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EVALUATION OF VESSEL PICKING TENDENCY IN PRINTING

Authors*: Asikainen Sari
Fuhrmann Agneta
Kariniemi Merja
Särkilahti Airi

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ABSTRACT

Bleached eucalyptus kraft pulps, *Eucalyptus globulus* and *Eucalyptus grandis*, were fractionated using a hydrocyclone (Bauer 3") in order to enrich the vessel elements in one of the fractions. The vessel picking tendency was analyzed with a method developed at KCL. In this method, handsheets are printed with a full scale 4-colour sheet-fed offset printing machine using a commercial printing ink. The vessel picking printing test was performed on the unfractionated eucalyptus kraft pulps, the vessel-rich and the vessel-poor fractions. The picked particles were analyzed and counted using an image analyzer. The vessel picking printing test was also done on the vessel-rich fractions after a PFI mill beating at 2000 revolutions. Hydrocyclone separated the vessels according to their size and shape successfully. The microscopy analysis showed that vessels in the vessel-rich fraction were larger and more square-shaped than those in the vessel-poor pulp. The refining of the vessel-rich fraction decreased the vessel picking tendency to the same or even to a lower level than that of the unfractionated pulp.

INTRODUCTION

The composition of pulp elements influences paper properties interacting like strength and bonding (runnability), surface roughness and surface strength (printability). Papermaking properties of vessel elements are inferior, since they do not bond well and contribute little to the paper strength. The vessel picking is a common problem in printing papers containing hardwood pulps. The vessel picking trouble is a phenomenon by which some of the hardwood vessel elements in paper surface tend to be picked off by the ink tackiness of the printing press (Ohsawa, 1988). Hardwood vessel picking in the offset printing of uncoated fine papers is characterized by the emergence of small white spots in solid and halftone printed areas. These imperfections will replicate exactly in the same area of the print for several hundred impressions, but they will eventually become smaller and less intense until they fade away. The shapes of these white spots are either elongated or may appear more as squares of the order of 1mm or less in dimension. Vessels on the blanket of a conventional offset press are intrinsically oleophobic because of its preferential wetting by the fountain solution. Vessels become oleophilic and accept ink only after some few hundred impressions. Thus, if a vessel picking problem is going to occur, it usually becomes evident after the printing of few hundred sheets (Shallhorn, 1997).

It is generally accepted that vessel picking tendency is mainly caused by the presence of large vessel elements in hardwood pulps, and the problem becomes more severe when the bonding strength between vessel and fibers is excessively weak (Ohsawa, 1988). The number of vessel elements picked off during printing is considered to be caused by factors such as: 1) number, size and shape of vessel elements in paper surface; 2) bonding strength between vessel elements and paper sheet; and 3) number and bonding strength of fibers covering the vessel elements (Ohsawa, 1988; Colley, 1975).

Decrease of vessel picking tendency of hardwood pulps can be achieved through: 1) reducing vessel content in the stock by selecting a suitable hardwood raw material with small and slender vessel elements and conformable fibers (Ohsawa, 1988) or removing large and square-shaped vessel elements by mean of a hydrocyclones (Ohsawa *et al*., 1982; Mukoyoshi, Ohsawa, 1986; Mukoyoshi, 1986; Ohtake *et al*., 1987; Ohtake, Okagawa, 1988); 2) reducing vessel elements size by refining the pulp at high consistency (Ohsawa *et al*., 1984; Nanko *et al*., 1988) or refining the pulp with low refining intensity, i.e. low specific edge load (de Almeida *et al*., 2006; Joy *et al*., 2004); 3) improve vessel to fiber bonding strength by increasing fibers conformability via application of a pulp with high hemicellulose content, by surface sizing, by high consistency pulp refining (Ohsawa *et al*., 1986; Mukoyoshi *et al*., 1986) or by pulp treating with carboxymethyl cellulose (Blomstedt *et al*., 2008; Rakkolainen *et al*, 2009); 4) forming a suitable sheet structure, i.e. covering the vessel elements with fibers (Nanko *et al*., 1987); 5) vessel picking can also be decreased by treating the pulp with enzymes (Uchimoto *et al*., 1988). Besides these pretreatments, paper manufacturing technologies (headboxes, paper machine, wet

***Authors' references:**
VTT Technical Research Center of Finland - Box 1000, FI-02044 VTT, Finland – Tekniikantie 2
Corresponding author: Sari Asikainen – E-mail: sari.asikainen@vtt.fi

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pressing, calendering) and printing machine characteristics (speed, temperature, fountain solution, ink supply, ink type and equipment cleanliness) also affect vessel picking effect.

