pre-treatment of birch chips (CTMP-Bn30 and CTMP-Bns30) yielded almost no effect on the tensile index compared to the CTMP-B30.

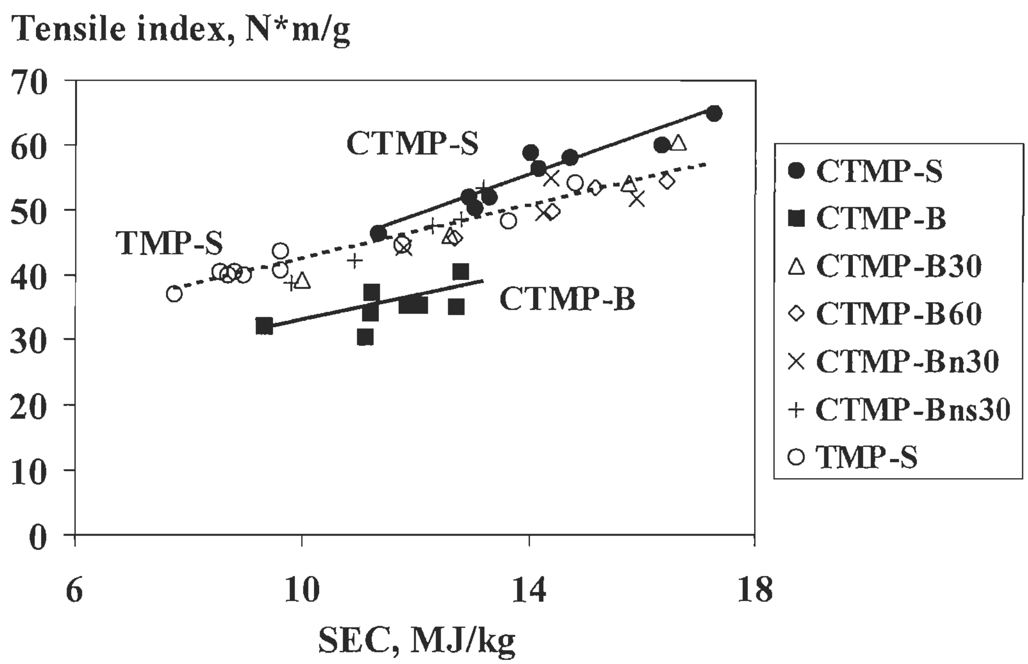


Figure 7.28 Tensile index of the CTMPs as a function of SEC.

Burst strength

As expected, white birch produced the CTMP with the lowest burst strength while black spruce gave superior CTMP (Figure 7.29). Chip mixtures containing 30-60% white birch decreased slightly the burst strength compared to the CTMP-S but they still produced the pulps with a burst index similar to the TMP-S. The substitution percentage (30 to 60%) and the chemical pre-treatment of birch chips yielded little effect on the burst index.

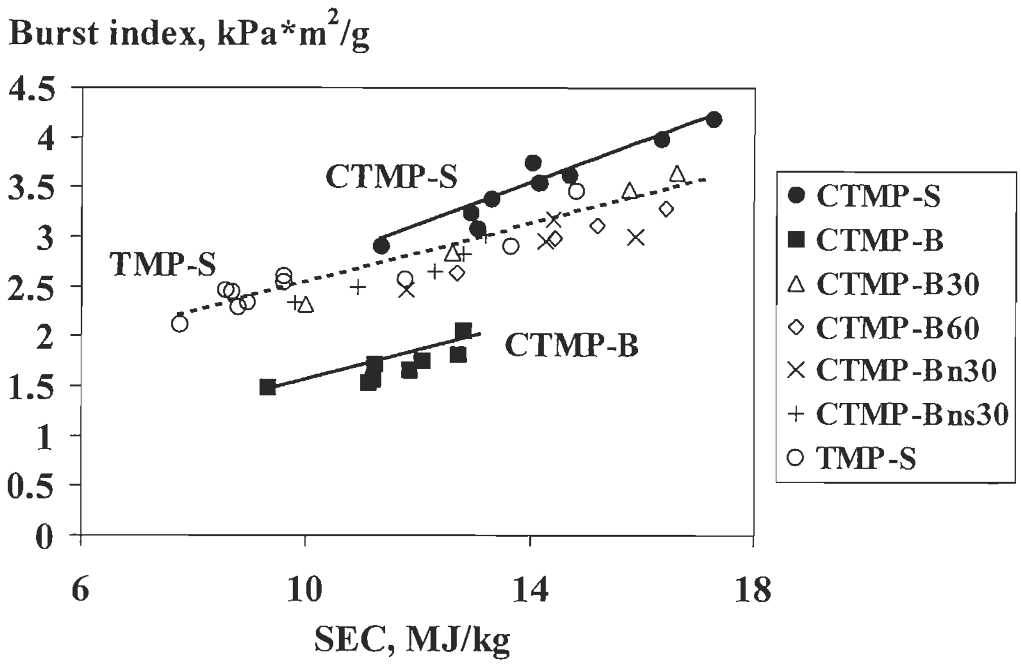


Figure 7.29 Burst index of the CTMPs as a function of SEC.

7.4 Optical properties

The optical properties of the pulps studied included light scattering coefficient, light absorption coefficient and brightness, which are shown in Figures 7.30 to 7.32.

Light scattering and absorption coefficient

For all the pulps, the light scattering coefficient increased with increasing refining energy input since the fines content augmented also at the same time, as shown in Figure 7.30. Being different from the TMP, only slightly higher light scattering coefficient can be observed with the CTMP-B compared to the CTMP-S. The use of white birch from 30 to 60% in the chip mixtures had almost no effect on the light scattering coefficient compared to CTMP-S. However, the chemical pre-treatment of birch chips prior to mixing with untreated spruce chips had some beneficial effect on the light scattering coefficient. This is probably due to the fact that the fines produced from black spruce have similar characteristics to those of TMP-S which has no chemical or only sodium sulfite used during the co-refining. However, all the CTMP pulps had lower light scattering coefficient than that of TMP-S due to the use of chemicals, which decreased the content of short-fibres and fines.

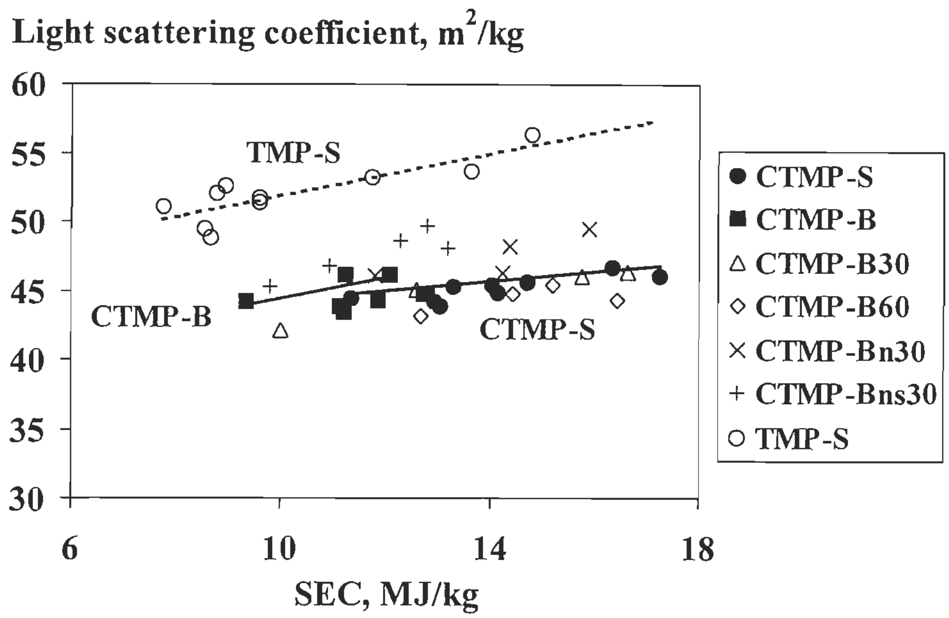


Figure 7.30 Light scattering coefficient of the CTMPs as a function of SEC.

For all the pulps, except the CTMP-Bns30, some variability in light absorption coefficient distribution was noted, which was somewhat higher or lower than that of the TMP-S. The CTMP-Bn30 had the lowest light absorption coefficient than the other pulps (Figure 7.31).

Brightness

The reduction in brightness was noticed on both of the white birch and the black spruce when alkali-sulfite was used during refining, comparing Figure 7.32 to Figure 6.28. However, the CTMP-B still had a substantial higher brightness than the CTMP-S. The presence of white birch up to 60% improved somewhat the brightness compared to the CTMP-S. A remarkable improvement in brightness was found in the CTMP-Bn30 and the CTMP-Bns30 in comparison with the CTMP-B30 due to the chemical pre-treatment on white birch prior to mixing with the untreated black spruce chips. In this case, no alkaline darkening effected on spruce chips during co-refining. The CTMP-Bn30 had higher brightness than the CTMP-Bns30, which illustrated that the presence of sodium sulfite without alkali during co-refining has a positive bleaching effect not only on the white birch but also on the black spruce. With the help of alkali or alkali-sulfite pre-treatment of white birch prior to mixing with untreated black spruce followed by co-refining without chemicals or with only sulfite, it is possible to produce a pulp with a brightness close to the TMP-S.

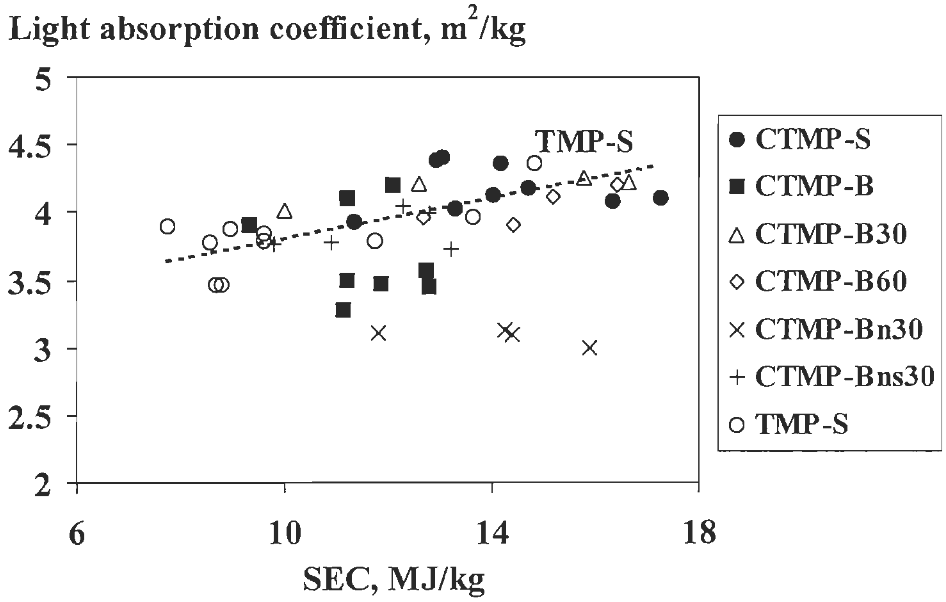


Figure 7.31 Light absorption coefficient of the CTMPs as a function of SEC.

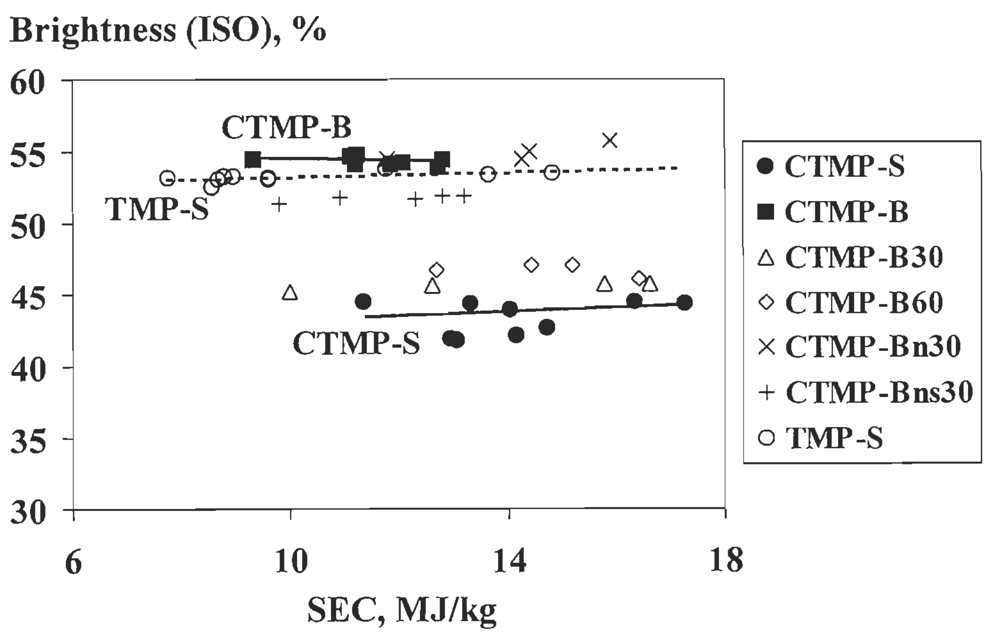


Figure 7.32 Brightness of the CTMPs as a function of SEC.

7.5 Sheet structure properties

A linear relationship existed between the handsheet density and SEC for all the CTMP pulps, except that some variability was found in the CTMP-Bn30 (Figure 7.33). Apparently, a significant improvement in density of the sheets made from white birch pulps was noted due to the use of alkali, which corresponded well to the fibre flexibility and RBA improvement, as discussed previously. These improvements can also be found in the co-refining with black spruce. On the other hand, the chemicals had little effect on density of paper prepared from the black spruce pulps.

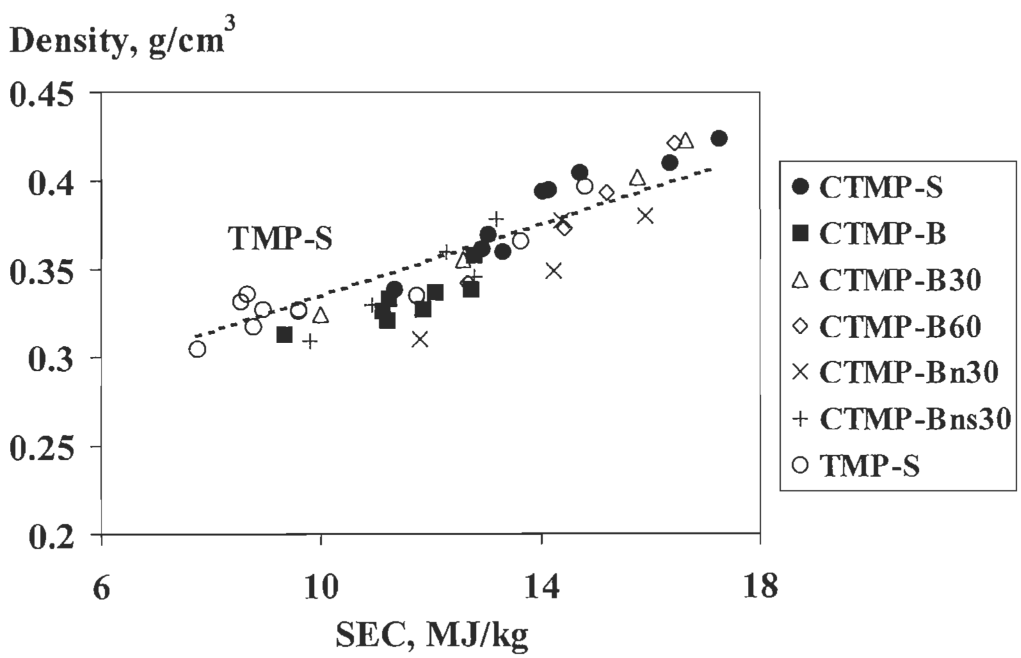


Figure 7.33 Density of the CTMPs as a function of SEC.

The handsheet of CTMP-B had a higher porosity than that of the CTMP-S, especially at low refining energy input (Figure 7.34). Increasing the SEC reduced rapidly the porosity in the CTMP-B. Comparing Figure 6.30 to Figure 7.34 indicates that alkali-sulfite is helpful to increase the white birch fibre flexibility and collapsibility and sheet density, thus decreasing the porosity. Conversely, using alkali-sulfite augmented slightly the porosity at low SEC for black spruce and then influenced marginally with increasing

SEC. For the CTMP-B30, CTMP-Bn30 and CTMP-B60, the porosity was similar compared to that of the CTMP-B at low SEC but then close to that of the CTMP-S at high SEC. The CTMP-Bns30 had a slightly lower porosity than the CTMP-S.

For all the pulps, except the CTMP-Bns30, the roughness decreased linearly with increasing SEC (Figure 7.35). The CTMP-Bns30 had roughness somewhat lower than that of the other pulps at the same SEC. The low porosity and roughness of the CTMP-Bns30 implies that it has a good inter-fibre bonding probably due to its slightly higher fibre flexibility, as discussed previously.

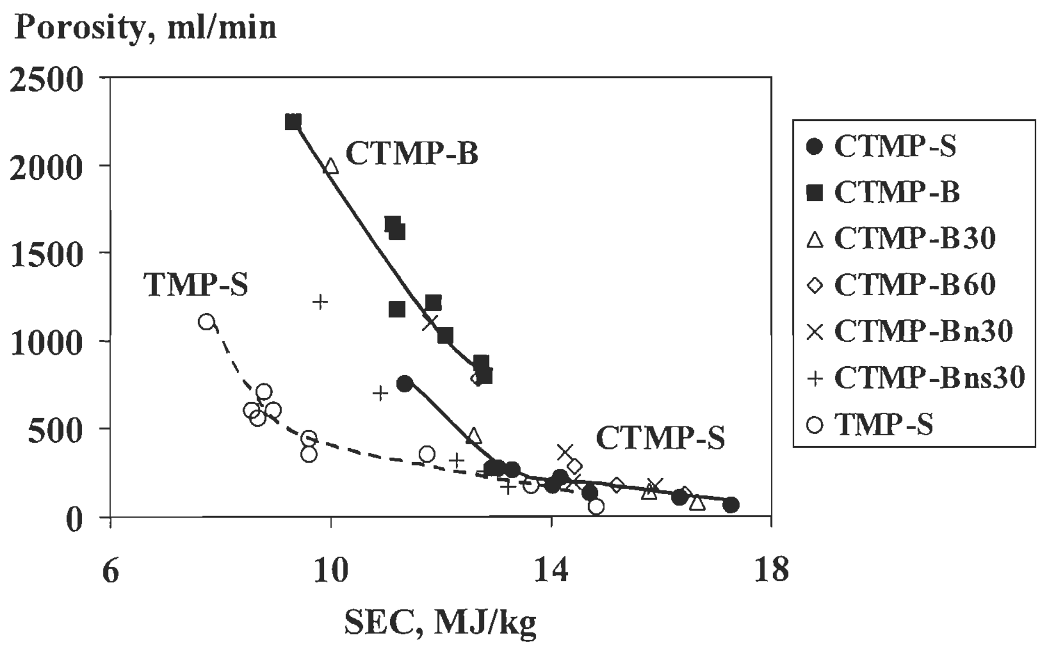


Figure 7.34 Porosity of the CTMPs as a function of SEC.

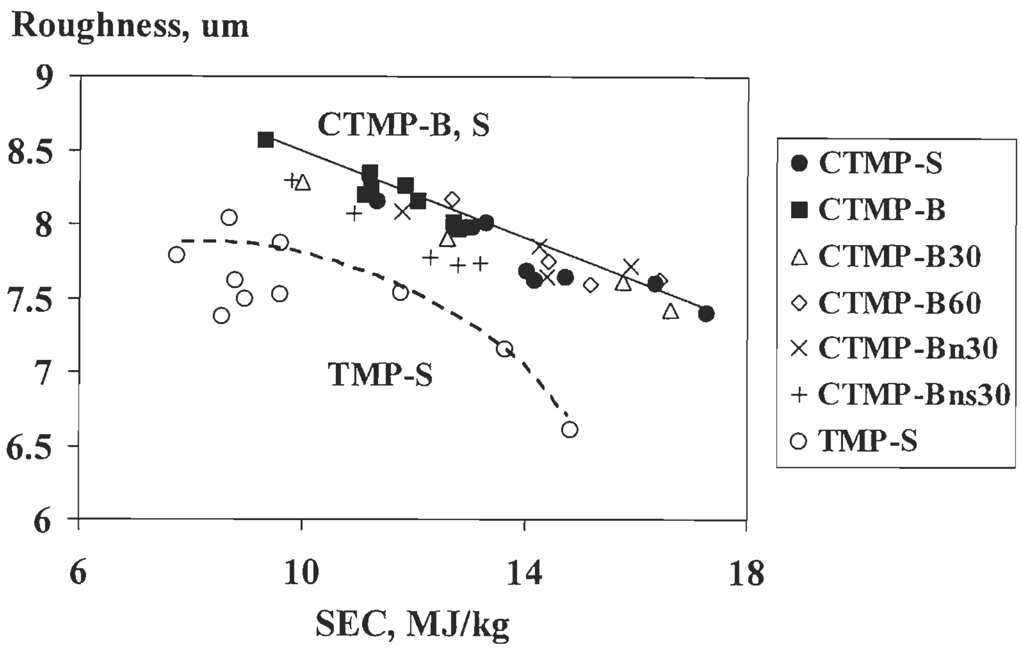


Figure 7.35 Roughness of the CTMP pulps as a function of SEC.