Vessels are composed of single cells; their size and distribution within the growth ring of the tree vary according to the species. Vessel elements are shorter than hardwood fibers, and the diameter of vessels varies greatly from species to species (Ilvessalo-Pfäffli, 1995). In general, there is about 3 to 25 vessel per mm^2 of eucalyptus xylem cross section. Some species have more vessels than others. There is also much variation between the dimensions of vessel elements, but have mostly a diameter ranging from 60 to 250 µm and a length between 200 to 600 µm. Wood rich in vessels having them very wide in diameter may reach approximately 25% to 30% of its volume taken by vessels. In most commercial eucalyptus species and clones the proportion of vessels in the wood volume ranges from 10% to 20% (Foelkel, 2007).

The vessel wall is relatively thin, practically equal to the fiber wall thickness, between 2.5 and 5 µm. The chemical composition of the vessels is similar to that of the fiber in its chemical constituents, but there are some differences between fibers and vessels. Vessel elements have been found to be richer in cellulose compared with fibers, and lignin has been found in vessel elements even after bleaching (Fardim, Lidström, 2009). There are also indications that the lignin in vessels is more hydrophobic, richer in guaiacyl units than in syringyl (Watanabe, 2004). The syringyl to guaiacyl ratio may reach about 0.5 to 1 for the vessels, while that of fibers is from 2 to 6 (Foelkel, 2007). It has been also stated that the xylan content of vessel elements is higher than that of the fibers (Figueiredo Alves *et al*., 2009).

A laboratory printability tester is not a reliable device for analyzing the vessel picking tendency of commercially made fine papers and not even of different pulps, this because the area of printed paper is too small (a 2.5 cm wide and 30 cm long strip) to capture the statistically rare vessel pick defect. In this study, the vessel picking tendency was analyzed by printing laboratory handsheets with a full scale printing machine, a 4-colour sheet-fed offset printing press, and use of a commercial printing ink.

OBJECTIVES

The aim of this study was evaluating the effects of vessel content, vessel size, vessel shape and pulp refining on vessel picking tendency. Also, the chemical composition of the vessel-free and vessel-rich fractions was determined. The evaluation of the vessel picking tendency was performed using a method developed at KCL.

MATERIALS AND METHODS

Raw material

The bleached eucalyptus kraft pulps used in the trials were of *Eucalyptus globulus*, from South Europe, and *Eucalyptus grandis*, from South America. Both pulps were mill dried.

Fractionation

The mill dried pulps were allowed to swell overnight, and the next morning they were disintegrated using a 50-litre disintegrator. The disintegration time was 15 minutes, and consistency 5%.

The pulps were fractionated using a Bauer 3" hydrocyclone. Trials were performed with feed pulp consistency of 0.1% and differential pressure was 1.6 bar. The trial configuration for Eucalyptus globulus is shown in **Figure 1**. In this paper, the eucalyptus pulp fed to the hydrocyclone is called feed pulp, the accept pulp is called vessel-poor fraction, and the reject pulp is called vessel-rich pulp.

Eucalyptus globulus was fractionated in a two stage system (Figure 1). The reject of the first stage was fed to the second stage. The accept pulp from the second stage was not recovered. *Eucalyptus grandis* was fractionated in a four stage system (Figure 1). The reject of the first stage was fed to the second stage and the reject of the second stage was fed to third stage, etc. Also in this case the accept pulps from the second, third and fourth stages were not recovered.