7.6 Linting propensity

The handsheets made from the CTMP-B, B30, B60, Bn30, Bns30 and CTMP-S at about freeness 150 ml were chosen for linting measurements. As discussed earlier, large improvements in flexibility and RBA were noticed on the short-fibre fraction (R100 and R200) of the CTMP-B due to the use of chemicals and thus the improved density handsheets. For this reason, a significant reduction in linting was achieved for the CTMP-B in comparison with the TMP-B (Figures 6.28, 6.29, 7.31 and 7.32). The number of removed fibres decreased from more than 2000 to less than 720, and the cumulated fibres length decreased from more than 150 m/m^2 to lower than 42 m/m^2. On the other hand, the use of chemicals yielded almost no influence on the linting propensity for black spruce pulps. Similar to the TMP, substituting up to 60% of white birch for black spruce for producing CTMP yielded little influence on the linting propensity compared to the CTMP-S. For all the samples, the removed materials during the printing test had a similar distribution as shown in Figure 7.33. Through the microscopic observation, the principal lint materials observed were the ray cells, some whole intact fibre as well as fibre fragments. All the removed fibres had a smooth surface although sometimes exposed S_2 layer is. For the CTMP-B and the pulps form the chip mixtures, some vessel fragments were also found in the lint materials, but the frequency of vessel fragments was lower than that for the TMP, probably due to the sulfonated lignin in the vessel fragments. No shives were found in the linting materials, which illustrated a better fibre separation due to the addition of chemicals in comparison with the TMP.

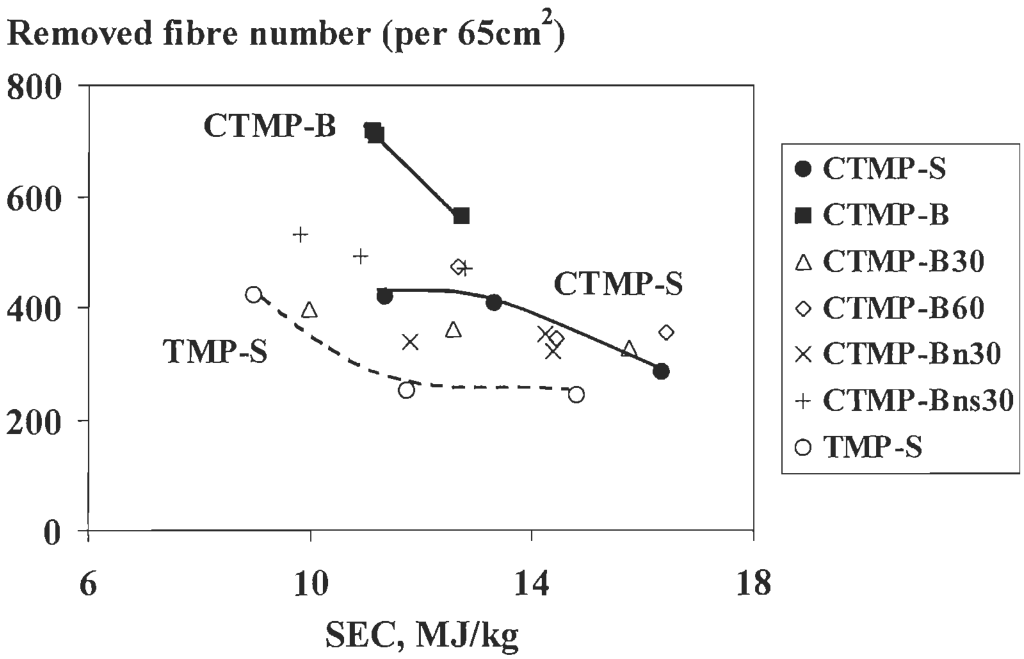


Figure 7.36 Removed fibres number during linting propensity test vs. SEC.

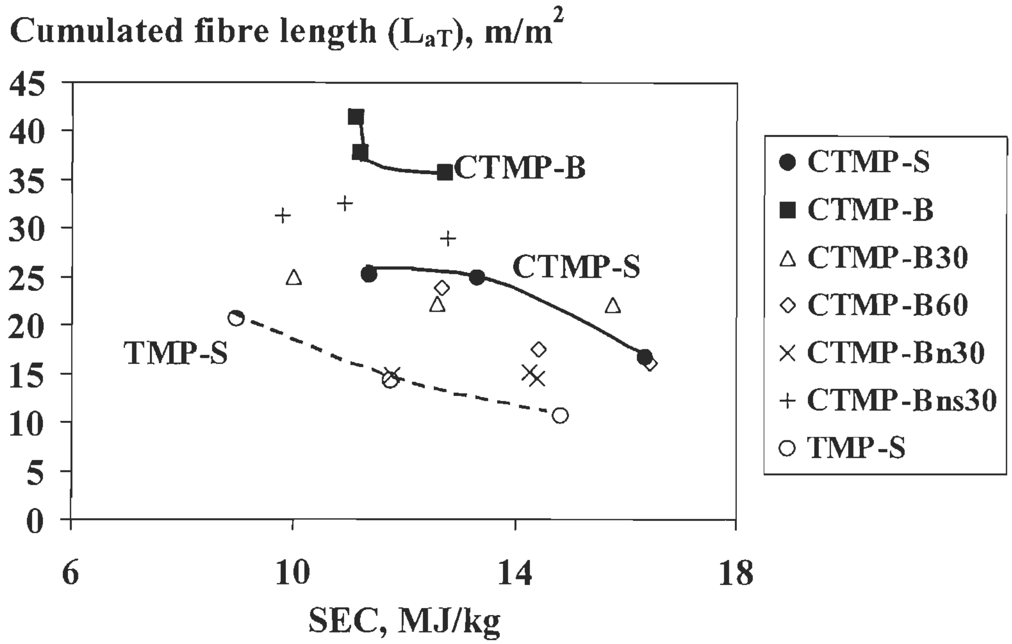


Figure 7.37 Cumulated fibres length of removed fibres of linting propensity test.

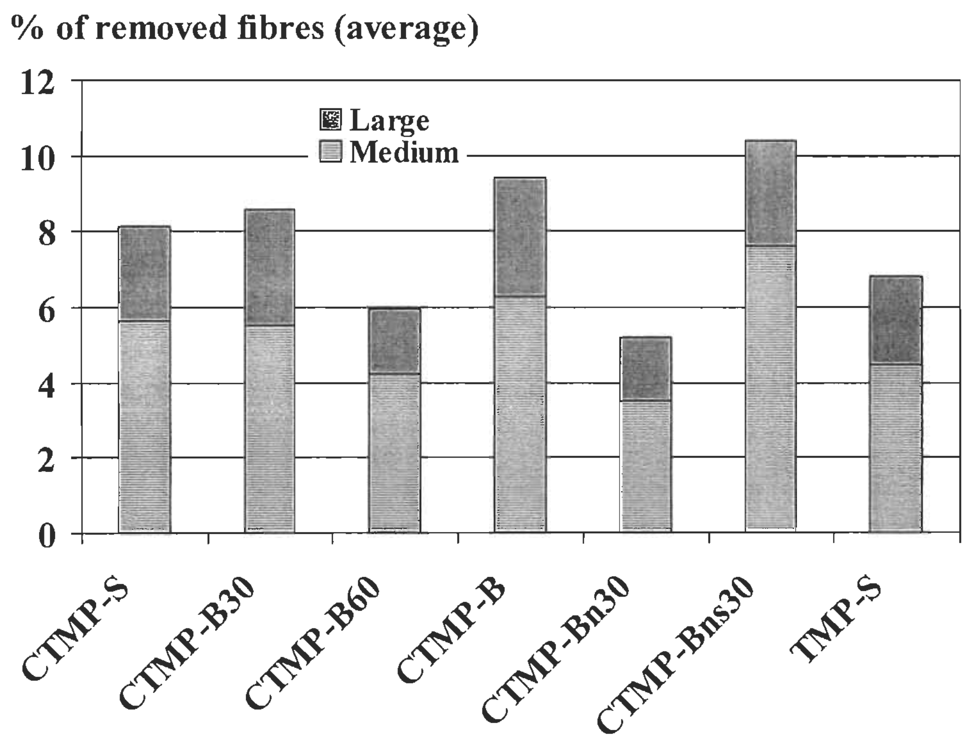


Figure 7.38 Removed fibres distribution during linting propensity test.

7.7 Conclusion

In CTMP, similar to TMP, the use of white birch showed little influence on the long fibre qualities, but decreased the short fibre and especially the fine qualities, as measured by the flexibility and hydrodynamic specific volume. These reductions were not as high as those found in the TMP since the use of chemicals improved largely the white birch fibre qualities. The CTMPs of the chip mixtures had comparable tensile, tear and burst strength compared to the 100% black spruce TMP, although a little lower than those of the 100% black spruce CTMP. The main disadvantage of using chemicals was the reduction of light scattering. The chemical pre-treatment of white birch prior to mixing with black spruce followed by co-refining was a compromised alternative to improve the strength properties by modifying the quality of white birch fibres while reducing the loss of light scattering due to the absence of alkaline treatment on the black spruce fibres.

A significant reduction in linting was achieved for the CTMP-B in comparison with the TMP-B due to the use of chemicals. Similar to the TMP, the problem of linting became less important when white birch was refined together with black spruce in producing CTMP.

Chapter 8 - INFLUENCE OF USING WHITE BIRCH AND CHEMICAL TREATMENT

In the Chapters 6 and 7, we studied the thermomechanical and the chemithermomechanical pulps made from B/S chip mixtures with 0-100% white birch substitutions. In this Chapter, we compared the properties of the TMP and the CTMP focusing on the influence of using white birch and chemicals on energy consumption and the final pulp properties, particularly the fibre and fines characteristics.

8.1 Energy consumption

Comparing Figures 6.1 and 7.1, we found that the alkali-sulfite treatment reduced the SEC of white birch pulps and increased that of black spruce pulps. Blending white birch with black spruce in the TMP process had little effect on the SEC compared to the TMP-S, while decreasing slightly the SEC in the CTMP process when compared to the CTMP-S. The refining of alkaline-sulfite pre-treated white birch chips with untreated black spruce chips consumed less SEC than the reference CTMP at the same substitution degree of white birch, since the chemicals was not applied to the black spruce chips.

8.2 Tensile index and scattering coefficient

The strength and optical properties are two important factors affecting the quality of mechanical pulps. To evaluate the effects of refining energy and chemicals and the use of white birch on the pulp qualities, we plated the light scattering coefficients of the CTMP and the TMP pulps against the corresponding tensile indices as shown in Figure 8.1. Irrespective of the original materials, there is a single relationship between tensile index and light scattering coefficient within each pulp type. Both the tensile index and the light scattering coefficient increased with augmenting refining energy. The improvement in specific surface due to the production of fines, contributed positively to both the physical and the optical properties but with different degree due to the using of white birch and chemicals. The TMP-S showed a better balance between the tensile index and the light scattering coefficient than the other pulps. It had superior tensile index compared to that of the TMP-B and TMP-B30 at a given light scattering coefficient. On the other hand, the light scattering coefficient of the TMP-S was higher than that of the CTMPs at a given tensile strength.

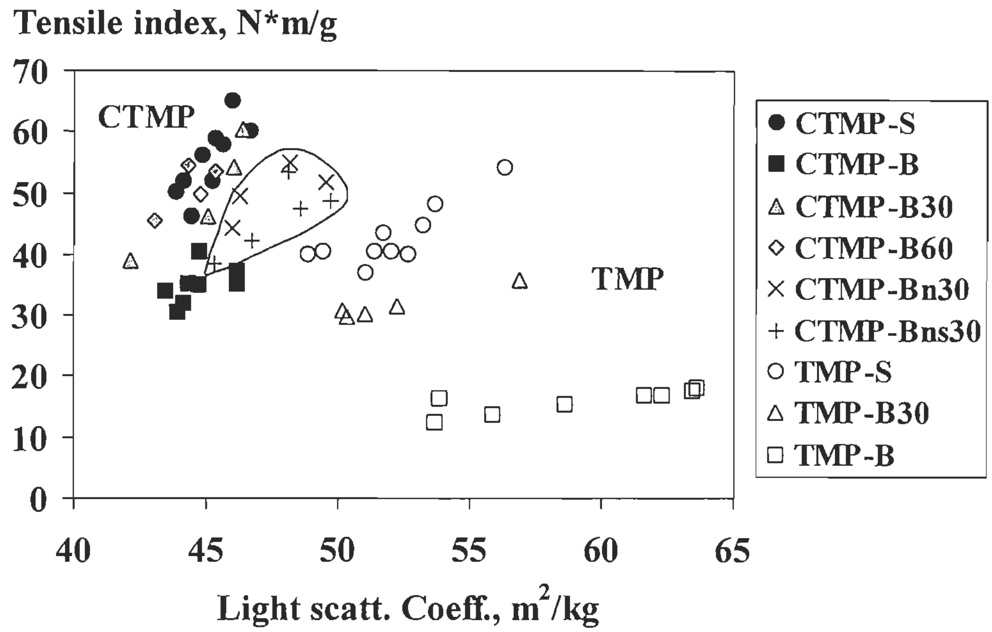


Figure 8.1 Relationship of tensile index with light scattering of various pulps.

The use of white birch in producing TMP decreased the tensile index while increasing the light scattering coefficient at a given SEC. On the other hand, Introducing white birch in the CTMP had a slight effect on both tensile index and light scattering coefficient. It seems that white birch benefits much more in improving pulp strength from the chemicals than black spruce but with a loss of light scattering.

In the CTMP process, the introduction of sulfonic groups improves the separation of fibres and transforms the lignin into a more hydrophilic structure, thus improves the qualities of fibres and fines. The fibres of the CTMP become more flexible than those of the TMP, especially for the pulp made from 100% white birch. As shown in Figure 8.2, more than 60% and 100% improvement was found in fibre flexibility of the R48 and the R100 of the CTMP-B, respectively, when compared to the TMP-B. Only about 20% and 3% improvement in fibre flexibility were found for the R48 and the R100 of the CTMP-S, respectively, when compared to the TMP-S. The chemical treatment reduced the difference of fibre flexibility between white birch and black spruce. Moreover, the benefit of using chemicals on improving the white birch fibre flexibility was shown in co-refining with black spruce. Clearly, the bonding potential improveed with increased fibre flexibility, as shown in Figure 8.3.

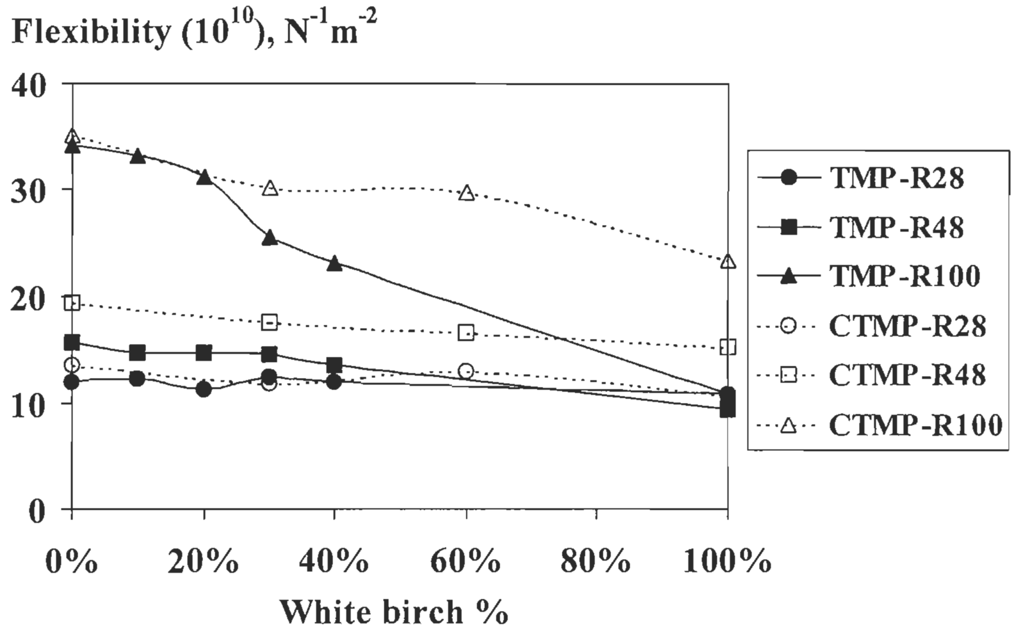


Figure 8.2 Fibre flexibility of the fractions of the pulps with about 150 ml CSF.

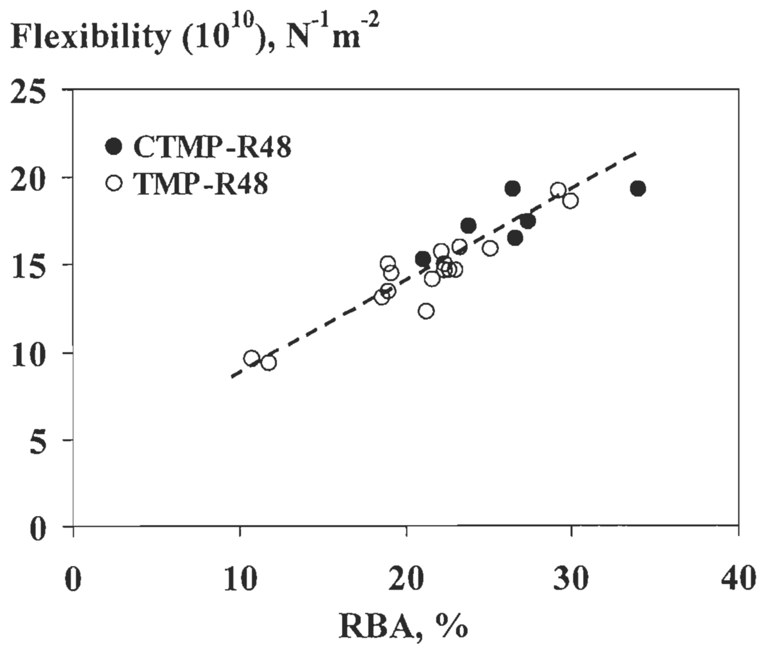


Figure 8.3 Relationship between the fibre flexibility and RBA of R48.

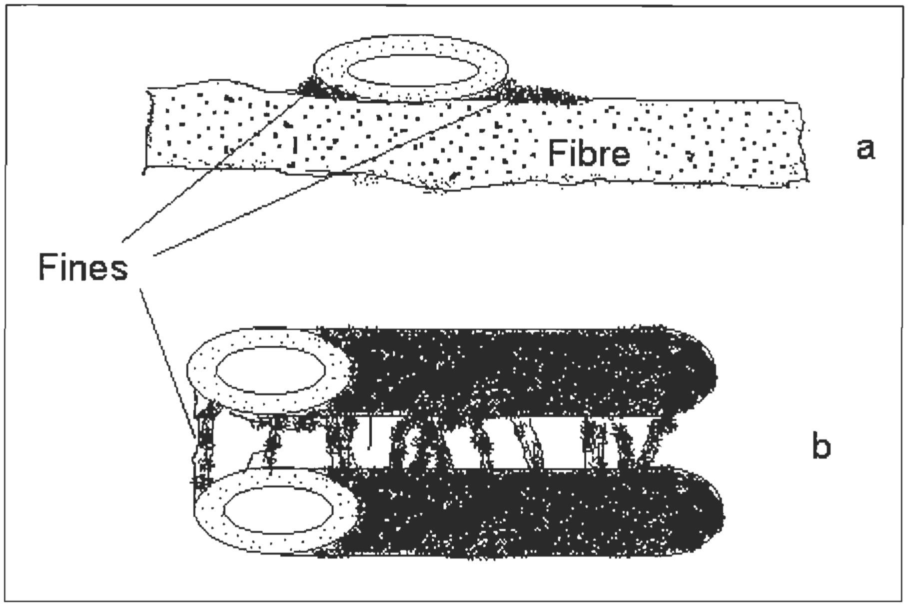


Figure 8.4 Strengthening effects of the fines from chemical (a) and mechanical pulps (b) [120].

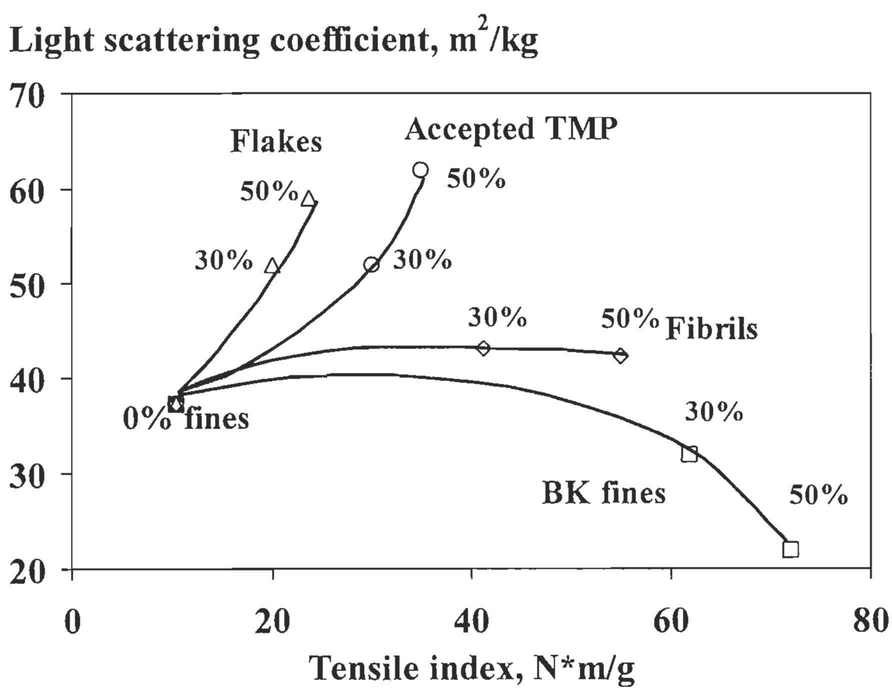


Figure 8.5 Effect of fines quantity and quality on tensile index and light scattering coefficient [113].