After each fractionation stage the pulp samples were analyzed with a Kajaani FS-300, and the number, length and width of vessel elements were determined. This was done to monitor the separation efficiency.

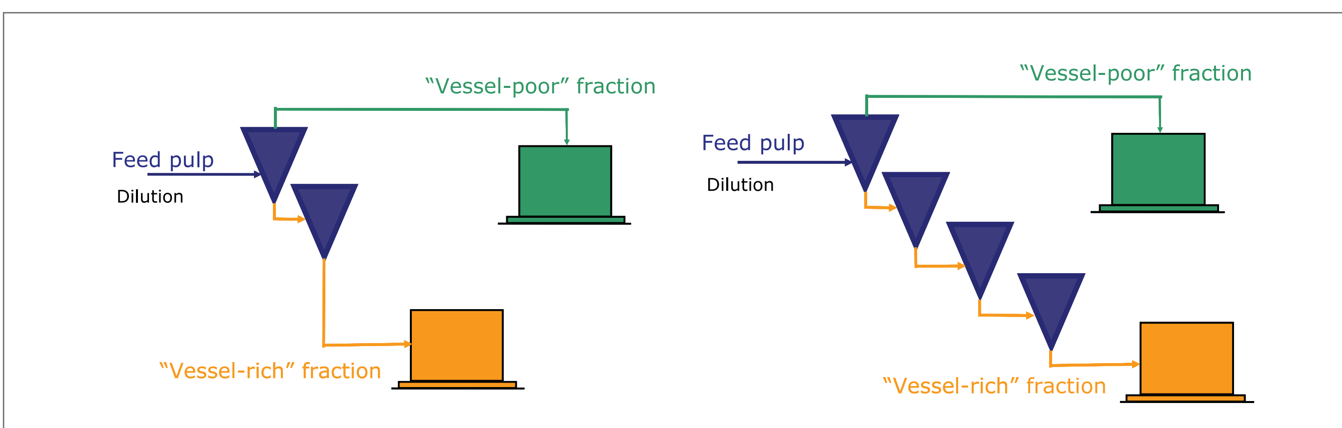

Figure 1. Trial configuration for ***Eucalyptus globulus***, on the left, and for ***Eucalyptus grandis***, on the right

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Table 1. Cell type composition of *Eucalyptus globulus*

m/m, %	Feed	Vessel-poor	Vessel-rich
Fibers	96.5	97.4	98.4
Vessels	0.4	0.2	1.2
Ray cells	3.1	2.4	0.4

Table 2. Cell type composition of *Eucalyptus grandis*

m/m, %	Feed	Vessel-poor	Vessel-rich
Fibers	96.7	95.5	96
Vessels	0.5	0.4	4.0
Ray cells	2.8	4.1	traces

Analyses

Calculation of cell type composition (fibers, vessels and ray cells) - SCAN-G3:90 - was performed for the feed pulps, vessel-rich and vessel-poor fractions. The vessel length and width was also determined using light microscope; 300 vessels were measured.

The following chemical analyses were conducted on the feed, vessel-rich and vessel-poor fractions:

- Total residual lignin, Klason lignin and acid soluble lignin (KCL internal method, TAPPI T222 modified)
- Uronic acids (KCL internal method, SCAN Forsk 737)
- Acetone extracts (SCAN-CM 49)
- Carbohydrate composition (TAPPI T249 modified)

Before these analyses, fines were removed from pulp samples.

Vessel picking test

The feed, vessel-poor and vessel-rich pulps were used in unrefined state. In addition, the vessel-rich fractions were refined with a PFI mill at 2000 revolutions in order to see the refining effect on vessels.

Handsheets were formed according to standard EN ISO 5269-1 from unrefined feed pulps, vessel-poor and vessel-rich pulp fractions and also from the refined vessel-rich pulp fractions, five sheets for each sample. Target grammage of the sheets was 60 g/m^2.

Handsheets were calendered with a sheet calender. Calendering conditions being: line pressure of 94 kN/m (15 bar) through a single nip. The calendered laboratory sheets were taped to a carrier sheet. Sheets were printed with a 4-colour sheet-fed offset printing press using a commercial printing ink and one back trap nip. Pick marks were collected from the blanket with adhesive tapes. The tapes were analyzed with an image analyzer to count picking tendency: total number of picks/cm^2 and picked area µm. As the method is laborious, no parallel measurement were done, so the reliability of the method cannot be properly estimated.

RESULTS AND DISCUSSION

Cell type composition

Enrichment of the vessel elements succeeded to the reject fraction. Ohsawa *et al.*, (Ohsawa, 1982) had also found possible to separate vessel elements by hydrocycloning, and that the vessel elements are accumulated to the reject fraction. **Table 1** and **Table 2** show the cell type composition of *Eucalyptus globulus* and *Eucalyptus grandis*, respectively.

When the hydrocycloning was performed in a two stage system, Table 1, it was possible to increase the vessel content of the pulp from 0.4% (m/m) to 1.2% (m/m). In the four stage system the vessel content of the pulp increased from 0.5% (m/m) to 4.0% (m/m), Table 2. Somewhat better separation efficiency is found in the literature of Ohsawa *et al.*, (Ohsawa, 1984). In their study, vessel elements were separated with a hydrocyclone-centricleaner 600 - a more efficient hydrocyclone than the one used in this study - from eucalyptus pulp and succeeded to enrich about 5.7 weight% of vessels to the reject fraction.

Table 1 and Table 2 show that the ray cells content of the vessel-poor fractions were higher than that of the vessel-rich fractions. In the *Eucalyptus grandis* case the ray cell content of the vessel-poor fraction was even higher than that of the feed pulp. The enrichment of ray cells to the accept fraction has also been seen earlier (Panula-Ontto, 2002).

The calculation of the vessel elements showed higher values after refining (**Table 3**). This is because under refining vessels are broken and splitted, as shown in **Figure 2.**

Table 3. Vessel content of the unrefined and refined pulp, *Eucalyptus grandis*

m/m, %	Unrefined vessel-rich	Refined vessel-rich
Fibers	96	95.1
Vessels	4.0	4.9
Ray cells	traces	-

Figure 2. Refined *Eucalyptus globulus* vessel-rich fraction

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Table 4. Vessel dimension of *Eucalyptus globulus*

Vessel dimension, µm	Feed	Vessel-poor	Unrefined vessel-rich	Refined vessel-rich
Length	305	293	307	334
Width	178	153	190	171
Width/length	0.58	0.52	0.62	0.51

Table 5. Vessel dimension of *Eucalyptus grandis*

Vessel dimension, µm	Feed	Vessel-poor	Unrefined vessel-rich	Refined vessel-rich
Length	357	346	368	394
Width	179	167	208	220
Width/length	0.50	0.48	0.57	0.56

Ohsawa *et al.,* (Ohsawa, 1984) have also found that especially high consistency refining decrease vessel picking effect. In their study, pulps were beaten with a PFI mill at a consistency of 10% or 20%. According to them, high consistency refined pulp contained more fibrillated fibers and fibrillated vessels. In this study, fibrillation of vessel elements was not detected (Figure 2).

Dimension of vessels

Table 4 and **Table 5** show that the hydrocyclone separated the vessels according to their size. The vessel-rich fractions had wider vessels than the other pulps. The length of the vessels was about the same in all pulps. In addition, vessels of the vessel-rich fractions were more square-shaped (width/length) than those of the feed pulp and of the vessel-poor pulp. The same observation has also been made by Mukoyoshi *et al*., (Mukoyoshi 1986).

Table 4 and Table 5 also show that the dimensions and the shape of the vessel elements were different after refining, this because vessels were broken and splitted during refining. Width/length ratio was lower, which means that the vessels were not so much square-shaped than before refining.