Flakes: P300/R400 of the TMP after the first-stage refiner; Fibrils: P300/R400 of the reject-refined pulp; BK: bleached kraft pine.

Retulainen *et al* [68, 120] proposed that the fines from chemical pulps strengthen the fibre-to-fibre bonding mainly by covering the fibre surfaces and filling the peripheral regions at fibre crossing points. This process improves largely the paper strength but decreases the light scattering (Figures 8.4a and 8.5). Being different from the chemical fines, the TMP fines bring fibres into closer contact, thus facilitating the bonding between the fibres while increasing the light scattering coefficient by augmenting the number of scattering sites into the sheet (Figure 8.4b and 8.5). The fibrils and flake-like particles of the TMP fines contribute differently to the strength and optical properties [113]. The fibrils increase largely the strength properties but with minor effect on light scattering. On the other hand, the flake-like particles improve significantly the light scattering but with little effect on strength properties. In view of this point, the tensile strength and light scattering are two relatively contrary properties.

The fines of white birch TMP contain lots of flake-like particles (e.g. ray cell, vessel fragments and fibre fragments) and behave like fillers, and thereby increase the light scattering but has little effect on the strength properties. As discussed previously, in the TMP process, the co-refining of white birch with black spruce did not change the characteristics of the fines generated from the white birch. On the contrary, the fines of the reference CTMPs were modified due to the introduction of the sulfonic groups into the lignin. The increase in hydrodynamic specific volume of the P200 fraction was remarkable for the CTMPs compared to the TMPs, except for the pulps made from 100% white birch (Figure 8.6). Figures 8.7 and 8.8 show that the augmentation of fines content of TMP increases both the tensile index and the light scattering coefficient. Otherwise the augmentation of fines of CTMP increased the tensile index but with little influence on the light scattering coefficient. It seems that the fines of the CTMP contribute more to the reinforcement of bonging between the fibres than to increase the number of scattering site. Thereby the CTMPs of 100% black spruce and the chip mixtures have a tensile index superior to that of the corresponding TMPs but with a lower light scattering coefficient (Figure 8.1).

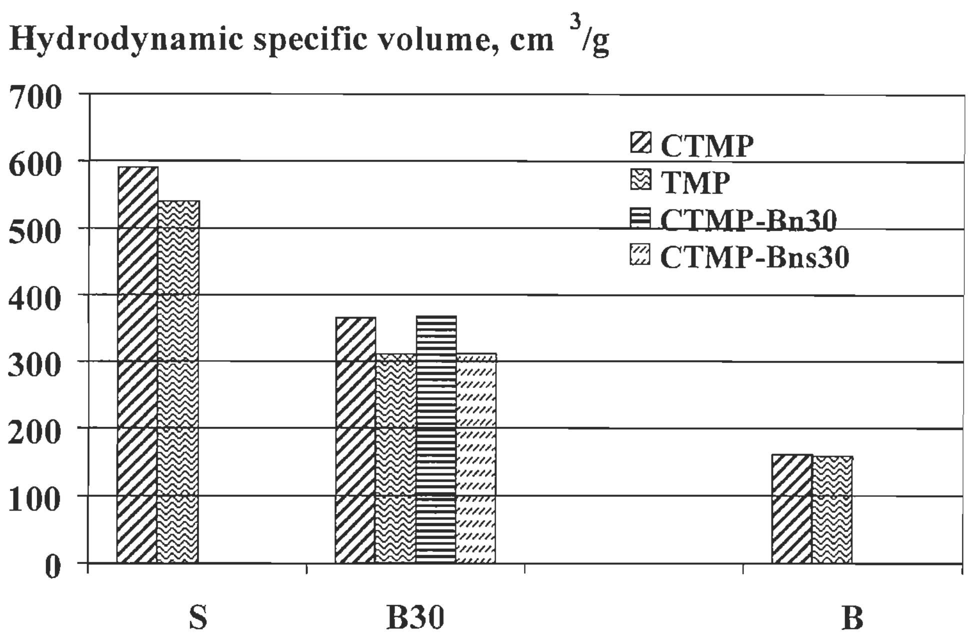


Figure 8.6 Hydrodynamic specific volume of the P200 fraction.

The chemical pre-treatment of white birch prior to mixing with black spruce followed by co-refining is a compromised alternative to improve the strength properties by modifying the quality of white birch fibres while reducing the loss of light scattering due to the absence of alkaline treatment on black spruce fibres. From Figure 8.1, an increase of the light scattering coefficient is noted when the white birch chips were pre-treated with alkali-sulfite or alkali alone prior to blending with the untreated black spruce chips (CTMP-Bn30 and CTMP-Bns30 compared to CTMP-B30). Some improvement in light scattering coefficient can also be observed on the CTMP-Bn30 and the CTMP-Bns30 compared to the CTMP-B30 at a given level of fines content (Figure 8.8).

8.3 Linting propensity

As discussed previously, improvement in fibre flexibility of white birch was noticed on the short-fibre fraction (R48 and R100) due to the use of chemicals. As a result, the strength and density of the handsheets were improved. Thereby, the CTMP-B had a linting propensity much lower than that of the TMP-B. At the same time, the amount of removed long fibres and short fibres during the linting test decreased from 20% to less than 10% (Figure 8.8). On the other hand, the using of chemicals during refining had little effect on the linting propensity for black spruce. For both the TMP and the CTMP, blending white birch with black spruce influenced slightly the linting propensity when compared to TMP-S.

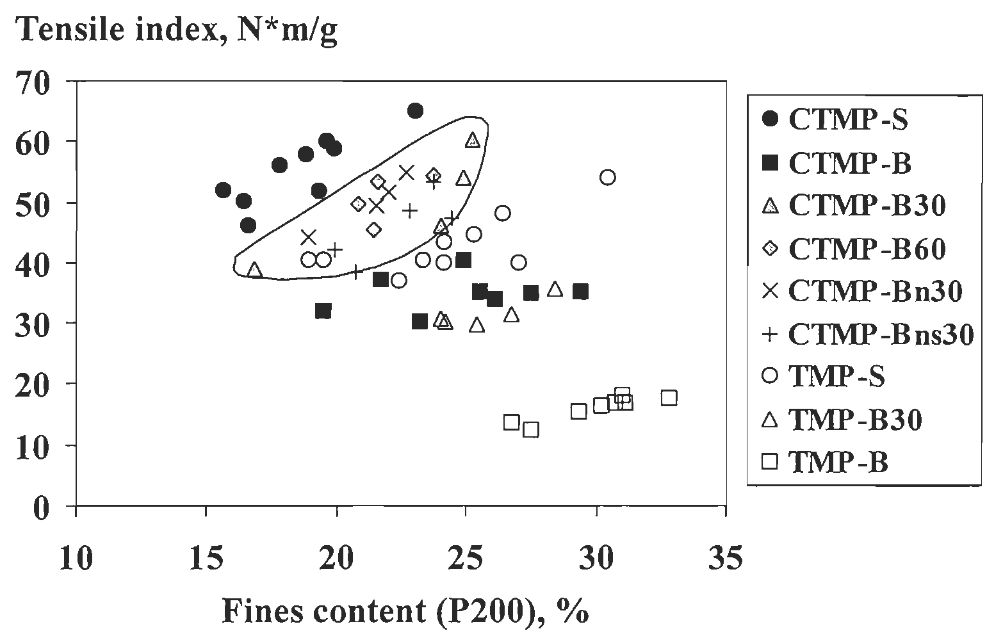


Figure 8.7 Effect of fines quantity on tensile index.

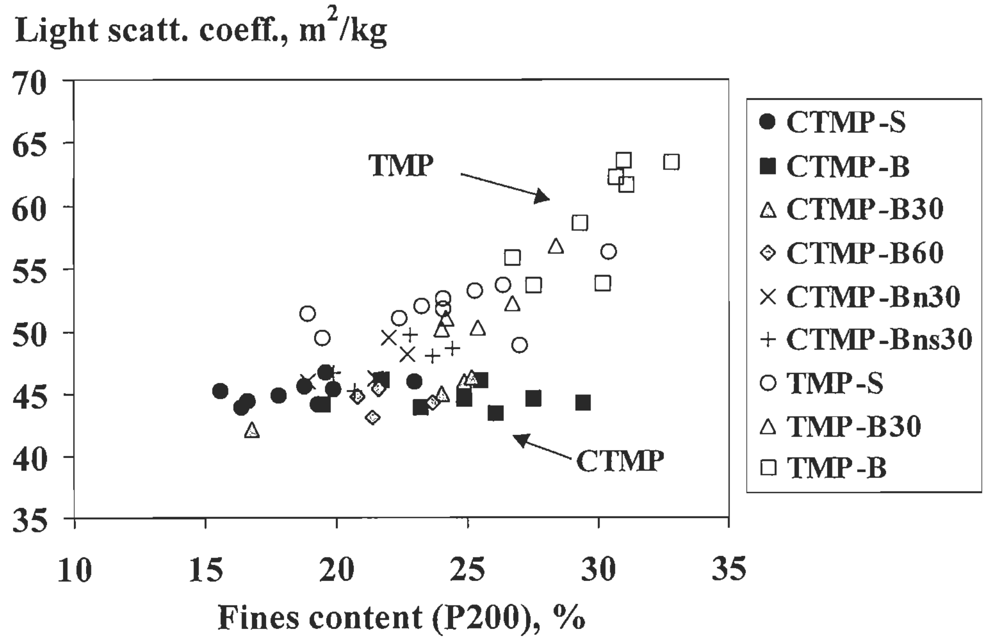


Figure 8.8 Effects of fines quantity on light scattering coefficient.

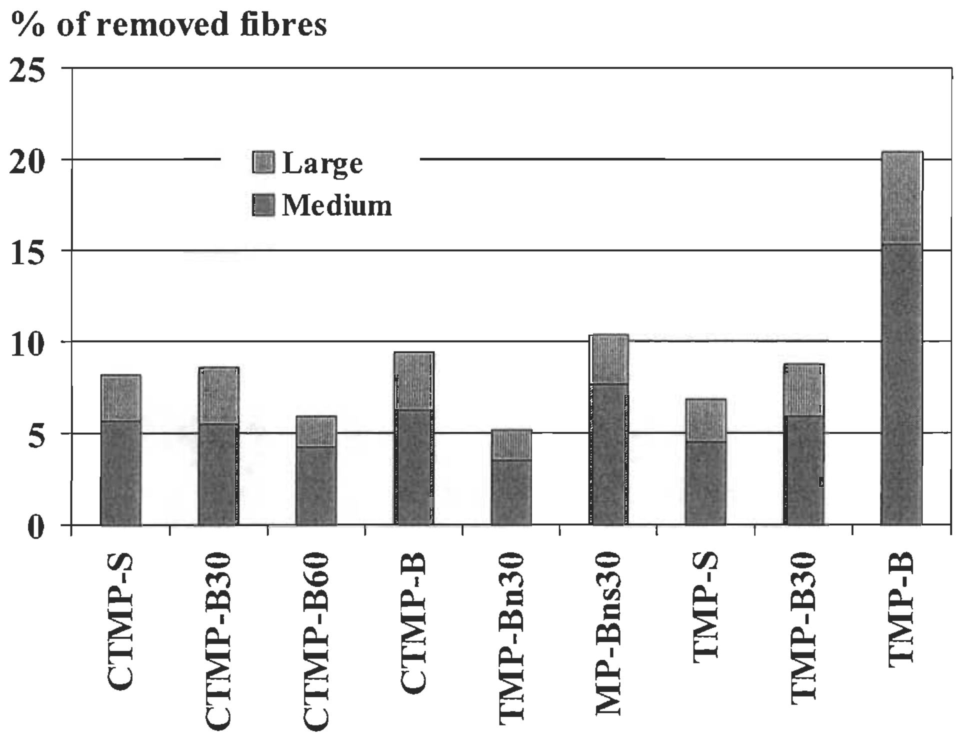


Figure 8.9 Distribution of removed fibres during linting test.

Chapter 9 - CONCLUSION

The chip mixtures containing up to 20% white birch decreased slightly the tear, tensile and burst strength for TMP. Higher substitution up to 40% white birch decreased largely the strength properties of the pulps, when compared with the TMP-S. The main advantages resulting from the use of white birch were increases in scattering coefficient and brightness.

In the CTMP process, the use of chemicals improved largely the bonding potential of white birch fibres, thus producing pulps with better strength from the chip mixtures. The main disadvantage was the reduction in light scattering. Refining of chemical pre-treated white birch with untreated black spruce produced pulps with reasonable good strength quality, while minimizing the loss of light scattering. The substitution degree of black spruce by white birch was less important for CTMP compared to TMP in terms of pulp strength properties and fibre properties.

Due to morphological differences between white birch and black spruce, the coarseness and water retention value become less meaningful for evaluating the effect of white birch and chemicals used on the fibre development during co-refining. In this case, the fibre flexibility and hydrodynamic specific volume as well as the microscopic feature become much more important for explaining the fibre behaviours in co-refining. The main conclusions are summarized as follows:

1. White birch has a poorer fibre development (such as delamination and fibrillation) in refining than that of black spruce without the help of chemicals. Although little difference in fibre stiffness and fibrillation was observed in the long-fibre fraction of the TMP-B and the TMP-S shown by microscopic observation, large improvement in the fibrils content can be found in the short-fibre and fines fractions of the TMP-S but not of the TMP-B. These observations were in accordance with the measurements of fibre flexibility and hydrodynamic specific volume. These characteristics provoked the low strength properties of the TMP-B but with superior light scattering coefficient.

2. The Bauer-McNett classification of TMP showed that there was a decrease in long-fibre content when white birch was used in the chip mixtures. On the other hand, the incorporating of white birch increased the short-fibre content but had no significant effect on fines content, at a given refining energy consumption. Blending white birch with black spruce for producing TMP had a little influence on the long fibre qualities, but decreased largely the short fibre and especially the fines qualities, as measured by the flexibility and hydrodynamic specific volume. These influences were well in agreement with microscopic observations. It seems that the co-refining of chip mixtures without chemicals did not change the nature of fibre development for both the white birch and the black spruce fibres. This means that the two species behave independently. However, a synergetic effect on the RBA of the R200 was found when the white birch and black spruce were refining together, probably due to the impact of a small amount of vessel fragments on the fibres bonding.

3. The thermomechanical pulps from chip mixtures containing up to 40% of white birch required lower refining energy when compared to the 100% white birch. This energy requirement was, however, similar to that for the black spruce TMP.

4. The thermomechanical pulps from chip mixtures containing up to 20% of white birch had a tear strength similar to that of the 100% black spruce TMP, while the tensile and burst strengths were slightly lower. Increased substitution up to 40% white birch decreased much largely the strength properties of the pulps, when compared with the black spruce TMP. The main advantage resulting from the use of white birch was slight increases in scattering coefficient and brightness.

5. The TMP of 100% white birch may have a linting problem when being used as one of the components of newsprint furnish. Using up to 40% of white birch increased slightly the linting propensity when compared to the TMP-S. The slight increase in linting propensity was probably due to the fact that the negative effect of a certain amount of the vessel fragments might be compensated by the high quality fibres and fines from black spruce.

6. In the CTMP process, white birch gained more in fibre flexibility and collapsibility, thus increasing fibre-bonding potentials when compared to black spruce. Unfortunately, the higher light scattering property of the TMP was lost due to the use of chemicals, especially for white birch.

7. In the CTMP process, the use of white birch decreased the long-fibre content and increased the short-fibre and the fines contents. Similar to the TMP, the use of white birch had a little influence on the long fibre qualities, but it decreased the short fibre and especially the fine qualities, as measured by the flexibility and hydrodynamic specific volume. These reductions were not as high as what is found in the TMP since the use of chemicals improved largely the white birch qualities, such as fibre flexibility. And again, these changes were affected marginally by the replacement degree 30% to 60%. It seems that there is a positive effect in blending white birch with black spruce to produce CTMP due to the benefits from the chemical treatment and the protection on the white birch fibres against fibre-cutting from the black spruce fibres during co-refining.

8. The chemithermomechanical pulps from chip mixtures containing up to 60% of white birch had a refining energy requirement slightly lower than that of the 100% black spruce CTMP but higher than that of the 100% white birch CTMP and the 100% black spruce TMP. Alkali-sulfite pre-treatment of white birch prior to blending with untreated black spruce followed by co-refining without chemicals prevents the increases in refining energy consumption.

9. Alkaline pre-treatment of white birch prior to mixing with black spruce followed by co-refining with the addition of sodium sulfite softens the white birch chips and render the reduction in rejects when compared to the controlled CTMP..

10. The CTMPs of the chip mixtures had tensile, tear and burst strength comparable to those of 100% black spruce TMP, although a little lower than those of 100% black spruce CTMP. The main disadvantage of using chemicals was the reduction in light scattering. Both the substitution degree (30 to 60%) and the chemical pre-treatment

of white birch chips prior to mixing with untreated black spruce chips yielded little effect on pulp strength.

11. The chemical pre-treatment of white birch prior to mixing with black spruce followed by co-refining is a compromised alternative to improve the strength properties by modifying the quality of white birch fibres while reducing the loss of light scattering due to the absence of alkaline treatment on the black spruce fibres. This implies that it is possible to increase the substitution of white birch in black spruce to keep a balance of pulp qualities (strength and optical properties) when the white birch chips are pre-treated by chemicals prior to mixing with black spruce and followed by a co-refining without chemicals.

12. A significant reduction in linting was achieved for the CTMP-B in comparison with the TMP-B due to the use of chemicals. Similar to the TMP, using up to 60% of white birch for producing CTMP had little influence on the linting propensity as compared to the CTMP-S.

FUTURE WORK

1. Composition of shives

This study has determined the relative amount of the shives and the aggregates in the rejects. But this is not enough to better understand the behaviors of fibres in refining and co-refining. The quantitative analysis of the birch and spruce fibres in the shives and the aggregates by the microscopic observation will be useful to complete the explanation of the co-refining mechanism.

2. Sulfonic groups

The measurement of sulfonic groups in the CTMP pulps and their fractions will help to better understand the influence of using chemicals on improving fibre flexibility and fines bonding potential.

3. Exploring the strategies of co-refining

To enlarge the utilization of birch in the high-yield pulps, some other strategies are worth doing: birch receives a preliminary refining treatment instead of chemical pre-treatment prior to a co-refining operation with spruce. In this case, the plates with different forms could be tried to find the optimum pre-refining operation of birch.

Appendix A - EXPERIMENTAL DATA

Part 1	Fibre properties:	Table A.1 to Table A.6 (TMP)
		Table A.7 to Table A.10 (CTMP)
Part 2	Handsheet properties:	Table A.11 to Table A.16 (TMP)
		Table A.17 to Table A.20 (CTMP)
Part 3	Linting propensity:	Tables A.21 and A.22
Part 4	Fibre and fines properties:	Table A.23 to Table A.29

Table A.1 Fibre characteristics of 100% black spruce TMP.

Code	TMP-S					TMP-S, repeat				
Number	1	3	4	5	6	2	4	5	6	7
SEC, MJ/kg	8,55	8,67	9,61	9,60	13,63	7,75	8,79	8,96	11,76	14,81
Freeness, ml	161	167	141	133	96	222	180	184	136	46
Bauer-McNett fractions, %										
R 14	19	17,5	19,1	18,3	16,1	19,2	20,2	19,2	18	12,7
14/28	32,3	28,6	32,2	28,6	27,7	30,4	30	29,9	29,6	28,1
28/48	15,5	14,5	15,7	15,2	15,4	14,8	12,9	13	12,7	12,7
48/100	8,5	7,6	8,8	8,7	8,9	8,3	10,6	10,7	11,1	12,2
100/200	5,2	4,8	5,3	5,1	5,5	4,9	3	3,1	3,3	3,9
P 200	19,5	27	18,9	24,1	26,4	22,4	23,3	24,1	25,3	30,4
Long-fibre fraction (+28)	51,3	46,1	51,3	46,9	43,8	49,6	50,2	49,1	47,6	40,8
Short-fibre fraction (28/200)	29,2	26,9	29,8	29	29,8	28	26,5	26,8	27,1	28,8
Fines fraction (P200)	19,5	27,0	18,9	24,1	26,4	22,4	23,3	24,1	25,3	30,4
Rejects (Pulmac 0,10 mm), %	0,9302	1,0653	1,0639	0,9845	0,7325	1,3069	1,0995	1,1032	0,9889	0,5997
Fibre length (lw, FQA), mm	1,879	1,918	1,875	1,923	1,838	1,99	1,93	1,92	1,83	1,72
Coarseness, mg/m	0,223	0,225	0,238	0,225	0,224	0,242	0,248	0,227	0,226	0,216

Table A.2 Fibre characteristics of 100% white birch TMP.

Code	TMP-B					TMP-B, repeat		
Number	**5**	**6**	**7**	**8**	**9**	**3**	**4**	**5**
SEC, MJ/kg	9,82	9,95	10,88	12,85	12,39	10,08	12,19	12,29
Freeness, ml	242	208	160	124	112	130	115	101
Bauer-McNett fractions, %								
R 14	0,2	0,2	0,2	0,2	0,2	0,1	0,1	0,1
14/28	12,9	12,9	10,7	9,0	6,2	9,0	7,8	5,5
28/48	33,0	32,6	32,0	31,3	30,7	31,6	31,1	28,5
48/100	18,4	19,5	19,3	19,4	21,8	20,1	21	22,7
100/200	8.0	8,1	8,5	9,0	10,1	9,0	9,3	10,4
P 200	27,5	26,7	29,3	31,1	31	30,2	30,7	32,8
Long-fibre fraction (+28)	13,1	13,1	10,9	9,2	6,4	9,1	7,9	5,6
Short-fibre fraction (28/200)	59,4	60,2	59,8	59,7	62,6	60,7	61,4	61,6
Fines fraction (P200)	27,5	26,7	29,3	31,1	31	30,2	30,7	32,8
Rejects (Pulmac 0,10 mm), %	1,1682	0,8371	0,6115	0,308	0,1942	0,2481	0,2093	0,1454
Fibre length (lw, FQA), mm	0,982	0,958	0,946	0,905	0,858	0,909	0,898	0,835
Coarseness, mg/m	0,188	0,182	0,176	0,178	0,164	0,178	0,179	-

Table A.3 Fibre characteristics of TMP from 10% B / 90% S chip mixture.