Chemical composition of the pulps

The polysaccharide composition and lignin content of the various pulps did not show any difference, despite the vessels enrichment. Content of extractives was below the determination limit in all cases. The only difference was seen in the content of hexenuronic acid. The *Eucalyptus grandis* vessel-rich pulp contained more hexenuronic acid (11 mmol/kg) than the *Eucalyptus grandis* feed pulp (7.2 mmol/kg) and the vessel-poor pulp (below the determination limit of 4.5 mmol/kg). Higher xylan content of vessel-rich pulp was already reported (Figueiredo Alves *et al*., 2009), and it is known that methylglucuronic acid - the side group in native xylan - is partly converted into hexenuronic acid during kraft cooking (Teleman *et al*., 1995; Danielson, 2007). Based on this information, it is likely that the vessel-rich fraction could have higher hexenuronic acid content than the vessel-poor fraction. However, it should be kept in mind that this difference is not necessarily due to the vessel elements, because vessel content of the vessel-rich fraction was still fairly low, 4% (m/m).

Vessel picking tendency of the pulps

Figure 3 shows pictures taken from printed sheets of *Eucalyptus grandis.*

Picked areas are shown as white spots in the handsheets. Pictures taken from handsheets made from the feed pulp (Figure 3, on the left) and the vessel-poor fraction (Figure 3, in the middle) are almost alike. The handsheet made from the feed pulp contained somewhat more occurrences and showed a little larger pick marks than the sheet made from the vessel-poor pulp.

The sheet made from the vessel-rich fraction (Figure 3, on the right) had such a high number of vessel elements in the printed

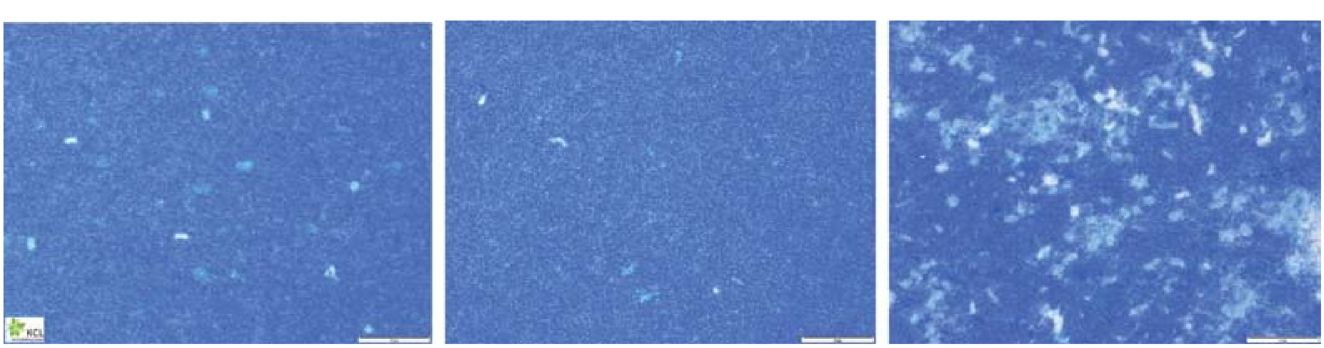

Figure 3. Printed handsheets of feed pulp (on the left), of vessel-poor fraction (in the middle) and of vessel-rich fraction (on the right) of *Eucalyptus grandis*

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Table 6. Vessel picking results for *Eucalyptus grandis*

Number of picks/cm²	Feed	Vessel-poor	Vessel-rich
Ink	3.2	2.3	Too many picks to count
Back trap	2.1	1.3	Too many picks to count
Total	5.3	3.6	Too many picks to count
Picked area, μm²			
Ink	0.20	0.08	Too many picks to count
Back trap	0.06	0.03	Too many picks to count
Total	0.26	0.11	Too many picks to count

Table 7. Vessel picking results for *Eucalyptus globulu*

Number of picks/cm²	Feed	Vessel-poor	Vessel-rich
Ink	4.1	3.0	16.2
Back trap	2.2	1.7	10.8
Total	6.4	4.7	27.0
Picked area, μm²			
Ink	0.19	0.12	1.09
Back trap	0.04	0.03	0.35
Total	0.23	0.15	1.44