Code	TMP-B10				
Number	**3**	**4**	**5**	**6**	**7**
Energy, MJ/kg	8,04	9,19	9,19	11,80	14,20
Freeness, ml	210	167	151	124	49
Bauer-McNett fractions, %					
R 14	19,5	16,9	17,9	15,5	12,3
14/28	33,0	30,8	30,7	29,9	27,0
28/48	17,4	16,3	3,8	4,0	3,7
48/100	9,4	8,8	21,7	21,9	22,0
100/200	5,2	5,1	3,1	3,5	3,6
P 200	15,5	22,1	22,8	25,2	31,4
Long-fibre fraction (+28)	52,5	47,7	48,6	45,4	39,3
Short-fibre fraction (28/200)	32	30,2	28,6	29,4	29,3
Fines fraction (P200)	15,5	22,1	22,8	25,2	31,4
Rejects (Pulmac 0,10 mm), %	1,4975	1,49265	1,2899	1,05165	0,63895
Fibre length (lw, FQA), mm	1,88	1,89	1,81	1,82	1,69
Coarseness, mg/m	0,24	0,23	0,24	0,22	0,21

Table A.4 Fibre characteristics of TMP from 20% B / 80% S chip mixture.

Code	TMP-B20					TMP-B20, repeat				
Number	**2**	**4**	**5**	**6**	**7**	**3**	**4**	**5**	**6**	**7**
SEC, MJ/kg	6,97	8,22	8,21	12,38	16,62	7,18	8,29	8,46	10,19	13,71
Freeness, ml	217	172	164	99	42	243	197	143	165	73
Bauer-McNett fractions , %										
R 14	14,5	13,9	13,5	11,7	8,1	16,5	16,6	19,9	13,4	9,1
14/28	30,7	28,6	29,7	28,6	26,5	32,2	31,4	28,4	29	26,8
28/48	17,9	17,3	18,1	18,5	17,4	4,4	4,6	9,4	4,5	4,0
48/100	10,4	9,9	10,9	11,3	11,5	24,4	24,1	13,5	24,3	24,8
100/200	5,5	5,3	5,9	6,1	6,6	3,6	3,7	2,3	3,8	3,9
P 200	21	25	21,9	23,8	29,9	18,9	19,6	26,5	25,0	31,4
Long-fibre fraction (+28)	45,2	42,5	43,2	40,3	34,6	48,7	48,0	48,3	42,4	35,9
Short-fibre fraction (28/200)	33,8	32,5	34,9	35,9	35,5	32,4	32,4	25,2	32,6	32,7
Fines fraction (P200)	21,0	25,0	21,9	23,8	29,9	18,9	19,6	26,5	25,0	31,4
Rejects (Pulmac 0,10 mm), %	1,8726	1,6939	1,42	1,01295	0,55695	2,2009	2,0099	1,0209	1,3258	0,6626
Fibre length (lw, FQA), mm	1,729	1,694	1,697	1,614	1,593	1,742	1,762	1,867	1,688	1,559
Coarseness, mg/m	0,228	0,229	0,229	0,218	0,206	0,253	0,246	0,242	0,229	0,221

Table A.5 Fibre characteristics of TMP from 30% B / 70% S chip mixture.

Code	TMP-B30					TMP-Bt30				
Number	**2**	**3**	**4**	**5**	**6**	**2**	**3**	**4**	**5**	**6**
SEC, MJ/kg	7,64	7,59	8,71	8,91	11,65	7,57	7,94	9,20	9,46	14,23
Freeness, ml	183	177	159	158	106	245	238	187	159	98
Bauer-McNett fractions, %										
R 14	11,7	11,4	11,0	10,9	9,8	13,4	13,3	14,2	13,0	10,2
14/28	29,5	29,8	29,7	28,2	26,4	31,4	30,5	29,0	27,6	25,5
28/48	13,2	14,0	14,4	14,2	14,3	21,6	21,0	20,8	20,0	20,4
48/100	17,2	17,0	17,5	16,7	17,2	10,9	10,6	10,6	10,6	10,9
100/200	3,0	3,6	3,4	3,3	3,9	5,0	5,4	5,5	5,6	6,0
P 200	25,4	24,2	24,0	26,7	28,4	17,7	19,2	19,9	23,2	27,0
Long-fibre fraction (+28)	41,2	41,2	40,7	39,1	36,2	44,8	43,8	43,2	40,6	35,7
Short-fibre fraction (28/200)	33,4	34,6	35,3	34,2	35,4	37,5	37	36,9	36,2	37,3
Fines fraction (P200)	25,4	24,2	24	26,7	28,4	17,7	19,2	19,9	23,2	27
Rejects (Pulmac 0,10 mm), %	1,6894	1,7872	1,7768	1,6955	1,1622	1,5868	1,5285	1,1804	0,9837	0,7020
Fibre length (lw, FQA), mm	1,618	1,565	1,625	1,587	1,517	1,618	1,672	1,633	1,608	1,573
Coarseness, mg/m	0,230	0,224	0,224	0,215	0,222	0,242	0,244	0,233	0,231	0,226

Table A.6 Fibre characteristics of TMP from 40% B / 60% S chip mixture.

Code	TMP-B40					TMP-B40, repeat				
Number	2	3	4	5	6	3	4	5	6	7
SEC, MJ/kg	7,54	7,66	9,00	9,53	13,45	7,77	9,79	8,92	10,40	15,62
Freeness, ml	209	206	172	155	88	200	177	161	134	63
Bauer-McNett fractions, %										
R 14	8,4	10,4	8,9	7,8	6,3	9,2	9,8	9,0	8,3	5,8
14/28	29,7	30,8	29,2	28,6	26,4	30,1	30,4	27,5	27,7	25,3
28/48	16,2	16,4	18,1	18,8	17,8	21,5	21,7	20,9	21,2	21,3
48/100	17,5	18,3	16,5	16,2	16	11,2	12,3	12,0	12,3	12,8
100/200	3,5	3,4	4,2	4,5	4,3	6,0	6,6	6,3	6,4	7,4
P 200	24,7	20,7	23,1	24,1	29,2	22,0	19,2	24,3	24,1	27,4
Long-fibre fraction (+28)	38,1	41,2	38,1	36,4	32,7	39,3	40,2	36,5	36,0	31,1
Short-fibre fraction (28/200)	37,2	38,1	38,8	39,5	38,1	38,7	40,6	39,2	39,9	41,5
Fines fraction (P200)	24,7	20,7	23,1	24,1	29,2	22,0	19,2	24,3	24,1	27,4
Rejects (Pulmac 0,10 mm), %	2,1487	2,12915	1,7191	1,49895	1,08015	1,9826	1,74405	1,6721	1,2905	0,9133
Fibre length (lw, FQA), mm	1,576	1,544	1,514	1,483	1,399	1,541	1,536	1,502	1,441	1,392
Coarseness, mg/m	0,217	0,232	0,222	0,210	0,205	0,231	0,219	0,224	0,217	0,201

Table A.7 Fibre properties of 100% black spruce CTMP.

Code	CTMP-S				CTMP-S, repeat				
Number	**4**	**5**	**6**	**7**	**4**	**5**	**6**	**7**	**8**
SEC, MJ/kg	12,93	13,04	14,16	14,72	11,35	13,31	14,03	16,35	17,27
Freeness (CSF), ml	164	206	130	107	210	145	132	93	78
Bauer-McNett fractions, %									
R14	27,9	29,5	27,7	25,5	31,5	30,9	28,2	27,1	24
P14/R28	28,7	29,4	29	29,1	28,5	28,8	27,5	27,6	27,4
R28/P48	10,2	11,1	13,8	14,3	13,1	13,5	13,2	13,5	13,4
R48/P100	10,1	9,9	7,4	7,8	6,7	7,3	7,2	7,5	7,6
R100/P200	3,8	3,7	4,3	4,5	3,6	3,9	4,0	4,7	4,6
P 200	19,3	16,4	17,8	18,8	16,6	15,6	19,9	19,6	23
Long-fibre fraction (R14+R28), %	56,6	58,9	56,7	54,6	60	59,7	55,7	54,7	51,4
Short-fibre fraction (P28/R200), %	24,1	24,7	25,5	26,6	23,4	24,7	24,4	25,7	25,6
Fines fraction (P200), %	19,3	16,4	17,8	18,8	16,6	15,6	19,9	19,6	23
Rejects (Pulmac 0,10 mm), %	-	-	-	-	0,221	0,217	0,145	0,083	0,035
Fibre average length (lw, FQA), mm	2,012	2,100	2,045	1,995	2,070	2,060	2,055	1,995	1,954
WRV, %	262	256	267	306	246	247	289	295	392

Table A.8 Fibre properties of 100% white birch CTMP.

Code	CTMP-B				CTMP-B, repeat			
Number	**3**	**8**	**9**	**10**	**6**	**7**	**8**	**9**
SEC, MJ/kg	9,33	11,22	12,07	12,79	11,12	11,20	11,85	12,72
Freeness (CSF), ml	175	127	129	76	152 (123)	143	143	107
Bauer-McNett fractions, %								
R14	1,8	2,9	3,3	2,6	3,4	2,5	2	2
P14/R28	29,2	28,8	27,8	26,4	28,4	28,1	26,5	26,2
R28/P48	29,5	27,4	25,2	26,4	25,6	25,2	24,4	25,3
R48/P100	14,5	13,6	12,5	13,8	13,5	12,2	11,8	13
R100/P200	5,5	5,6	5,7	5,9	5,9	5,9	5,9	6
P 200	19,5	21,7	25,5	24,9	23,2	26,1	29,4	27,5
Long-fibre fraction (R14+R28), %	31	31,7	31,1	29	31,8	30,6	28,5	28,2
Short-fibre fraction (P28/R200), %	49,5	46,6	43,4	46,1	45	43,3	42,1	44,3
Fines fraction (P200), %	19,5	21,7	25,5	24,9	23,2	26,1	29,4	27,5
Rejects (Pulmac 0,10 mm), %	0,462	0,310	0,321	0,171	0,389	0,279	0,429	0,295
Fibre average length (lw, FQA), mm	1,154	1,144	1,161	1,127	1,158	1,155	1,145	1,121
WRV, %	276	370	286	-	281	283	340	433

Table A.9 Fibre properties of CTMP made from chip mixtures.

Code	CTMP-B30				CTMP-B60			
Number	5	6	7	8	6	7	8	9
SEC, MJ/kg	9,99	12,59	15,77	16,64	12,68	14,43	15,18	16,43
Freeness (CSF), ml	277	168	84	66	146	110	90	78
Bauer-McNett fractions, %								
R14	24,5	22,1	22,2	19,8	22,1	21,8	21,7	18,2
P14/R28	29,3	26,5	26,4	26,6	27,0	26,8	27,0	26,8
R28/P48	17,4	15,7	14,9	15,8	17,2	17,0	16,3	17,3
R48/P100	8,4	7,8	7,5	8,2	8,3	9,4	9,1	9,3
R100/P200	3,6	3,9	4,1	4,4	4,0	4,2	4,3	4,7
P 200	16,8	24,0	24,9	25,2	21,4	20,8	21,6	23,7
Long-fibre fraction (R14+R28), %	53,8	48,6	48,6	46,4	49,1	48,6	48,7	45,0
Short-fibre fraction (P28/R200), %	29,4	27,4	26,5	28,4	29,5	30,6	29,7	31,3
Fines fraction (P200), %	16,8	24	24,9	25,2	21,4	20,8	21,6	23,7
Rejects (Pulmac 0,10 mm), %	0,407	0,564	0,444	0,394	0,775	0,628	0,398	0,317
Fibre average length (lw, FQA), mm	1,827	1,693	1,618	1,614	1,647	1,676	1,646	1,573
WRV, %	-	-	-	381	-	290	345	339

Table A.10 Fibre properties of CTMP made from chip mixtures containing 30% treated white birch.

Code	CTMP-Bn30				CTMP-Bns30				
Number	**6**	**7**	**8**	**9**	**2**	**5**	**6**	**7**	**8**
SEC, MJ/kg	11,79	14,25	14,39	15,90	9,80	10,92	12,29	12,79	13,20
Freeness (CSF), ml	177	113	87	84	198	157	122	99	83
Bauer-McNett fractions, %									
R14	22,4	20,8	19,4	17,7	19,8	21,6	20,6	19,9	16,7
P14/R28	29,2	28,4	28,3	29	30,4	28,9	26,8	27,3	28
R28/P48	16,9	16,8	16,9	17,9	16,8	17,2	16,1	16,9	18
R48/P100	8,8	8,5	8,5	9,1	8,3	8,2	7,9	8,5	8,9
R100/P200	3,8	4,0	4,2	4,3	4,0	4,2	4,2	4,6	4,7
P 200	18,9	21,5	22,7	22	20,7	19,9	24,4	22,8	23,7
Long-fibre fraction (R14+R28), %	51,6	49,2	47,7	46,7	50,2	50,5	47,4	47,2	44,7
Short-fibre fraction (P28/R200), %	29,5	29,3	29,6	31,3	29,1	29,6	28,2	30,0	31,6
Fines fraction (P200), %	18,9	21,5	22,7	22	20,7	19,9	24,4	22,8	23,7
Rejects (Pulmac 0,10 mm), %	0,360	0,181	0,167	0,042	0,749	0,606	0,619	0,490	0,424
Fibre average length (lw, FQA), mm	1,810	1,721	1,695	1,665	1,808	1,760	1,764	1,718	1,684
WRV, %	273	303	316	351	249	265	281	279	323

Table A.11 Handsheet properties of 100% black spruce TMP.

Code	TMP-S					TMP-S, repeat				
Number	**1**	**3**	**4**	**5**	**6**	**2**	**4**	**5**	**6**	**7**
Grammage, g/m^2	60,9	60,6	60,7	59,9	60,5	59,0	60,7	59,3	60,7	59,6
Specific volume, cm^3/g	3,02	2,98	3,06	3,07	2,73	3,28	3,15	3,06	2,99	2,52
Density, g/cm^3	0,33	0,34	0,33	0,33	0,37	0,30	0,32	0,33	0,33	0,40
Breaking length, km	4,12	4,08	4,14	4,44	4,92	3,77	4,13	4,07	4,55	5,52
Stretch, %	1,94	1,98	1,93	1,90	2,11	1,79	1,92	1,83	2,13	2,18
TEA, J/m^2	32,06	32,17	31,82	33,30	41,64	26,16	31,70	28,74	39,09	47,52
Burst index, kPa*m^2/g	2,46	2,45	2,55	2,61	2,91	2,11	2,29	2,34	2,58	3,45
Tear index, mN*m^2/g	10,03	10,10	10,75	10,03	9,74	10,96	10,96	9,95	10,91	9,12
Tensile index, N*m/g	40,44	39,99	40,57	43,50	48,26	36,95	40,50	39,90	44,61	54,14
Roughness, µm	7,38	8,05	7,88	7,53	7,16	7,79	7,62	7,50	7,54	6,61
Porosity, ml /min	602	560	438	356	174	1106	708	603	357	56
Brightness (8-457nm), %	52,6	53,1	53,2	53,1	53,4	53,2	53,3	53,3	53,8	53,0
Opacity, %	94,8	94,3	95,2	95,0	95,6	93,8	94,9	94,6	95,3	96,3
Scattering Coef., m^2/kg	49,4	48,8	51,4	51,7	53,7	51,0	48,8	52,6	53,2	56,3
Absorp. Coef., m^2/kg	3,8	3,5	3,8	3,8	4,0	3,9	3,5	3,9	3,8	4,4

Table A.12 Handsheet properties of 100% white birch TMP.

Code	TMP-B					TMP-B, repeat		
Number	**5**	**6**	**7**	**8**	**9**	**3**	**4**	**5**
Grammage, g/m^2	60,2	59,6	58,8	60,2	60,8	60,0	59,9	60,5
Specific volume, cm^3/g	3,77	3,67	3,48	3,44	3,31	3,53	3,36	3,21
Density, g/cm^3	0,26	0,27	0,29	0,29	0,30	0,28	0,30	0,31
Breaking length, km	1,25	1,40	1,57	1,71	1,84	1,67	1,72	1,81
Stretch, %	0,81	0,85	0,93	0,97	1,02	1,00	0,96	0,97
TEA, J/m^2	3,80	4,39	5,44	6,18	7,11	6,36	6,16	6,69
Burst index, $kPa*m^2/g$	0,43	0,49	0,60	0,66	0,67	0,62	0,63	0,68
Tear index, $mN*m^2/g$	2,59	2,54	2,92	3,07	3,10	2,28	2,91	2,83
Tensile index, N*m/g	12,31	13,71	15,41	16,81	18,00	16,37	16,86	17,72
Roughness, µm	8,09	7,98	7,57	7,34	7,47	7,38	7,24	7,04
Porosity, ml/min	2669	2557	2243	1957	1698	2147	1940	1785
Brightness (8-457nm), %	55,4	55,8	56,0	56,4	56,1	57,0	57,2	57,1
Opacity, %	95,6	95,8	96,2	96,8	97,3	96,4	96,6	97,0
Scattering coef., m^2/kg	53,7	55,9	58,6	61,6	63,6	53,8	62,3	63,4
Absorption coef., m^2/kg	4,0	4,0	4,2	4,3	4,6	4,0	4,0	4,3

Table A.13 Handsheet properties of TMP from 10% B / 90% S chip mixture.

Code	TMP-B10				
Number	**3**	**4**	**5**	**6**	**7**
Grammage, g/m^2	61,9	59,6	60,9	61,7	60,4
Specific volume, cm^3/g	3,24	3,12	3,13	2,95	2,72
Density, g/cm^3	0,31	0,32	0,32	0,34	0,37
Breaking length, km	3,56	4,05	4,15	4,29	5,21
Stretch, %	1,88	1,94	2,00	1,96	2,37
TEA, J/m^2	27,36	30,92	33,57	33,90	49,81
Burst index, kPa*m^2/g	1,95	2,20	2,35	2,56	3,06
Tear index, mN*m^2/g	10,70	10,93	11,76	10,03	9,25
Tensile index, N*m/g	34,90	39,67	40,73	42,10	51,05
Roughness, µm	8,38	8,17	8,08	7,68	7,43
Porosity, ml/min	1556	865	667	355	89
Brightness (8-457nm), %	53,4	53,4	54,1	54,1	54,2
Opacity, %	94,2	94,5	94,9	95,3	96,5
Scattering coef., m^2/kg	47,2	49,8	51,4	52,3	58,8
Absorption coef., m^2/kg	3,4	3,7	3,6	3,6	4,3

Table A.14 Handsheet properties of TMP from 20% B / 80% S chip mixture.

Code	TMP-B20					TMP-B20, repeat				
Number	2	4	5	6	7	3	4	5	6	7
Grammage, g/m^2	59,6	60,0	60,6	60,2	60,5	62,9	60,4	59,3	63,6	62,2
Specific volume, cm^3/g	3,30	3,13	3,25	3,02	2,60	3,63	3,36	3,04	3,09	2,83
Density, g/cm^3	0,30	0,32	0,31	0,33	0,38	0,28	0,30	0,33	0,32	0,35
Breaking length, km	3,09	3,55	3,61	4,12	5,07	3,60	3,62	4,28	3,14	2,86
Stretch, %	1,46	1,64	1,74	1,94	2,00	2,12	1,82	1,93	1,64	1,46
TEA, J/m^2	17,35	22,59	25,02	32,13	40,56	37,42	26,37	31,95	21,50	16,82
Burst index, kPa*m^2/g	1,70	1,96	1,98	2,33	3,20	1,36	1,78	2,69	1,87	2,51
Tear index, mN*m^2/g	9,05	9,15	9,64	9,46	8,70	9,28	10,29	11,72	9,87	9,31
Tensile index, N*m/g	30,31	34,79	35,36	40,37	49,68	35,35	35,46	41,99	30,79	28,02
Roughness, µm	8,14	7,81	7,98	7,64	6,61	9,04	8,34	8,04	8,37	7,56
Porosity, ml/min	1887	1018	1063	397	72	2427	1348	363	1020	165
Brightness (8-457nm), %	53,6	54,1	54,1	54,3	53,7	52,8	53,4	53,3	53,7	54,2
Opacity, %	94,2	94,4	94,8	95,4	96,6	94,6	94,7	94,9	95,5	96,8
Scattering coef., m^2/kg	49,3	50,5	51,3	54,3	58,0	46,9	49,9	51,8	50,5	59,1
Absorption coef., m^2/kg	3,5	3,5	3,6	3,8	4,5	3,5	3,6	3,9	3,6	4,3

Table A.15 Handsheet properties of TMP from 30% B / 70% S chip mixture.

Code	TMP-B30					TMP-Bt30				
Number	**2**	**3**	**4**	**5**	**6**	**2**	**3**	**5**	**6**	**7**
Grammage, g/m^2	61,2	61,5	62,2	61,0	61,5	60,4	59,6	60,4	59,8	61,7
Specific volume, cm^3/g	3,42	3,41	3,32	3,27	3,21	3,36	3,36	3,19	3,24	2,92
Density, g/cm^3	0,29	0,29	0,30	0,31	0,31	0,30	0,30	0,31	0,31	0,34
Breaking length, km	3,03	3,10	3,14	3,22	3,65	3,25	3,19	3,74	3,75	3,88
Stretch, %	1,56	1,57	1,61	1,63	1,67	1,51	1,49	1,68	1,69	1,47
TEA, J/m^2	18,86	19,60	20,51	20,88	24,21	19,22	18,32	24,94	24,92	22,14
Burst index, $kPa*m^2/g$	1,53	1,53	1,64	1,66	1,98	1,67	1,65	1,91	1,95	2,38
Tear index, $mN*m^2/g$	7,67	7,32	7,61	7,58	7,42	9,78	10,18	9,78	10,22	9,86
Tensile index, N*m/g	29,74	30,35	30,83	31,54	35,77	31,90	31,32	36,72	36,76	38,04
Roughness, µm	9,03	9,05	8,95	9,00	8,92	8,73	8,60	8,32	8,48	7,89
Porosity, ml/min	1489	1424	1128	1073	446	2483	2461	1646	1230	330
Brightness (8-457nm), %	53,6	53,5	53,2	53,6	54,1	53,0	52,5	53,1	53,5	53,7
Opacity, %	95,1	95,3	95,4	95,6	96,5	93,6	93,5	94,1	94,5	95,8
Scattering coef., m^2/kg	50,3	51,0	50,2	52,3	56,9	45,3	44,8	46,5	48,9	52,6
Absorption coef., m^2/kg	3,8	3,7	3,9	3,9	4,2	3,5	3,7	3,6	3,8	4,0

Table A.16 Handsheet properties of TMP from 40% B / 60% S chip mixture.

Code	TMP-B40					TMP-B40, repeat				
Number	**2**	**3**	**4**	**5**	**6**	**3**	**4**	**5**	**6**	**7**
Grammage, g/m^2	60,9	61,5	60,5	59,4	61,1	59,9	60,5	60,8	60,2	61,1
Specific volume, cm^3/g	3,55	3,62	3,42	3,42	3,15	3,49	2,93	3,28	3,29	2,83
Density, g/cm^3	0,28	0,28	0,29	0,29	0,32	0,29	0,34	0,30	0,30	0,35
Breaking length, km	2,64	2,58	3,05	3,00	3,47	2,73	3,17	3,19	3,38	3,96
Stretch, %	1,38	1,36	1,54	1,52	1,50	1,45	1,45	1,55	1,76	1,69
TEA, J/m^2	14,19	13,66	18,54	17,84	20,15	15,35	18,16	19,72	23,67	26,14
Burst index, $kPa*m^2/g$	1,32	1,22	1,47	1,50	1,88	1,32	1,68	1,64	1,66	2,24
Tear index, $mN*m^2/g$	6,99	6,99	7,64	6,87	6,63	6,80	7,11	7,39	7,28	6,67
Tensile index, N*m/g	25,87	25,35	29,92	29,41	34,02	26,75	31,13	31,31	33,13	38,80
Roughness, µm	7,92	8,09	7,82	7,72	7,12	7,83	6,82	7,71	7,46	6,66
Porosity, ml/min	1957	2000	1450	1287	402	1870	916	1060	951	224
Brightness (8-457nm), %	53,3	53,2	53,6	53,2	53,9	53,5	53,0	53,4	53,7	53,5
Opacity, %	95,3	95,3	95,6	95,8	96,8	94,7	95,1	95,8	95,6	97,0
Scattering coef., m^2/kg	50,8	50,4	52,9	53,4	57,9	50,1	49,9	53,3	53,0	58,8
Absorption coef., m^2/kg	3,9	3,9	4,0	4,4	4,6	3,7	4,0	4,1	4,0	4,7

Table A.17 Handsheet properties of 100% black spruce CTMP.

Code	CTMP-S				CTMP-S, repeat				
Number	**4**	**5**	**6**	**7**	**4**	**5**	**6**	**7**	**8**
Grammage, g/m^2	61,60	61,31	61,98	62,24	61,03	62,13	60,66	61,30	60,89
Specific volume, cm^3/g	2,77	2,71	2,54	2,47	2,96	2,78	2,54	2,44	2,36
Density, g/cm^3	0,36	0,37	0,39	0,40	0,34	0,36	0,39	0,41	0,42
Breaking length, km	5,28	5,11	5,73	5,91	4,72	5,30	5,99	6,12	6,63
Stretch, %	2,42	2,27	2,65	2,51	2,07	2,47	2,46	2,62	2,55
TEA, J/m^2	53,14	47,67	64,02	62,49	39,59	54,75	59,99	66,43	68,45
Burst index, kPa*m^2/g	3,23	3,08	3,54	3,61	2,91	3,38	3,74	3,98	4,18
Tear index, mN*m^2/g	12,83	12,43	11,67	11,11	13,80	12,46	11,03	10,52	9,71
Tensile index, N*m/g	51,82	50,08	56,21	57,92	46,27	51,94	58,77	60,06	64,97
Roughness, µm	7,98	7,98	7,62	7,64	8,16	8,01	7,68	7,60	7,40
Porosity, ml /min	272	270	220	134	754	262	176	103	58
Brightness (8-457nm), %	41,95	41,86	42,17	42,62	44,43	44,35	43,90	44,50	44,39
Opacity, %	94,91	94,84	95,08	95,13	94,23	94,70	94,64	94,82	94,64
Scattering Coef., m^2/kg	44,16	43,88	44,85	45,63	44,40	45,23	45,33	46,66	45,99
Absorption Coef., m^2/kg	4,38	4,40	4,36	4,18	3,93	4,02	4,12	4,08	4,11

Table A.18 Handsheet properties of 100% white birch CTMP.

Code	CTMP-B				CTMP-B, repeat			
Number	**3**	**8**	**9**	**10**	**6**	**7**	**8**	**9**
Grammage, g/m^2	61,36	60,91	59,59	60,84	61,06	60,10	60,44	61,54
Specific volume, cm^3/g	3.19	3.00	2.97	2.79	3.07	3.12	3.06	2.95
Density, g/cm^3	0,31	0,33	0,34	0,36	0,33	0,32	0,33	0,34
Breaking length, km	3.28	3.80	3.59	4.13	3.10	3.48	3.58	3.56
Stretch, %	1.34	1.53	1.43	1.68	1.18	1.48	1.56	1.40
TEA, J/m^2	17.37	23.10	19.44	27.62	13.95	20.17	22.08	19.60
Burst index, $kPa*m^2/g$	1,48	1,73	1,75	2,06	1,54	1,57	1,65	1,81
Tear index, $mN*m^2/g$	6,72	6,50	6,13	6,29	6,04	6,17	6,04	6,04
Tensile index, N*m/g	32,12	37,24	35,22	40,46	30,41	34,08	35,14	34,90
Roughness, μm	8.57	8.25	8.16	7.96	8.20	8.35	8.27	8.01
Porosity, ml /min	2243	1173	1023	799	1665	1612	1212	867
Brightness (8-457nm), %	54,47	54,74	54,23	54,42	54,68	54,12	54,15	53,95
Opacity, %	92,82	92,84	92,99	93,60	93,10	93,07	93,42	93,88
Scattering Coef., m^2/kg	44,17	46,14	46,15	44,71	43,89	43,43	44,34	44,69
Absorption Coef., m^2/kg	3,91	4,10	4,20	3,45	3,28	3,49	3,47	3,57

Table A.19 Handsheet properties of CTMP made from chip mixtures.

Code	CTMP-B30				CTMP-B60			
Number	**5**	**6**	**7**	**8**	**6**	**7**	**8**	**9**
Grammage, g/m^2	62,23	61,73	61,07	61,68	63,15	61,42	60,83	61,85
Specific volume, cm^3/g	3.09	2.82	2.49	2.37	2.93	2.69	2.55	2.38
Density, g/cm^3	0,32	0,35	0,40	0,42	0,34	0,37	0,39	0,42
Breaking length, km	3.98	4.70	5.53	6.16	4.63	5.07	5.45	5.54
Stretch, %	1.95	2.17	2.49	2.54	2.06	2.39	2.32	2.23
TEA, J/m^2	32.43	42.32	57.42	64.64	40.16	50.65	52.11	51.58
Burst index, kPa*m^2/g	2,31	2,85	3,48	3,64	2,64	2,98	3,12	3,28
Tear index, mN*m^2/g	11,95	12,39	9,97	9,64	11,34	10,43	10,27	10,07
Tensile index, N*m/g	39,06	46,10	54,21	60,42	45,45	49,68	53,44	54,34
Roughness, µm	8.288	7.90	7.61	7.42	8.17	7.748	7.592	7.618
Porosity, ml /min	2000	460	139	76	779	284	178	124
Brightness (8-457nm), %	45,22	45,61	45,76	45,78	46,70	46,99	47,06	46,06
Opacity, %	94,15	94,88	94,87	95,17	94,40	94,40	94,53	94,75
Scattering Coef., m^2/kg	42,10	45,04	46,01	46,37	43,07	44,78	45,37	44,30
Absorption Coef., m^2/kg	4,02	4,21	4,26	4,22	3,96	3,91	4,11	4,20

Table A.20 Handsheet properties of CTMP made from chip mixtures containing 30% treated white birch.

Code	CTMP-Bn30				CTMP-Bns30				
Number	**6**	**7**	**8**	**9**	**2**	**5**	**6**	**7**	**8**
Grammage, g/m^2	61,10	60,72	61,47	59,98	61,16	60,97	61,74	60,13	61,56
Specific volume, cm^3/g	3.22	2.87	2.65	2.63	3.24	3.03	2.79	2.89	2.65
Density, g/cm^3	0,31	0,35	0,38	0,38	0,31	0,33	0,36	0,35	0,38
Breaking length, km	4.50	5.03	5.59	5.27	3.93	4.30	4.84	4.95	5.43
Stretch, %	2.13	2.14	2.38	2.09	1.95	2.03	2.14	2.34	2.32
TEA, J/m^2	39.76	43.42	55.08	43.90	31.42	35.82	42.77	47.37	52.51
Burst index, $kPa*m^2/g$	2,47	2,96	3,18	3,01	2,33	2,49	2,65	2,83	3,01
Tear index, $mN*m^2/g$	11,83	10,88	9,96	9,25	11,38	11,01	10,06	10,02	9,71
Tensile index, N*m/g	44,14	49,38	54,81	51,64	38,57	42,14	47,48	48,55	53,28
Roughness, µm	8.08	7.85	7.64	7.72	8.30	8.07	7.77	7.73	7.73
Porosity, ml /min	1094	359	197	166	1222	697	318	259	167
Brightness (8-457nm), %	54,45	54,42	55,03	55,76	51,43	51,78	51,70	51,94	51,96
Opacity, %	93,26	93,31	93,87	93,59	94,11	94,35	95,16	94,97	94,85
Scattering Coef., m^2/kg	45,99	46,28	48,16	49,51	45,29	46,74	48,59	49,73	48,08
Absorption Coef., m^2/kg	3,11	3,13	3,09	3,00	3,76	3,77	4,05	3,99	3,74

Table A.21 Lint material properties of the TMP pulps.

Code	IWP	Average fibre length, mm				Cumulated fibre length, m/m²				N	Percentage, %		
	g/m²	L_f	L_m	L_l	L_T	L_{af}	L_{am}	L_{al}	L_{aT}	/65cm²	Fine	Medium	Large
TMP-S-5	4,958	0,242	1,056	2,208	0,319	14,696	3,250	2,802	20,748	423	93,31	4,73	1,95
TMP-S-6	5,042	0,253	1,047	2,225	0,341	9,095	1,772	2,310	13,177	252	92,94	4,37	2,68
TMP-S-7	5,058	0,242	1,043	1,948	0,285	8,475	1,684	1,724	10,682	244	93,34	4,30	2,36
TMP-B10-4	5,054	0,285	1,043	2,019	0,384	18,119	4,051	2,718	26,408	447	92,40	5,65	1,96
TMP-B10-6	4,992	0,252	1,038	2,000	0,318	16,606	3,153	2,615	22,374	457	93,82	4,32	1,86
TMP-B10-7	5,012	0,259	1,050	2,097	0,331	10,541	2,343	1,613	14,497	285	93,15	5,10	1,76
TMP-B20-5	5,004	0,260	1,060	2,111	0,343	17,399	4,036	4,465	24,947	473	91,86	5,23	2,91
TMP-B20-6	4,958	0,258	1,038	2,301	0,318	15,469	2,474	2,035	20,120	411	94,83	3,77	1,40
TMP-B20-7	5,042	0,248	1,016	2,311	0,323	11,174	2,150	1,955	15,508	312	93,83	4,41	1,76
TMP-B30-3	4,950	0,273	1,038	1,803	0,366	15,253	3,793	3,814	22,593	401	90,65	5,92	3,43
TMP-B30-5	4,959	0,295	1,031	2,037	0,389	15,391	3,410	3,447	22,248	372	91,25	5,79	2,96
TMP-B30-6	5,042	0,250	1,009	2,090	0,311	11,854	3,142	2,331	16,095	336	91,82	6,02	2,16
TMP-B40-3	4,962	0,247	1,051	1,999	0,324	20,449	4,485	3,921	28,855	580	93,01	4,79	2,20
TMP-B40-5	5,004	0,237	1,064	1,867	0,310	18,245	4,134	3,303	25,628	537	93,16	4,70	2,14
TMP-B40-6	4,954	0,264	1,069	1,842	0,341	18,470	4,604	2,764	25,837	493	92,34	5,68	1,98
TMP-B-6	5,035	0,309	1,068	1,806	0,530	87,402	60,084	38,562	190,956	2340	78,44	15,63	5,93
TMP-B-7	5,031	0,311	1,065	1,618	0,502	81,506	52,893	24,958	164,231	2127	80,11	15,18	4,71
TMP-B-9	5,019	0,318	1,058	1,679	0,495	81,182	51,426	24,798	157,406	2069	80,09	15,27	4,64
TMP-Bt30-3	5,008	0,270	1,048	1,823	0,383	14,987	4,513	3,786	23,721	402	89,68	6,96	3,36
TMP-Bt30-6	4,985	0,270	1,049	1,894	0,346	15,072	3,511	3,059	21,054	395	91,84	5,51	2,66
TMP-Bt30-7	4,989	0,249	1,020	2,191	0,337	7,270	1,884	1,517	10,671	206	91,99	5,83	2,18

Table A.22 Lint material properties of the CTMP pulps.

Code	IWP	Average fibre length, mm				Cumulated fibre length, m/m^2				N	Percentage, %		
	g/m^2	L_f	L_m	L_l	L_T	L_{af}	L_{am}	L_{al}	L_{aT}	/65cm^2	Fine	Medium	Large
CTMP-S-4r	4,955	0,309	1,054	1,948	0,392	18,297	4,215	2,847	25,360	420	91,55	6,19	2,26
CTMP-S-5r	5,035	0,310	1,058	2,178	0,398	17,797	3,866	3,268	24,931	407	91,77	5,83	2,39
CTMP-S-7r	5,027	0,291	1,023	2,165	0,380	11,751	2,203	2,665	16,619	285	92,27	4,92	2,81
CTMP-B30-5	4,954	0,306	1,051	1,917	0,407	17,189	3,801	3,023	24,969	399	91,53	5,90	2,57
CTMP-B30-6	4,958	0,297	1,041	2,289	0,399	15,193	3,043	3,521	22,191	362	91,98	5,26	2,77
CTMP-B30-7	5,019	0,324	1,036	2,225	0,438	14,851	2,830	4,365	22,136	329	90,72	5,40	3,88
CTMP-B60-6	4,965	0,256	1,063	2,114	0,328	17,382	3,681	2,765	23,828	472	93,44	4,76	1,80
CTMP-B60-7	4,973	0,257	1,056	2,319	0,331	12,767	2,152	2,587	17,506	344	94,04	3,85	2,11
CTMP-B60-9	4,95	0,232	1,033	2,391	0,292	12,025	2,305	1,655	15,985	355	94,65	4,08	1,27
CTMP-Bn30-6	4,956	0,217	1,084	2,285	0,284	10,741	2,042	1,757	14,798	339	94,90	3,62	1,48
CTMP-Bn30-7	4,969	0,223	1,029	1,898	0,276	11,541	1,820	1,679	15,041	354	95,12	3,25	1,63
CTMP-Bn30-8	4,989	0,221	1,042	2,275	0,291	10,384	1,883	2,187	14,454	323	94,43	3,64	1,93
CTMP-Bns30-2	4,992	0,295	1,045	1,960	0,384	21,906	5,949	3,542	31,398	532	90,84	6,95	2,21
CTMP-Bns30-5	4,962	0,315	1,063	2,132	0,431	21,290	6,380	5,002	32,672	493	89,00	7,91	3,09
CTMP-Bns30-7	5,004	0,294	1,039	1,895	0,401	18,975	6,035	4,008	29,018	471	89,05	8,02	2,92
CTMP-B-6r	4,977	0,266	1,036	2,105	0,376	26,903	6,496	6,475	41,571	718	91,54	5,68	2,79
CTMP-B-7r	4,969	0,239	1,050	2,082	0,346	23,782	6,703	7,367	37,852	711	90,93	5,83	3,23
CTMP-B-9r	5,012	0,292	1,048	2,062	0,412	22,601	6,650	6,186	35,753	565	89,24	7,31	3,45

Table A.23 Fibre coarseness (mg/m) of the Bauer-McNett fractions of the CTMP pulps.

Code	CTMP-B				CTMP-B, repeat				
Number	**3**	**8**	**9**	**10**	**6**	**7**	**8**	**9**	
SEC, MJ/kg	9,33	11,22	12,07	12,79	11,12	11,20	11,85	12,72	
R28	0,339	0,327	0,3145	0,3245	0,3325	0,333	0,356	0,34	
R48	0,1965	0,1975	0,192	0,195	0,186	0,188	0,1975	0,1975	
R100	0,163	0,159	0,158	0,161	0,161	0,16	0,16	0,158	
Code	**CTMP-S**				**CTMP-S, repeat**				
Number	**4**	**5**	**6**	**7**	**4**	**5**	**7**		
SEC, MJ/kg	12,93	13,04	14,16	14,72	11,35	13,31	16,35		
R28	0,2505	0,2325	0,231	0,234	0,2425	0,2235	0,224		
R48	0,186	0,1905	0,1915	0,1835	0,193	0,185	0,187		
R100	0,164	0,163	0,164	0,164	0,16	0,156	0,154		
Code	**CTMP-B30**				**CTMP-B60**				
Number	**5**	**6**	**7**	**8**	**6**	**7**	**8**	**9**	
SEC, MJ/kg	9,99	12,59	15,77	16,64	12,68	14,43	15,18	16,43	
R28	0,2445	0,225	0,2175	0,2115	0,236	0,2345	0,2305	0,2225	
R48	0,202	0,1915	0,188	0,178	0,202	0,1905	0,1875	0,1945	
R100	0,168	0,165	0,162	0,160	0,162	0,156	0,156	0,156	
Code	**CTMP-Bn30**				**CTMP-Bns30**				
Number	**6**	**7**	**8**	**9**	**2**	**5**	**6**	**7**	**8**
SEC, MJ/kg	11,79	14,25	14,39	15,90	9,80	10,92	12,29	12,79	13,20
R28	0,23	0,22	0,221	0,217	0,2285	0,222	0,21	0,214	0,199
R48	0,206	0,1955	0,1895	0,197	0,195	0,197	0,194	0,19	0,1875
R100	0,166	0,167	0,163	0,162	0,168	0,167	0,172	0,165	0,171

Table A.24 Fibre flexibility and RBA of the fractions of TMP.

Code	Fraction	CSF, ml (whole pulp)	Flexibility		RBA	
			$\times 10^{10}$ $N^{-1}m^{-2}$	Fibre number	%	Fibre number
TMP-S-1	R48	161	15,7	505	23,3	689
TMP-S-4	R48	141	16,0	412	25,3	734
TMP-S-7	R48	46	18,6	310	30	620
TMP-B10-3	R48	210	15,0	300	22,3	567
TMP-B10-5	R48	151	14,7	571	22,6	714
TMP-B10-7	R48	49	15,9	294	28,2	676
TMP-B20-2	R48	217	13,1	315	21,2	693
TMP-B20-5	R48	164	14,7	432	23	766
TMP-B20-7	R48	42	15,9	351	25,1	681
TMP-B30-3	R48	177	13,8	312	19,1	721
TMP-B30-5	R48	158	14,5	422	18,9	654
TMP-B30-6	R48	106	14,7	347	22,3	626
TMP-B40-3	R48	206	13,1	211	18,9	532
TMP-B40-5	R48	155	13,5	420	18,6	753
TMP-B40-6	R48	88	14,2	263	21,6	573
TMP-B100-6	R48	208	9,58	582	10,8	796
TMP-B100-7	R48	160	9,33	399	11,8	892
TMP-B100-9	R48	112	9,33	348	11,8	780
TMP-S-4	R100	141	34,2	352	32	811
TMP-B10-5	R100	151	33,1	238	31,6	772
TMP-B20-5	R100	164	31,2	231	29,1	726
TMP-B30-5	R100	158	25,5	243	26,8	730
TMP-B40-5	R100	155	23,1	250	20,1	687
TMP-B100-7	R100	160	10,8	773	12,4	995
TMP-S-4	R200	141			63,3	309
TMP-B10-5	R200	151			65,3	429
TMP-B20-5	R200	164			64,2	481
TMP-B30-5	R200	158			63,5	330
TMP-B40-5	R200	155			58,5	245
TMP-B100-7	R200	160			20,3	605

Table A.25 Fibre flexibility and RBA of the fractions of CTMP.