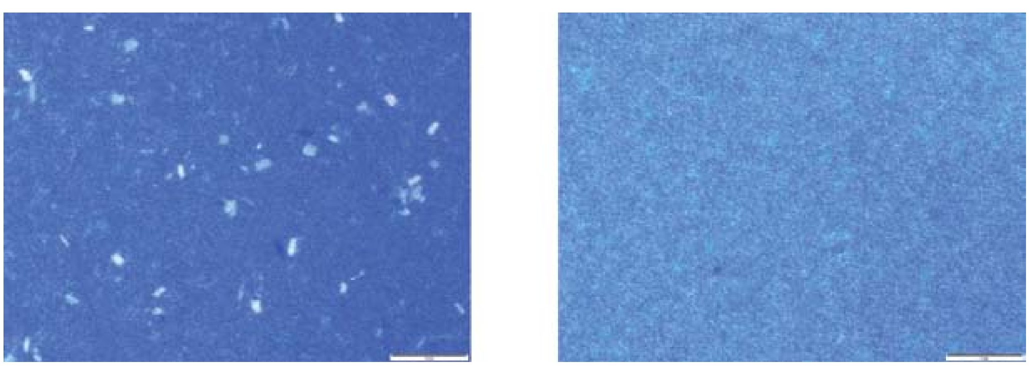

Figure 4. Printed handsheet made from unrefined (on the left) and refined (on the right) *Eucalyptus globulus* vessel-rich fractions pulp

sheets that the pick marks are shown as large areas rather than as spots. When the pick marks were observed with a loupe, it was noticed that the picked vessels had also attached released fibers from the paper surface.

The collected pick marks from the printing blanket were counted with an image analyzer. The total number of picks/cm² in the feed and vessel-poor *Eucalyptus grandis* pulps was 5.3 and 3.6, respectively (**Table 6**). The vessel-rich *Eucalyptus grandis* pulp contained too many picks to be analyzed with the image analyzer. The picked area of the vessel-poor *Eucalyptus grandis* pulp was clearly lower than that of the feed pulp, 0.11 μm² *vs.* 0.26 μm².

The total number of picks/cm² in the feed, vessel-poor and vessel-rich *Eucalyptus globulus* pulp was 6.4, 4.7 and 27.0, respectively (**Table 7**).

The picked area of the vessel–rich *Eucalyptus globulus* pulp was 14 times greater than that of the feed pulp. The picked area of the vessel-poor *Eucalyptus globulus* pulp was lower than that of the feed pulp, 0.15 μm² *vs.* 0.23 μm².

Refining effect on vessel picking

It is known from literature that high consistency refining is especially effective for vessel element destruction, and that it can considerably reduce the content of large vessel elements. Regardless of refining methods, the destruction of vessel elements reaches a certain level at CSF 400 mL, and further refining gives only small change in vessel elements size (Nanko, 1988). In this study, vessel-rich pulps were refined in a PFI mill (refining consistency 10%) at 2000 revolutions, and after this refining the picking tendency was determined.

Figure 4 and **Figure 5** show picture taken from printed handsheets

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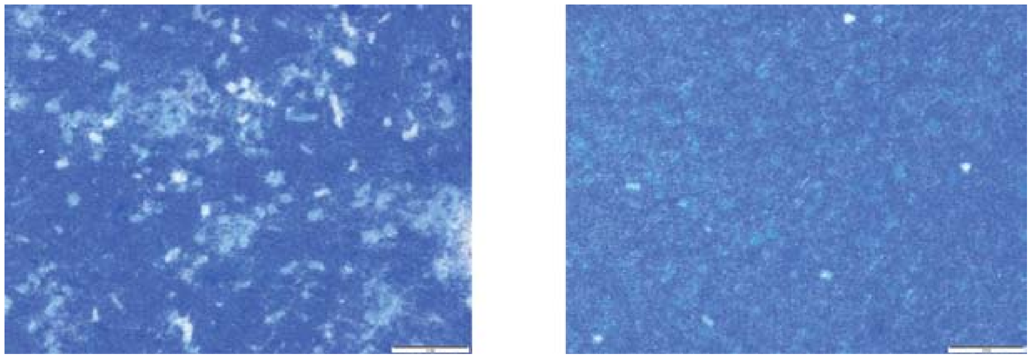

Figure 5. Printed handsheet made from unrefined (on the left) and refined (on the right) *Eucalyptus grandis* vessel-rich fractions pulp

made from the unrefined and the refined vessel-rich fraction of *Eucalyptus globulus* and *Eucalyptus grandis* pulps, respectively.