Code*	Fraction	Flex. ($\times 10^{10}$) $N^{-1}m^{-2}$	Flex. Fibre number	RBA %	RBA Fibre number
CTMP-5r	R28	13,5	358	28	661
CTMP-B30-6	R28	11,8	732	29,9	721
CTMP-B60-6	R28	12,9	817	29,4	702
CTMP-Bn30-6	R28	10,4	406	26	623
CTMP-Bns30-5	R28	12,9	499	25,2	691
CTMP-B-6r	R28	10,7	986	25,4	534
CTMP-5r	R48	19,3	678	34	775
CTMP-B30-5	R48	18,7	822	25,9	880
CTMP-B30-6	R48	17,5	595	27,4	937
CTMP-B30-7	R48	22,5	946	30	873
CTMP-B60-6	R48	16,5	749	26,7	900
CTMP-Bn30-6	R48	17,2	576	23,8	942
CTMP-Bns30-5	R48	19,3	752	26,5	793
CTMP-B-6r	R48	15,3	624	21,1	886
CTMP-5r	R100	35,1	528	42,4	680
CTMP-B30-6	R100	30,2	971	32,3	1000
CTMP-B60-6	R100	29,7	996	27,5	1000
CTMP-Bn30-6	R100	33,7	1000	28,7	1000
CTMP-Bns30-5	R100	34,8	913	33,6	1000
CTMP-B-6r	R100	23,3	942	27,2	1000
CTMP-5r	R200			60,3	966
CTMP-B30-6	R200			53,2	1032
CTMP-B60-6	R200			50,8	1324
CTMP-Bn30-6	R200			48,8	1102
CTMP-Bns30-5	R200			51,3	883
CTMP-B-6r	R200			44,8	1762

r: repeat

Table A.26 Fibre coarseness of the fractions of TMP and CTMP (~150 ml, CSF).

Code	Birch %	Coarseness, mg/m		
		R28	R48	R100
TMP-S-4	0%	0,254	0,209	0,18
TMP-B10-5	10%	0,252	0,205	0,18
TMP-B20-5r	20%	0,248	0,206	0,179
TMP-B30-5	30%	0,263	0,201	0,174
TMP-B40-5	40%	0,258	0,199	0,175
TMP-B-7	100%	0,247	0,178	0,157
CTMP-S	0%	0,234	0,188	0,16
CTMP-B30	30%	0,228	0,192	0,166
CTMP-B60	60%	0,236	0,200	0,162
CTMP-B	100%	0,336	0,191	0,161

* r: repeat

Table A.27 Hydrodynamic specific volume of the fractions of TMP and CTMP.

Code	CSF, ml (whole pulp)	Hydrodynamic specific volume, cm^3/g			
		R48	R100	R200	P200
CTMP-S-5r	145	223	220	540	590
CTMP-B30-6	168	179	183	322	423
CTMP-Bn30-6	177	175	174	276	368
CTMP-Bns30-5	157	166	186	300	311
CTMP-B-6	152	133	136	145	162
TMP-S-4	141	190	189	539	542
TMP-B10-5	151	191	187	441	445
TMP-B20-5r	164	176	170	391	401
TMP-B30-5	158	162	160	314	312
TMP-B40-5	155	163	161	300	300
TMP-B-7	160	133	130	137	160

* r: repeat

Table A.28 Hydrodynamic specific volume and coarseness of the fractions of TMP.

Code	CSF ml	Hydr. specific vol. cm^3/g	Coarseness mg/m		
	(whole pulp)	R200	R28	R48	R100
TMP-S-1	161	502	0,247	0,215	0,189
TMP-S-4	141	539	0,254	0,209	0,18
TMP-S-7	46	652	0,208	0,204	0,177
TMP-B10-3	210	359		0,221	0,167
TMP-B10-5	151	441	0,252	0,205	0,18
TMP-B10-7	49	627		0,198	0,161
TMP-B20-2r	217	307		0,211	0,154
TMP-B20-5r	164	391	0,248	0,206	0,179
TMP-B20-7r	42	541		0,186	0,155
TMP-B30-3	177	280		0,201	0,177
TMP-B30-5	158	314	0,263	0,199	0,174
TMP-B30-6	106	355		0,189	0,163
TMP-B40-3	206	241		0,197	0,165
TMP-B40-5	155	300	0,258	0,211	0,175
TMP-B40-6	88	353		0,201	0,159
TMP-B-6	208	125	0,25	0,182	0,17
TMP-B-7	160	133	0,247	0,178	0,157
TMP-B-9	112	142	0,218	0,18	0,153

* r: repeat

Table A.29 Freeness of the fractions of CTMP.

Code	Whole pulp	R14	R28	R48	R100	R200
CTMP-S-6	132	>700	>700	>700	447	135
CTMP-B30-6	168	>700	>700	>700	593	174
CTMP-Bn30-6	177	>700	>700	>700	667	148
CTMP-Bns30-6	157	>700	>700	>700	577	176
CTMP-B-6r	152	>700	>700	>700	706	291

Appendix B – SEM MICROGRAPHS

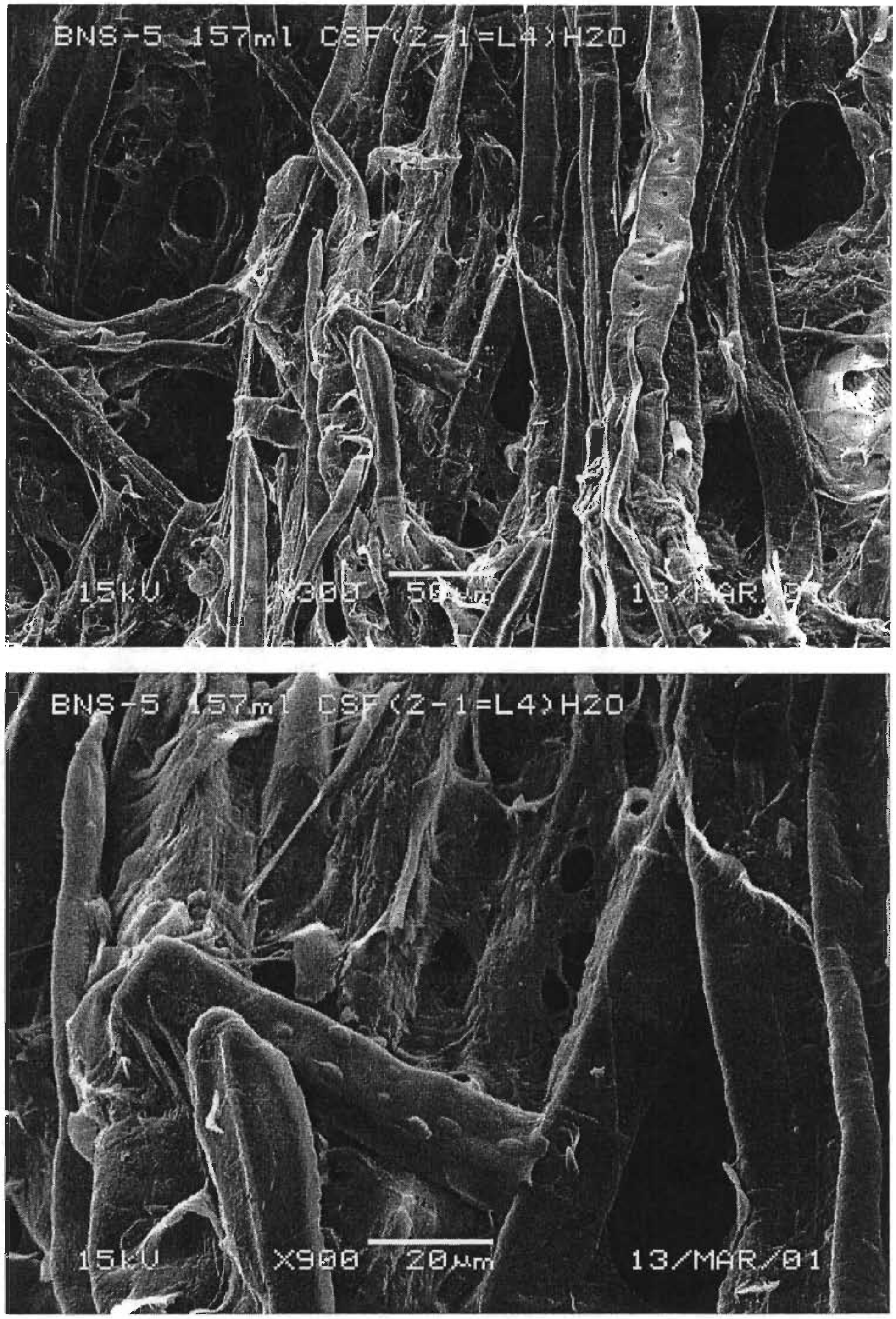


Figure B.1 SEM mircographs of CTMP-Bns30 prepared by air drying.

Air drying causes great shrinkage of the fibre surface. The fines and the fibrils are collapsed against the surface of the fibres.

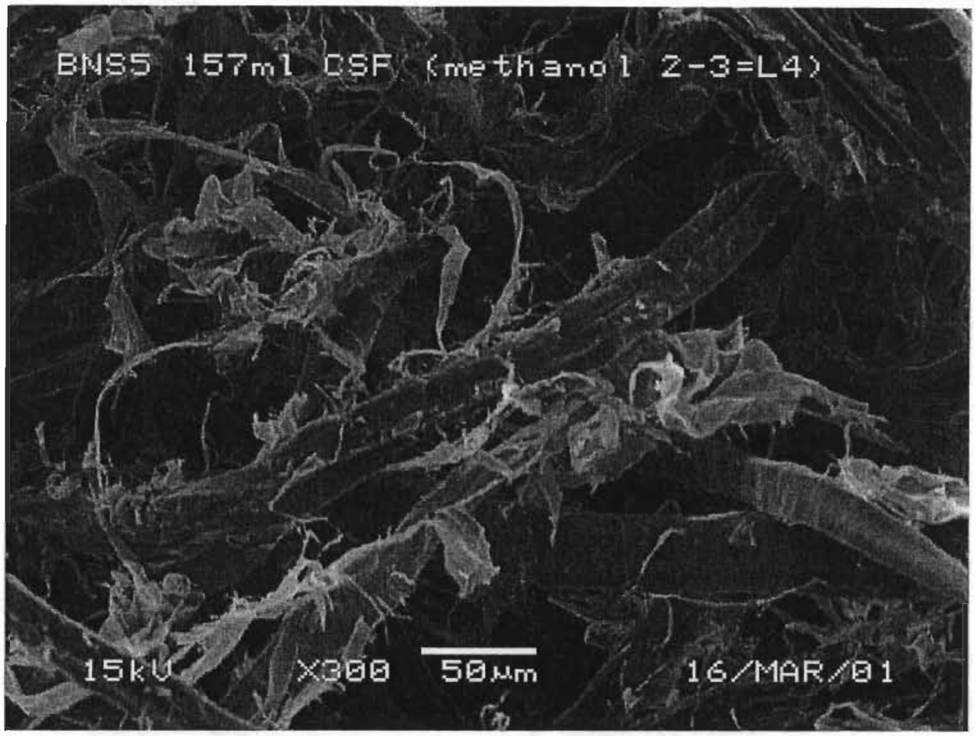
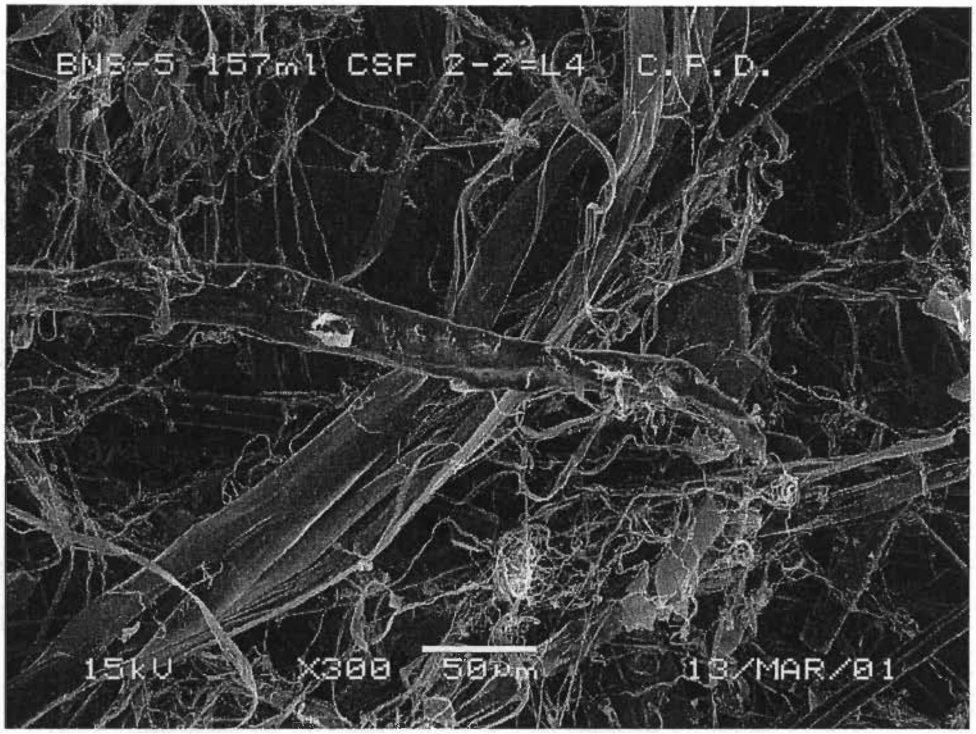


Figure B.2 SEM mircographs of CTMP-Bns30 prepared by solvent-exchange.

The fine details of the fibres are clearly shown (the surface characteristics and the fibrils).



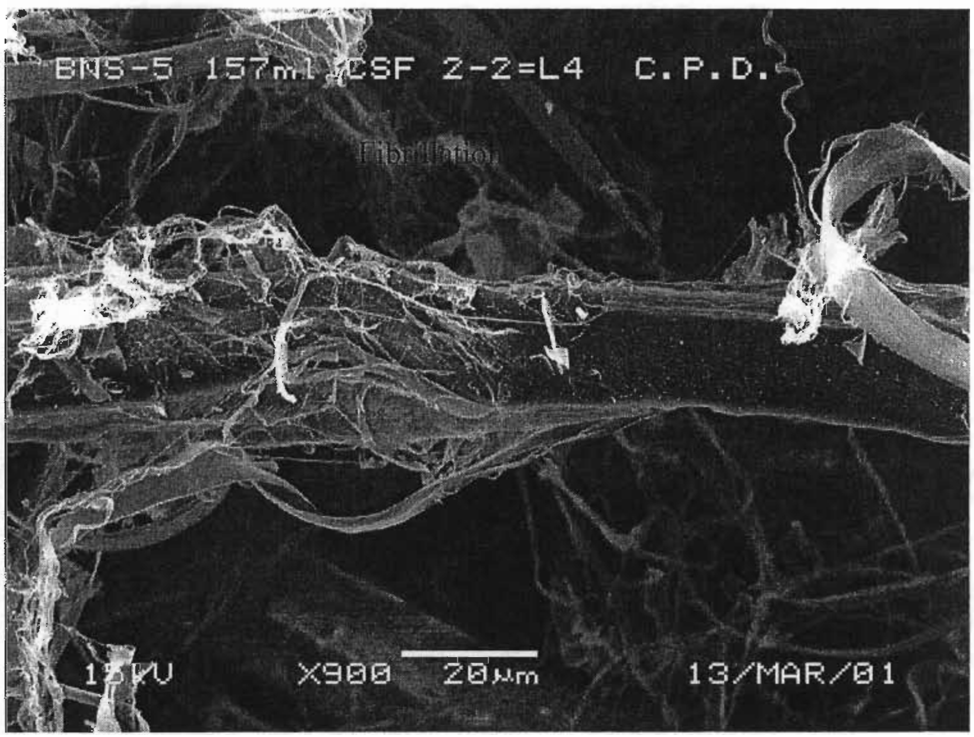


Figure B.3 SEM micrographs of CTMP-Bns30 prepared by CPD.

The fine details of the fibres are clearly shown (the surface characteristics and the fibrils).

Appendix C - LIST OF STANDARD METHODS USED

Hot disintegration	CPPA standard C. 8P
Wood chip moisture (%)	CPPA standard A.10P
Freeness (ml)	CPPA standard C1
Shive content (%)	Pulmac (0.004″)
Bauer McNett	TAPPI 233 OS-75
Pulp handsheet	CPPA standard C.4
Basis weight (g/m^2)	CPPA standard D.12
Bulk (m^3/kg)	CPPA standard D.5H
Density (kg/m^3)	CPPA standard D.5H
Roughness (μm)	CPPA standard D.29p
Porosity (ml/min)	CPPA useful method 524
Tensile energy absorption (TEA)	CPPA standard D.34p
Tensile index (N*m/g)	CPPA standard D.34p
Tensile stretch (%)	CPPA standard D.34p
Tear index ($mN*m^2/g$)	CPPA standard D.9
Burst index ($kPa*m^2/g$)	CPPA standard D.8
Water retention value	TAPPI UM 256
Brightness, ISO (%)	CPPA standard E.2
Light scattering coefficient (m^2/kg)	CPPA standard E.2
Light absorption coefficient (m^2/kg)	CPPA standard E.2
Opacity (%)	CPPA standard E.1
Linting propensity	CPPA useful method L.5U

Appendix D – PUBLICATIONS

Traitement des copeaux de bouleau blanc en vue de leur incorporation à l'épinette pour la production de papier journal

Meng Ran Wu[1], Robert Lanouette[1] et Jacques L. Valade[2].

Résumé

La possibilité d'améliorer les copeaux de bouleau blanc (*Betula papyfera Marsh*) par un pré-traitement chimique suivi d'un co-raffinage avec des copeaux non traités d'épinette noire (*Picea mariana*) est étudiée et comparée avec les CTMP et TMP standards obtenus à partir des copeaux non traités de bouleau blanc et d'épinette noire en mélange. Les mélanges substitués de bouleau blanc jusqu'à 60 % sans ou avec un pré-traitement chimique peuvent avoir des propriétés physiques supérieures ou équivalentes à la pâte TMP-S mais avec un faible coefficient de diffusion. Le pré-traitement chimique sur les copeaux de bouleau blanc seuls et avant leur incorporation au mélange suivi d'un raffinage avec sulfite seul ou sans produit chimique peut augmenter le coefficient de diffusion. L'intégration de copeaux de bouleau blanc jusqu'à 60 % sans ou avec un pré-traitement chimique a peu d'influence sur peluchage lorsque comparée avec la pâte CTMP-S. La pâte TMP de bouleau montre une forte propension au peluchage lequel s'atténue rapidement lorsque les copeaux de bouleau sont raffinés en mélange avec l'épinette.

MOTS-CLÉS : bouleau blanc, *Betula papyfera* Marsh, épinette noire, *Picea mariana*, pâte chimico-thermomécanique, pâte thermomécanique, rupture, coefficient de diffusion, peluchage.

Abstract

The feasibility of upgrading white birch chips by chemical pre-treatment followed by co-refining with untreated black spruce chips is studied in comparison with the controlled CTMP and TMP produced from untreated chip mixtures of white birch and black spruce. Using up to 60 % of white birch with or without chemical pre-treatment produced a pulp with comparable physical properties to TMP-S with a lower scattering coefficient. The chemical pre-treatment of white birch prior to mixing with black spruce following the

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co-refining with sulfite only or without chemicals is beneficial in terms of increasing the scattering coefficient. Utilising up to 60 % of white birch with or without chemical pre-treatment in black spruce for producing CTMP shows little influence on linting propensity when compared to CTMP-S. The birch TMP shows a very strong linting propensity, which is radically reduced by the co-refining of birch with spruce.

KEY WORDS : white birch, *Betula papyfera* Marsh, black spruce, *Picea mariana*, chemi-thermomechanical pulp, thermomechanical pulp, tensile, scattering coefficient, linting

Introduction

Le bouleau est la deuxième essence la plus répandue parmi les bois feuillus avec un volume de plus d'un milliard de m^3 distribué au travers presque tout le Canada[1,2]. Au Québec, les bois feuillus représentent environ 30 % du volume marchand forestier. L'essence dominante est le bouleau avec une proportion de 44,6 %[2]. Jusqu'à présent l'utilisation de bois feuillus à haute densité, comme le bouleau, reste encore marginale dans l'industrie canadienne des pâtes et papiers.

La mise en pâte thermomécanique (TMP) est le procédé le plus répandu au Québec[3]. La pâte TMP de résineux possède une bonne combinaison de propriétés de résistance et de propriétés optiques qui rendent cette pâte apte à la production de papier journal. De plus, il est possible d'ajouter des produits chimiques avant, pendant ou après le raffinage pour améliorer les propriétés physiques, comme dans le procédé de mise en pâte chimico-thermomécanique (CTMP). Présentement, les bois utilisés au Canada dans la production de pâtes TMP et CTMP sont surtout l'épinette noire, le sapin baumier et le tremble. La pâte TMP de bouleau blanc ne produit pas du papier de bonne qualité à cause, entre autre, de sa faible résistance[4]. Un des moyens pour améliorer la résistance de la pâte de bouleau blanc est l'introduction de produits chimiques dans le procédé. Dans ce cas, un certain niveau d'alcali est nécessaire pour fabriquer une pâte possédant une bonne résistance. Les désavantages principaux sont les baisses d'opacité et de blancheur causées par la présence de produits chimiques dans le procédé. L'autre moyen d'augmenter l'utilisation du bouleau blanc est d'intégrer celui-ci avec les essences résineuses dans le procédé de mise en pâte.

Plusieurs études ont favorisé cette avenue surtout en ce qui a trait aux propriétés physiques lors de la mise en pâte mécanique dans un mélange d'essences[5,6,7,8,9,10]. Les résultats montrent que les propriétés physiques des pâtes en mélange sont proportionnelles à la fraction de la pâte pure et ce pour le procédé TMP. Des effets synergiques sont cependant quelquefois remarqués sur certaines propriétés physiques dans les mélanges où des produits chimiques sont utilisés dans le procédé CTMP. Jusqu'à présent, peu de travaux se sont préoccupés de la théorie du co-raffinage ou encore de l'augmentation du peluchage due à l'introduction de bois feuillu dans le mélange de base.

Ainsi, l'utilisation de bouleau blanc (*Betula papyfera Marsh*) avec l'épinette noire (*Picea mariana*) pour la production de papier journal présente un défi intéressant non seulement en recherche mais aussi pour l'industrie papetière. Le but du projet dans son ensemble est donc d'étudier l'impact de la présence de bois feuillus dans la composition de base en ciblant le développement des fibres de bois résineux et de bois feuillus dans le raffineur, soit comme essence pure ou en mélange résineux/feuillus. Pour se faire, divers mélanges ont donc été effectués pour des contenus en feuillus variant de 0 à 100 %, avec ou sans traitement chimique. Les pâtes ont ensuite été étudiées, tant au niveau des propriétés morphologiques des fibres que des propriétés des papiers produits. Un complément d'information est aussi obtenu par analyse visuelle au microscope optique et au microscope à balayage.

Le présent travail porte sur les résultats d'une partie de cette étude, soit celle reliée aux effets sur le coefficient de diffusion de la lumière et le peluchage du traitement chimique des fibres de bouleau en combinaison avec l'épinette ou en pré-traitement sur les copeaux de bouleau seuls avant leur incorporation au mélange. Les résultats sont comparés aussi avec ceux des pâtes TMP.

Expérimentation

Matière première

Les copeaux d'épinette noire (S) provenaient de l'usine Kruger de Trois-Rivières tandis que les billes de bouleau blanc (B) venaient de la compagnie Malette de St-Georges-de-Champlain (Québec, Canada). Les billes de bouleau blanc ont été écorcées et mises en copeaux. Les copeaux ont été classés avec un classificateur à disque de type Rader en acceptant les copeaux de 2 mm à 6 mm d'épaisseur. Les copeaux ont été lavés séparément et ont été mélangés en poids.

Pré-traitement chimique des copeaux

Le plan de travail comportait un essai de référence où le mélange de copeaux a été traité ensemble avec 2,5 % de sulfite et de 2,5 % d'hydroxyde de sodium selon le procédé CTMP conventionnel. La proportion de bouleau blanc utilisée était de 0, 30, 60 et 100 % (CTMP-a). De plus, dans deux autres essais avec 30 % de bouleau blanc un pré-traitement chimique a été appliqué sur les copeaux de bouleau blanc seuls avant leur incorporation au mélange avec les copeaux d'épinette noire non-traités. Dans ce cas, le traitement CTMP-b consistait en une addition d'hydroxyde de sodium seulement lors du trempage, suivi d'un raffinage CTMP utilisant 2,5 % du sulfite de sodium seulement. Le procédé CTMP-c présente une addition simultanée de 2,5 % de sulfite et de 2,5 % d'hydroxyde de sodium par trempage des copeaux de bouleau avant leur raffinage TMP conventionnel en mélange avec l'épinette non traitée. Les symboles utilisés dans les figures sont expliqués au tableau 1.

Identification	Procédé	Bouleau blanc, %	Épinette noire, %
CTMP-S	CTMP-a	0	100
CTMP-B	CTMP-a	100	0
CTMP-B30	CTMP-a	30	70
CTMP-B60	CTMP-a	60	30
CTMP-Bn30*	CTMP-b	30	70
CTMP-Bns30**	CTMP-c	30	70

*Les copeaux de bouleau blanc sont pré-traités au NaOH avant d'être mélangés avec les copeaux d'épinette noire.
**Les copeaux de bouleau blanc sont pré-traités au NaOH + Na_2SO_3 avant d'être mélangés avec les copeaux d'épinette noire.

Tableau 1 - ***Illustration des symboles utilisés dans les figures.***

Conditions de raffinage

Les pâtes TMP et CTMP ont été produites en deux étapes avec le raffineur de laboratoire CD 300 (Metso inc.) du Centre de recherche en pâtes et papiers de l'UQTR. La première étape du raffinage s'effectue sous pression tandis que la seconde étape est à pression atmosphérique.

Évaluation des pâtes

La latence des pâtes a été enlevée avant l'évaluation. Les propriétés physiques ont été mesurées conformément aux procédures de l'ATCPP. Les propriétés optiques ont été analysées avec un photomètre Technibrite. La flexibilité de la fibre a été analysée à l'aide d'un appareil CyberFlex basé sur la méthode Steadman[11].

Résultats et discussion

Comme mentionné précédemment, l'utilisation du bouleau blanc se heurte à 2 grands problèmes qui sont une faible résistance mécanique et une augmentation considérable du peluchage des papiers produits. L'ajout de produits chimiques lors d'un procédé CTMP permet d'atténuer partiellement ces problèmes mais au prix d'une perte importante du coefficient de diffusion de la lumière et souvent de la blancheur puisque l'on utilise de l'hydroxyde de sodium lequel produit un noircissement alcalin.

Propriétés des papiers

Une bonne façon de visualiser l'effet relatif de l'énergie spécifique de raffinage et des produits chimiques sur le coefficient de diffusion la lumière est d'étudier la relation entre l'indice de rupture et ce dernier. Sans considération pour l'essence de bois utilisée, une relation entre l'indice de rupture et le coefficient de diffusion très forte existe. L'indice de rupture et le coefficient de diffusion augmentent tous deux avec l'augmentation d'énergie de raffinage, et ce pour toutes les pâtes *(figure 1)*. Le développement de la surface spécifique et la production de fines contribuent positivement aux propriétés physiques et optiques mais à un degré différent dépendant de l'essence et du traitement chimique. La pâte TMP-S montre une bonne combinaison d'indice de rupture et du coefficient de diffusion. Elle a un indice de rupture supérieur pour un niveau de coefficient de diffusion équivalent aux pâtes TMP-B et TMP-B30. Par ailleurs, elle a un coefficient de diffusion supérieur pour un niveau de rupture équivalent aux pâtes CTMP.

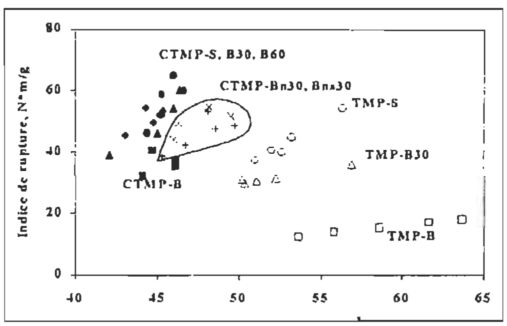

*Figure 1 - **L'indice de rupture en fonction du coefficient de diffusion.***

Pour le procédé CTMP, la sulfonation de la lignine amène une amélioration de la séparation des fibres ainsi que la qualité des fines produites. Une augmentation de la flexibilité de la fibre et du volume spécifique des fines est remarquée sur les pâtes CTMP lorsque que comparée avec les pâtes TMP *(figure 2 et 3)*, sauf dans le cas du volume spécifique des pâtes de 100 % bouleau blanc. Donc, les contacts intrinsèques dans le réseau fibreux sont améliorés. Finalement, les pâtes CTMP d'épinette noire et des mélanges ont un indice de rupture supérieur aux pâtes TMP mais avec un faible coefficient de diffusion. C'est-à-dire que les fines contribuent plus aux liaisons entre les fibres qu'à l'augmentation du coefficient de diffusion. Par contre, les fines des pâtes TMP de bouleau blanc et du mélange contribuent davantage à l'augmentation du coefficient de diffusion qu'aux propriétés de résistance[12]. Pour la pâte CTMP-B, une amélioration de la flexibilité de la fibre est remarquée due au ramollissement de la paroi cellulaire et à la sulfonation de la lignine par la soude et le sulfite tandis que le volume spécifique des fines demeure inchangé *(figure 2 et 3)*.

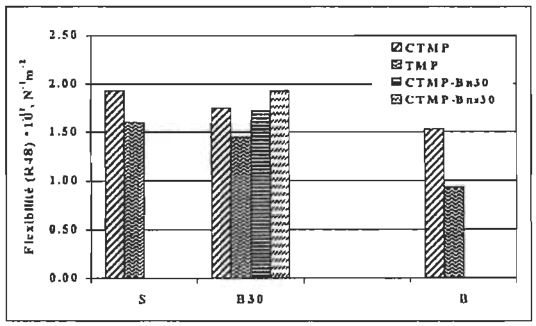

*Figure 2 - **La flexibilité des fibres de la fraction R48 par Bauer-McNett.***

Il importe donc de se rapprocher du comportement médian de la TMP d'épinette tout en ajoutant du bouleau dans le mélange. Un compromis devra nécessairement s'effectuer entre le traitement chimique et le traitement mécanique, d'où l'idée de traiter les copeaux de bouleau seulement avant leur incorporation au mélange. Ainsi, on peut tirer profit de l'augmentation de propriétés de liaison des fibres de bouleaux tout en minimisant la perte au niveau du coefficient de diffusion et éviter de traiter les fibres résineuses qui ne requièrent pas de traitement chimique. Un nouvel examen de la figure 1 nous montre que les pâtes CTMP des mélanges ont une relation entre l'indice de rupture et le coefficient de diffusion similaire à la pâte CTMP-S. Quand les copeaux de bouleau blanc sont pré-traités par la soude ou une combinaison de soude et sulfite avant d'être mélangés avec les copeaux non-traités d'épinette noire (les procédés CTMP-Bn30 et CTMP-Bns30), une augmentation de coefficient de diffusion est nettement remarquée (points entourés). Comparativement à un point fictif (P) situé au tiers de la distance entre le CTMP-B et le TMP-S, on note aussi une augmentation de l'indice de rupture non négligeable. Il y aurait donc ici un effet synergique favorable à ce type de raffinage.

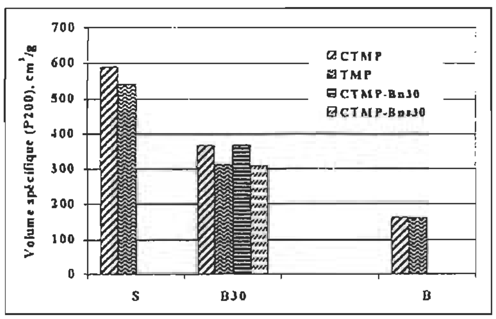

*Figure 3 - **Le volume spécifique des fines P200 par Bauer-McNett.***

Peluchage

Des formettes des pâtes CTMP-B, B30, B60, Bn30, Bns30, S and et TMP-B, B30, S avec un indice d'égouttage d'environ 150 ml ont aussi été préparées pour le test de peluchage. Tel que mentionné précédemment, l'augmentation de l'indice de rupture remarquée est due à une amélioration de la flexibilité pour la pâte CTMP-B. D'où une forte réduction du peluchage est réalisée pour la pâte CTMP-B en comparaison avec la pâte TMP-B (*figure 4 et 5*). Le nombre total de fibres détachées passe de plus de 2000 par 65 cm² à moins de 720 par 65 cm², et la longueur cumulative des fibres diminue de plus de 150 m/m² à moins de 42 m/m². Par contre, avec l'utilisation de produits chimiques, le peluchage de la pâte CTMP-S demeure presque inchangée lorsque comparé avec celui de la pâte TMP-S.

Pour les pâtes TMP et CTMP, la présence de bouleau blanc n'a qu'un effet léger sur le peluchage, résultant en une bande où se retrouve la majorité des données en fonction de l'énergie spécifique de raffinage. Dans le cas du TMP, on voit nettement l'avantage du raffinage en mélange qui semble neutraliser la propension au peluchage des fibres de bouleau.

La figure 6 nous montre la distribution des particules arrachées durant le test de peluchage. Les particules grosses et moyennes sont indiquées tandis que la différence pour atteindre 100 % se retrouve dans la fraction fines. Pour toutes les pâtes sauf pour la pâte TMP-B, plus de 90 % du matériel détaché est fin. L'examen au microscope optique nous indique que le matériel détaché est principalement constitué de rayon du bois et de fibres intactes peu développées. Quelques fragments de fibres sont aussi remarqués dans le matériel de peluchage, qui se sont possiblement détachés en même temps que les fibres intactes. Quelques débris sont observés dans le matériel de peluchage de la pâte TMP mais non dans celui de la pâte CTMP, ce qui signifie que la séparation de la fibre dans le procédé CTMP est bonne due à l'ajout de produits chimiques.

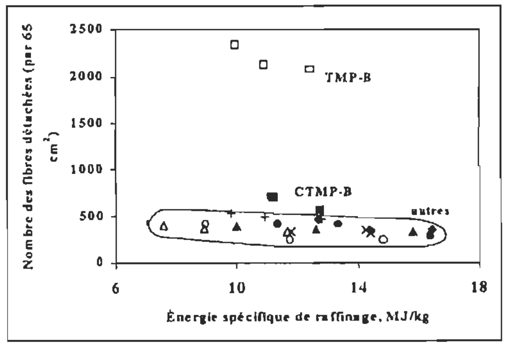

*Figure 4 - **Nombre total de fibres détachées en fonction de l'énergie de raffinage.***

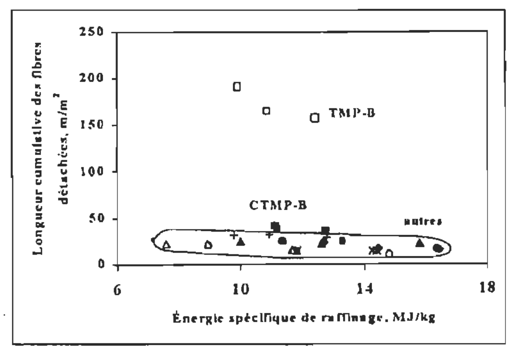

*Figure 5 - **Longueur cumulative des fibres en fonction de l'énergie de raffinage.***

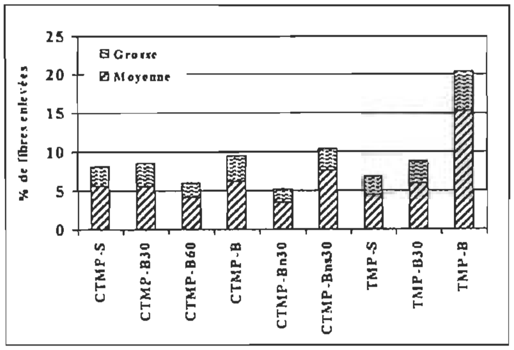

*Figure 6 - **Distribution des fibres détachées en pourcentage.***

Le peluchage occasionné par le bouleau peut donc, à la lumière des figures 4 à 6, être contrôlé assez facilement, soit directement par le mélange des copeaux avec l'épinette ou leur traitement chimique. Comme l'utilisation de bouleau pur n'est pas envisageable du point de vue des résistances mécaniques des pâtes produites, il semble que ce problème devient d'importance plus secondaire quant à son application industrielle.

Conclusion

Les mélanges avec substitution de bouleau blanc jusqu'à 60 % avec ou sans un pré-traitement chimique peuvent générer des propriétés physiques supérieures ou équivalentes à la pâte TMP-S mais avec un faible coefficient de diffusion. Le pré-traitement chimique sur les copeaux de bouleau blanc seuls avant leur incorporation au mélange suivi un raffinage avec sulfite seul ou sans produit chimique permet d'augmenter le coefficient de diffusion. Un léger compromis est nécessaire quant à la valeur du coefficient de diffusion de la lumière. Le tout pourrait s'avérer critique si cette valeur est déjà à la limite. La pâte thermomécanique de bouleau est très sensible au phénomène du peluchage due à un développement insuffisant de ses fibres et de ses vaisseaux. L'utilisation de bouleau en mélange diminue rapidement le peluchage à une valeur acceptable, possiblement dû à la présence des fines d'épinette de bonne qualité qui permettent de tenir le matelas fibreux en place. Un traitement chimique permet également d'augmenter la flexibilité des fibres de bouleau a un seuil suffisant pour assurer l'intégrité du matelas. L'intégration des copeaux de bouleau blanc jusqu'à 60 % sans ou avec un pré-traitement chimique a peu d'influence sur le peluchage en comparant avec la pâte CTMP-S.

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UNDERSTANDING THE FIBER DEVELOPMENT DURING CO-REFINING OF WHITE BIRCH AND BLACK SPRUCE MIXTURES.
PART 1. CHEMITHERMOMECHANICAL PULPING

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ABSTRACT

Co-refining of white birch with black spruce in the CTMP process showed little influence on the long fibres quality, but decreased qualities of the short fibres and especially the fines, as measured by the flexibility and hydrodynamic specific volume. These reductions were marginally affected by the substitution ratio of spruce by white birch. From that point of view, there was a positive effect of mixing white birch with black spruce to produce CTMP due to the benefits from chemical treatment and also probably the protection against fibre cutting of white birch fibres by black spruce fibres during co-refining. The CTMP pulps of chip mixtures could have comparable tensile and light scattering to the spruce CTMP. The chemical pre-treatment of white birch prior to mixing with black spruce followed by co-refining was a compromise alternative to maintain the strength properties while increasing the light scattering.

Keywords: white birch, *Betula papyfera* Marsh, black spruce, *Picea mariana*, chemi-thermomechanical pulp, newsprint furnish, linting propensity, flexibility, relative bonded area, hydrodynamic specific volume.

INTRODUCTION

In Canada, the pulp and paper economy is primarily based on market mechanical pulps and newsprint, which use softwood as the principal material, especially spruce. As one of the dominant hardwood species in Canada [1], the utilisation of birch wood in mechanical pulping for newsprint furnish is interesting, not only for research but also for pulp and papermaking industry of this country.

The morphological characteristics of wood are recognized to be the most important factor determining the mechanical pulp and paper quality [2]. The birch fibres have a much more rigid structure than spruce, such as higher density, shorter fibre length and thicker cell wall. These characteristics cause low responsive to refining and give low strength properties of mechanical pulp but with a good opacity when chemicals are not used [3]. However, birch responds well to chemical and chemimechanical pulping, such as Kraft [4, 5] and NSSC [6]. In mechanical pulping area, when handling birch wood, the greatest effects are achieved using sodium hydroxide treatment of the chips that reduces the energy consumption and more importantly improves the pulp strength properties [7, 8]. Unfortunately, the superior opacity of birch TMP is lost when chemicals are introduced. The reduction of brightness is not avoidable since relatively high alkali dosage is necessary to improve the strength properties of the mechanical pulp of birch and so the effectiveness of sulfite against alkaline darkening becomes limited. Co-refining with softwood is considered another alternative ways to enlarge the utilisation of birch in mechanical pulping. Several studies [8, 9, 10, 11, 12, 13] showed that a partial substitution of softwood by dense hardwood had advantages in reducing the refining energy consumption and modifying the optical properties when chemicals were not used. But the strength properties were reduced largely when more than 20% of softwood was replaced by dense hardwood. Hence, the commercial utilisation of birch in mechanical pulping is still on a relatively small scale although several studies have been carried out in this area during the last decade [7-13].

Furthermore, linting is the most important characteristics influencing the print quality in offset printing of newspaper. In modern pulping and papermaking industry, lint materials consist mostly of ray cells [14]. White birch has much more volume of parenchyma than spruce. In addition, it has 11% volume of vessel elements. These characteristics might increase the linting tendency when birch wood is used to produce mechanical pulps.

Till now, most of the previous studies of co-refining focused on the physical and optical properties and seldom concerned the fibre behavior of different species in the co-refining. The objective of this study is to determine the effects on the mechanical and optical properties due to the substitution of white birch (B) (*Betula papyfera* Marsh) for black spruce (S) (*Picea mariana)* in CTMP process and to study the fibre morphology in order to better understand the behavior of the short fibres of birch in co-refining. Since hardwoods and softwoods respond differently to the chemical treatment, the feasibility of upgrading the white birch chips by chemical pre-treatment before co-refining then with untreated black spruce chips is studied in comparison with the reference CTMP of fresh B/S chip mixtures.

EXPERIMENTAL

As a baseline study, the reference CTMP pulps were produced from B/S mixtures composing of the 0 to 100% white birch (Table 1). Also, the chemical pre-treated white birch chips were used in incorporating with untreated black spruce followed by the CTMP-b and CTMP-c processes (Table 2 and 3).

Table 1 Illustration of symbols used for each trial pulp.

Identification	Process	White birch %	Black spruce %
CTMP-S*	CTMP-a	0	100
CTMP-B*	CTMP-a	100	0
CTMP-B30	CTMP-a	30	70
CTMP-B60	CTMP-a	60	40
CTMP-Bn30	CTMP-b	30	70
CTMP-Bns30	CTMP-c	30	70

* The pulping was repeated

Raw Materials

The black spruce chips were obtained from Kruger mill in Trois-Rivières. The white birch logs obtained from Malette Company, St-Georges-de-Champlain (Québec), were debarked and chipped. All the chips were classified to remove the fines and the over-thick chips (more than 6 mm in thickness) by a Rader chip classifier. The accepted chips accounted for proximately 75% of the total chips.

Chip Pre-treatment and Mixing

According to Jackson *et al* [15], a short atmospheric pre-steaming (10 minutes) is sufficient to get a significant increase in liquid uptake during the subsequent impregnation at room temperature. In this study, the washing white birch chips were steamed for 15 min followed by soaking in an alkaline or alkaline sulfite solution at room temperature, shown in Table 2. A dose of 2.5% sodium hydroxide and 2.5% sodium sulfite both on dry wood was chosen for the convenient of industry application. After treatment, the chips were drained and then blended thoroughly with untreated black spruce chips to produce the desired mixtures before refining.

Table 2 White birch chip chemical pre-treatment conditions.