By refining the *Eucalyptus globulus* vessel-rich fraction, the number of picks/cm^2 was reduced from 27.0 picks/cm^2 to 2.3 picks/cm^2 (Table 4). As already shown, under refining vessels were broken (Figure 2) and they were not so much square-shaped as before refining. This was one reason for the reduced picking tendency. In addition, the conformability of the fibers is increased during refining, and vessel to fiber bonding strength is also increased (Ohsawa *et al.*, 1984; Ohsawa, 1988; Colley, 1975).

After refining, the number of picks/cm^2 was lower than that in the unrefined feed pulp and also even lower than that in the vessel-poor pulp. The number of picks/cm^2 of the feed pulp, vessel-poor pulp and refined vessel-rich fractions was 6.4, 4.7 and 2.3, respectively. Also, the picked area decreased remarkably with refining, from 1.44 µm^2 to 0.05 µm^2, and it was lower than that of the feed pulp (0.23 µm^2) and than that of the vessel-poor pulp (0.15 µm^2).

The number of picks/cm^2 and the picked area decreased in the refining of *Eucalyptus grandis* vessel-rich fraction. However, the total number of picks/cm^2 of the refined *Eucalyptus grandis* vessel-rich fraction was 7.0 (**Table 9**). This is still about 30% higher than that of the feed pulp. Also, the total picked area was about 20% higher for the refined vessel-rich fraction than that of the feed pulp.

Table 8. Vessel picking results for the *Eucalyptus globulus* feed pulp, vessel-poor, unrefined and refined vessel-rich fractions

Number of picks/cm^2	Feed	Vessel-poor	Unrefined vessel-rich	Refined vessel-rich
Ink	4.1	3.0	16.2	1.2
Back trap	2.2	1.7	10.8	1.1
Total	6.4	4.7	27.0	2.3
Picked area, µm^2				
Ink	0.19	0.12	1.09	0.03
Back trap	0.04	0.03	0.35	0.02
Total	0.23	0.15	1.44	0.05

Table 9. Vessel picking results for *Eucalyptus grandis* feed pulp and refined vessel-rich fraction

Number of picks/cm^2	Feed	Refined vessel-rich
Ink	3.2	4.2
Back trap	2.1	2.8
Total	5.3	7.0
Picked area, µm^2		
Ink	0.20	0.22
Back trap	0.06	0.10
Total	0.26	0.32

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CONCLUSIONS

Bleached eucalyptus kraft pulps - *Eucalyptus globulus* and *Eucalyptus grandis* - were fractionated using a hydrocyclone. The vessel picking tendency was analyzed by printing the handsheets with a full scale printing machine, 4-colour sheet-fed offset printing press, and using a commercial printing ink. Hydrocyclone separated vessels according to their size and shape; the vessel-rich fraction had larger and more square-shaped vessels than the vessel-poor fraction. The vessel-rich pulps had a higher number of picks/cm^2, and also the picked area was larger than that of the feed pulps and the vessel-poor pulps. During the refining process, vessels went broken and splitted, and the bonding strength of the fibers was increased. Due to this, refining of the vessel-rich fraction decreased the vessel picking tendency to the same or even lower level than that of the unfractionated pulp. Also, the area of the pick marks decreased. This study proved that the method developed at KCL properly evaluates the vessel picking tendency of the various pulps. It was also shown that fractionation technique enables the study of pulps with various vessel contents, the chemical composition of the pulps and the effect of separate pulp treatment on vessel picking tendency. ■

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