Series	% NaOH od wood	% Na_2SO_3 od wood	°C	Retention time, min	L/W* ratio
CTMP-a	-	-	-	-	-
CTMP-b	2.5	-	22	30	4.5:1
CTMP-c	2.5	2.5	22	30	4.5:1

* Liquor to wood ratio

Refining Processes

The wood chips were refined by a Sunds Defibrator CD300 pilot plant, following the chemical conditions shown in Table 3. The freeness of pulp from the first stage refining under pressure was controlled between 300 and 450 CSF. During the secondary stage under atmospheric pressure, pulps were sampled at four to five levels of refining energy covering a range of freeness between 80 ml and 200 ml. A different energy consumption was obtained by controlling the plate gap (1.0 mm to 0.2 mm). After the two stages refining, the latency was removed from the pulp before evaluation.

Table 3 Treatment conditions during CTMP process.

Process	% Na_2SO_3 od wood	% NaOH od wood	Steaming min	Time at 128°C min
CTMP-a	2.5	2.5	10	6
CTMP-b	2.5	-	10	6
CTMP-c	-	-	10	6

Fibre Analysis and Pulp Testing

FQA (Fibre Quality Analyzer, OpTest Equipment Inc.) was used to determine the average fibre length and fibre length distribution.

The method of conforming fibre on a wire developed by Steadman was utilised to measure the wet fibre flexibility (WFF) with CyberFlex (CyberMetrics Inc.). With the same instrument, the relative bonded area (RBA) was also determined.

The hydrodynamic specific volume (HSV) of the fractions was measured according to the method described by Marton *et al* [16] and Luukko [17].

The fractions obtained by Bauer-McNett classifier were then studied by light microscopy. The observed fibres and fines were stained with Safranin O to enhance the contrast between the fibre and the glass slide.

The strength properties were measured according to the standard methods of PAPTAC and the optical properties were measured with the Technibrite photometer. Also, linting propensity was evaluated with a RNA-52 printability tester (Research North America Inc.) according to the method L.5U of PAPTAC.

RESULTS AND DISCUSSION

Specific Energy Consumption (SEC)

CTMP-S required higher refining energy than CTMP-B at a given freeness, as shown in Figure 1. Co-refining of white birch with black spruce changed slightly SEC compared to CTMP-S. For the same substitution of 30% white birch, CTMP-Bns30 required lower SEC to reach the same freeness compared to CTMP-Bn30 and CTMP-B30. This is probably because neither alkali nor sodium sulfite was used during co-refining of CTMP-Bns30; thus there was no chemical treatment on black spruce.

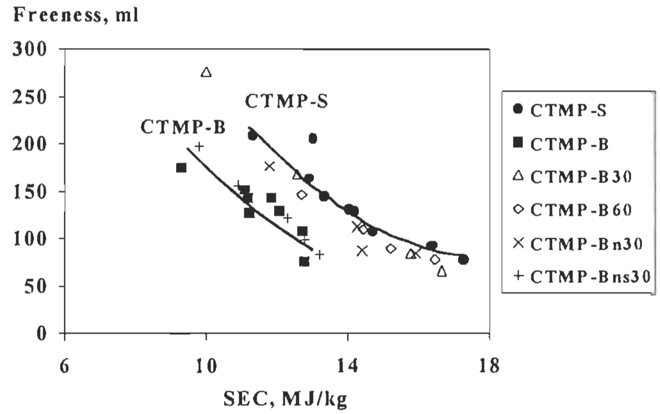

Figure 1 The SEC of the pulps vs. Freeness.

Fibre Properties

Fibre Classification

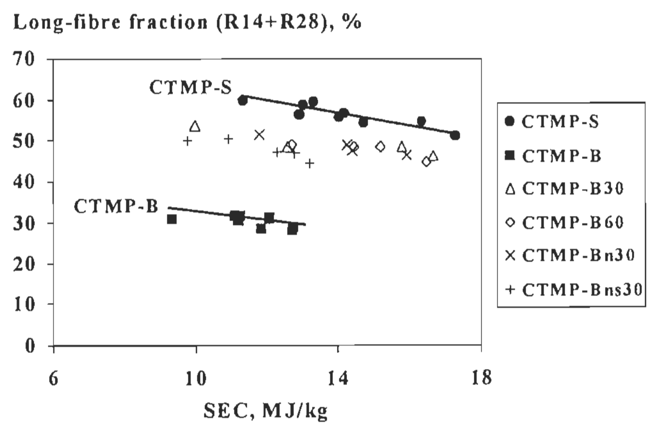

Figure 2 Long-fibre content measured by Bauer-McNett.

As expected, the CTMP-S had the highest long-fibre content while the CTMP-B had the lowest (Figure 2). Inversely, CTMP-B had the highest short-fibre and fines content while the lowest for CTMP-S (Figures 3 and 4). The use of white birch decreased the long-fibre content while increasing the short-fibre content and somewhat the fines content, regardless the substitution degree. This suggested that using white birch reduced the long-fibre content to a certain degree, and then neither the substitution ratio (30 to 60%) nor the chemical pre-treatment of white birch prior to mixing with black spruce affected the degree of fibre-cutting. In this case, all the pulps of chip mixtures had a similar average fibre length, which was located between CTMP-B and CTMP-S. It seems that the chemical treatment could maintain an average fibre length in co-refining probably due to the following reasons: one is that black spruce fibres protect white birch fibres from fibre-cutting; the other is that chemical treatment is much more efficient in swelling and sulfonating white birch thus improving the its' fibre flexibility and decreasing the fibre-cutting in co-refining.

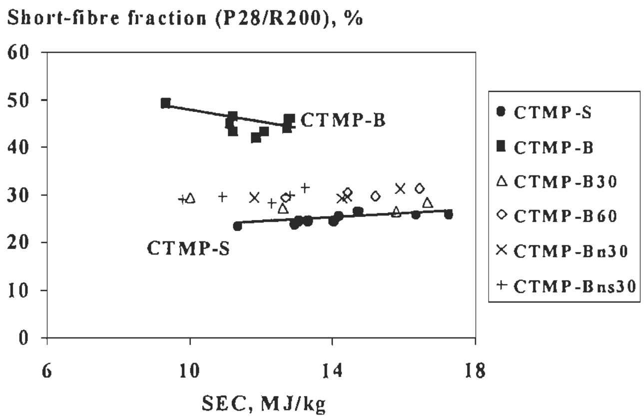

Figure 3 Short-fibre content measured by Bauer-McNett.

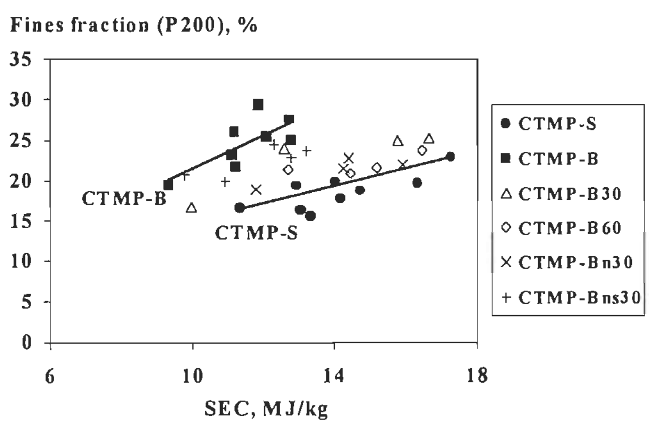

Figure 4 Fines content measured by Bauer-McNett.

Hydrodynamic Specific Volume (HSV)

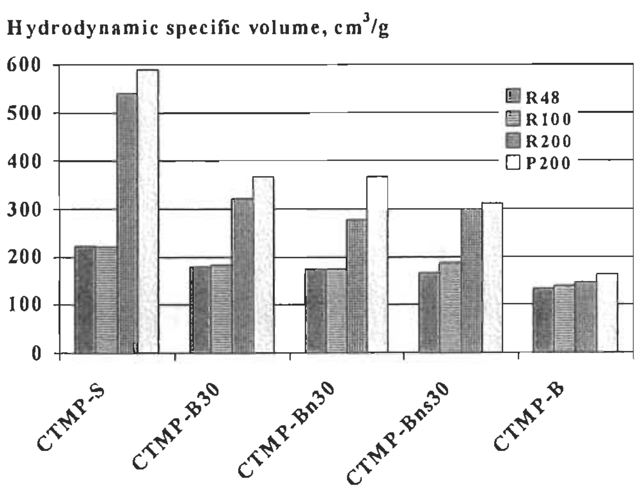

Figure 5 The HSV of the Bauer-McNett fractions.

For CTMP-S, a substantially higher HSV was observed in R200 and P200 compared to R48 and R100, shown in Figure 5. For CTMP-B, the difference of HSV between the fractions was marginal. It points out that the fines fraction has a higher degree of fibrillation than that of fibres fraction for CTMP-S, but not the case for CTMP-B. The use of white birch decreased slightly the HSV of R48 and R100, but largely those of R200 and P200. Compared to CTMP-B30, the chemical pre-treatment of white birch had little influence on HSV of the fractions. These phenomena corresponded well to the visual inspection by light microscopy. Compared to the same fraction of CTMP-S, more fibre fragments were observed in R200 of CTMP-B and they were less developed.

WFF and RBA

For all the samples, an increase of fibre flexibility was observed with the decrease of fibre length (Figure 6). CTMP-B had lower flexibility in these measured fractions than CTMP-S, especially in R100. The use of white birch in chip mixtures decreased the flexibility of R100 while influenced slightly those of R28 and R48. It seems that the substitution ratio of white birch from 30% to 60% had little influence on flexibility. The R100 fibres of CTMP-Bn30 and CTMP-Bns30 had higher flexibility than those of CTMP-B30, while little changes of flexibility were shown on R28 and R48 of CTMP-Bns30 and CTMP-Bn30 compared to CTMP-B30.

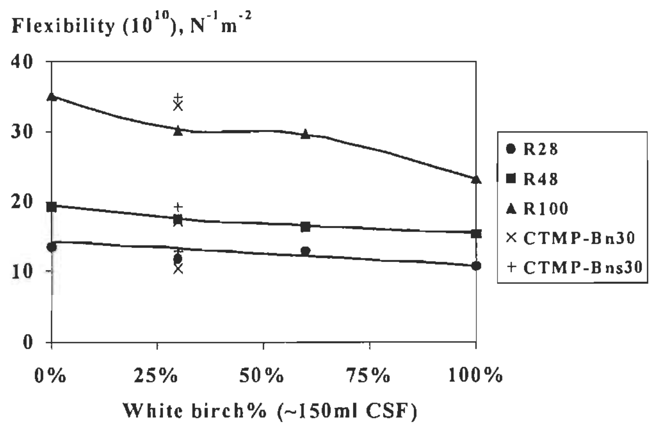

Figure 6 Effect of using white birch on fibre flexibility.

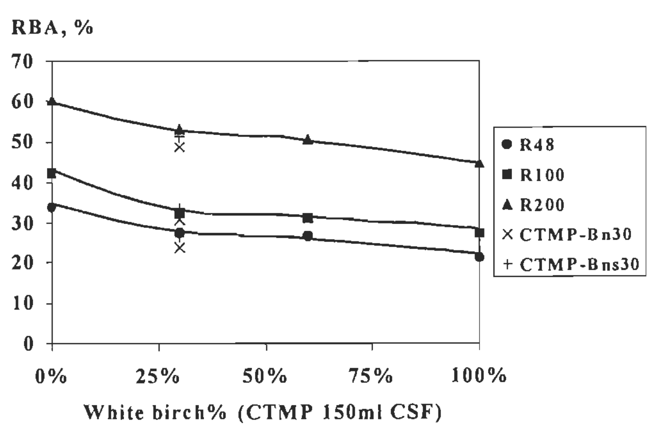

Figure 7 Effect of using white birch on RBA.

The RBA increased also following the decrease of fibre length, as shown in Figure 7. For each fraction, CTMP-B had lower RBA than CTMP-S, which was in agreement with the flexibility measurements. Using white birch for black spruce to produce CTMP decreased the RBA to some degree compared to CTMP-S. Similar to flexibility, this reduction was almost not affected by the substitution ratio of white birch. Compared to CTMP-B30, little modification of RBA was shown on these three fractions of CTMP-Bn30 and CTMP-Bns30. The probable reason is that some other fibre characteristics (e.g. fibrillation) affect the fibre bonding potential besides the flexibility.

Fibre Surface Characteristics

The observation of the fractions by light microscopy showed that considerable improvement of fibre fibrillation and delamination were found on R200 for CTMP-S but not for CTMP-B. For CTMP-B, only slight fibre fibrillation was noticed beginning on R200. Most of ray cells and their fragments were found in P200. The vessel fragments were mainly concentrated in R200. Visual inspection showed that the fractions of the pulps of chip mixtures had a tendency of fibre fibrillation and delamination similar to CTMP-S. In addition, the vessel fragments were introduced into the fractions of the pulps of chip mixtures, especially in R200.

Tensile index and light scattering

The strength and optical properties are two important factors with respect to the quality of mechanical pulps. As shown in Figure 8, for all the pulps, both tensile index and light scattering coefficient increased with augmenting the refining energy but with different degree due to the use of white birch with or without chemical pre-treatment. The CTMP-B had lower tensile strength than CTMP-S at a given light scattering coefficient. Introducing untreated white birch in CTMP had marginal effect on the relationship between tensile index and light scattering coefficient compared to CTMP-S. But, an increase of light scattering coefficient was observed when the white birch chips were pre-treated by alkali-sulfite or alkali alone prior to blending with untreated black spruce chips (CTMP-Bn30 and CTMP-Bns30 compared to CTMP-B30).

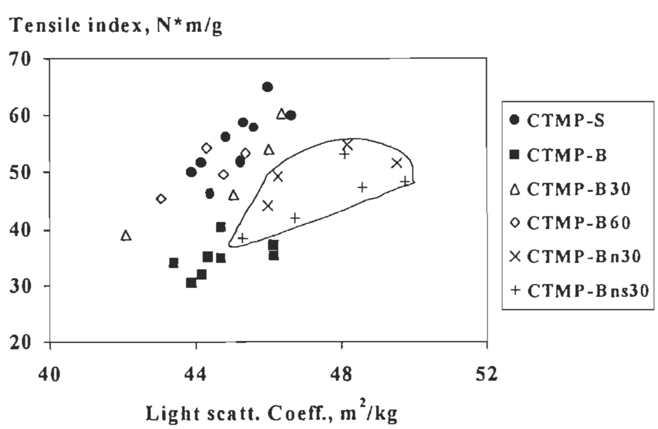

Figure 8 Effect of white birch and chemical pre-treatment on tensile index and light scattering coefficient.

The fines play as an important key in tensile strength and light scattering. Figures 9 and 10 show that the improvement of specific surface due to the production of the fines contributes differently to physical and optical properties. For all the pulps, the tensile index increased following the augmentation of the fines content (Figure 9). At a given fines content, CTMP-B had lower tensile index than CTMP-S, which indicated that the fines of white birch had poorer quality probably due to the presence of vessel and more ray cells besides the lower fibre flexibility. The use of white birch in co-refining with black spruce decreased the quality of fines to some degree but with little influence of substitution degree of white birch and of the chemical pre-treatment. From this point of view, there is a positive effect of using white birch when chemicals are introduced. On the other hand, the fines content of reference CTMP had little influence on light scattering coefficient (Figure 10). But some little improvement of light scattering coefficient can be observed on CTMP-Bn30 and CTMP-Bns30 compared to CTMP-B30 at a given level of fines content.

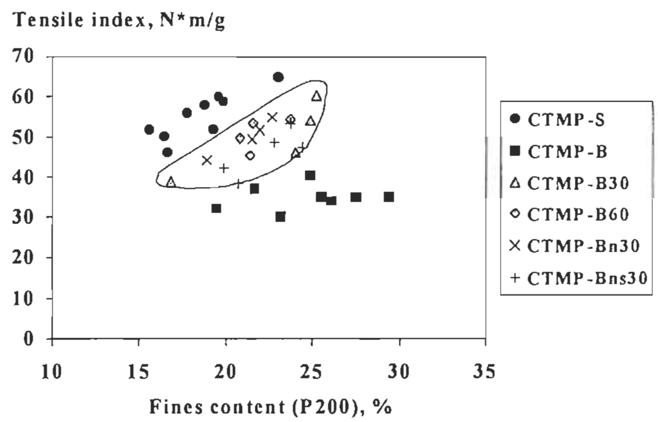

Figure 9 Effect of fines content on tensile index.

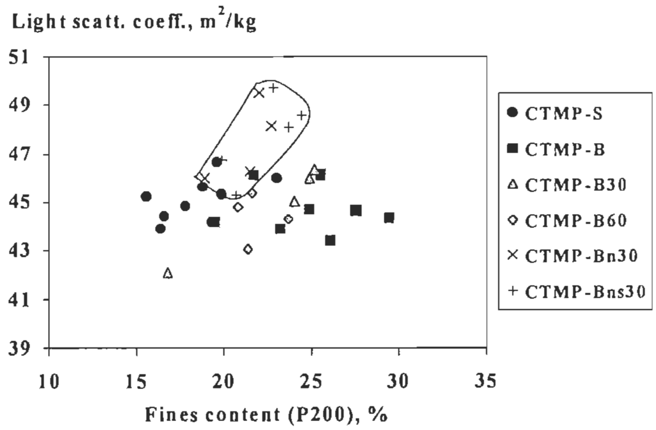

Figure 10 Effect of fines content on light scattering coefficient

Brightness

CTMP-B had a substantial higher brightness than CTMP-S (Figure 11). The presence of white birch up to 60% improved slightly the brightness compared to CTMP-S. Improvement in brightness was found for CTMP-Bn30 and CTMP-Bns30 compared to CTMP-B30. This is probably due to no alkaline darkening effected on spruce chips in co-refining. CTMP-Bn30 had higher brightness than CTMP-Bns30, which illustrated that the presence of sodium sulfite had a positive bleaching effect not only on white birch but also on black spruce. With the help of alkali or alkali-sulfite pre-treatment of white birch prior to mixing with untreated black spruce followed by co-refining without chemicals or with only sulfite, it is possible to produce a pulp with a brightness close to CTMP-B.

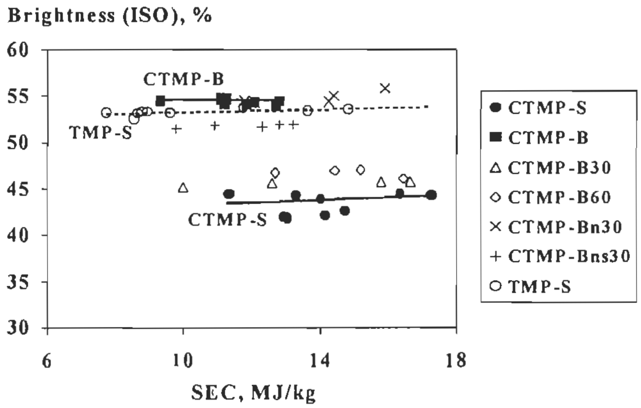

Figure 11 Effect of using white birch and chemical pre-treatment on brightness.

Linting Propensity

The hand sheets made from the pulps at about freeness 150 ml were chosen for linting measurements and the data is shown in Table 4. CTMP-B showed slight higher removed fibres number and cumulated fibres length compared to CTMP-S probably due to its higher ray cells content besides the vessel. Using up to 60% of white birch for black spruce to produce CTMP yielded little influence on linting propensity compared to CTMP-S. For all the samples, more than 90% of the removed materials during the printing test were fines, which were ray cells and some fibre fragments, as observed by light microscopy. Some but few whole intact fibres were found, and also some vessel fragments when white birch was introduced. All the removed fibres have a smooth surface although sometimes the S_2 layer is exposed.

CONCLUSION

The lower fibre flexibility and specific surface of the fines are the two important factors causing the poorer strength properties of the white birch CTMP compared to the black spruce CTMP. The use of white birch in blending with black spruce to produce CTMP showed little influence on the long fibre qualities, but decreased qualities of the short fibre and especially of the fines, according the measurements of flexibility and hydrodynamic specific volume. These reductions were marginally affected by the substitution ratio. However, the substitution of untreated white birch with black spruce could produce CTMP pulps with comparable tensile strength and light scattering to the black spruce CTMP. The alkaline and alkaline sulfite pre-treatments of white birch before co-refining then with untreated black spruce is an alternative to maintain the tensile strength while increasing the light scattering and the brightness due to the absence of alkaline treatment on black spruce fibres compared to the reference CTMP. Furthermore, the problem of linting becomes less important when white birch is co-refined with black spruce to produce CTMP. The probable reason is that sulfonation increases somewhat the bonding ability of the ray cells and the vessels besides the fact that certain amount of vessel fragments and ray cells could be compensated by the introduction of high quality fibres and fines from black spruce.

Table 4 Linting material properties of the pulps.

Code	CSF	IWP	Cumulated fibre length, m/m^2				N	Percentage, %		
	ml	g/m^2	L_{af}	L_{am}	L_{al}	L_{aT}	/65cm^2	Fine	Medium	Large
CTMP-S	145	5.035	17.797	3.866	3.268	24.931	407	91.77	5.83	2.39
CTMP-B30	168	4.958	15.193	3.043	3.521	22.191	362	91.98	5.26	2.77
CTMP-B60	146	4.965	17.382	3.681	2.765	23.828	472	93.44	4.76	1.80
CTMP-Bn30	177	4.956	10.741	2.042	1.757	14.798	339	94.90	3.62	1.48
CTMP-Bns30	157	4.962	21.290	6.380	5.002	32.672	493	89.00	7.91	3.09
CTMP-B	152	4.977	26.903	6.496	6.475	41.571	718	91.54	5.68	2.79

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