EFFECT OF DIFFERENT WOOD SPECIES ON THE PERFORMANCE OF SURFACTANTS USED TO IMPROVE THE RATE OF KRAFT LIQUOR PENETRATION INTO CHIPS

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Received April 29, 2010

The paper describes the application of the penetration instrument, previously developed and tested with aspen wood only, to other wood species. The evaluation was done for three resinous species (*Betula Pendula*, *Eucalyptus Globulus* and *Eucalyptus Grandis*), for Lodgepole pine samples in different stages of infestation by mountain pine beetle and, finally, for non-resinous softwood species (black spruce). It was found out that the amount and the chemical composition of extractives play an important role in the efficiency of surfactants, which are more effective with highly resinous wood. Surfactants considerably improved the liquor penetration through the grey stage (the most advanced stage) of Lodgepole pine infestation, even if this had not been possible with samples in the red stage. It was confirmed again that the rate of penetration into non-/resinous softwood species cannot be improved with surfactants.

Keywords: penetration, *Betula Pendula*, *Eucalyptus Globulus*, *Eucalyptus Grandis*, Lodgepole pine, aspen, mountain pine beetle, extractives, Kraft process, surfactants

INTRODUCTION

The application of surfactants in pulp and paper industry is not new. Surfactants have been widely used in pulp washing, pulp bleaching and deinking. It has been reported that surfactants can improve wetting of wood surfaces and the dispersion and emulsification of resins in kraft pulping.[1,2] Published reports have also claimed that, when using surfactants as pulping additives,[3-5] screened yield is increased and screen rejects are reduced without sacrificing pulp quality.

Surfactants can influence wood impregnation by modifying the surface properties of wood and liquor, by removing resins, or by a combination of both. The complex interaction between a liquid and a solid surface can be considered a combination of three different processes: wetting, absorption and adsorption.[6]

According to published literature, surfactant-based digester additives allow for a more thorough and a faster penetration of the pulping liquor into the wood chip. Blackstone[4] has reported a 5% decrease in screen rejects when using surfactants in kraft cooking of southern pine chips – for obtaining the same kappa number, with and without surfactants. Researchers from China[7] have observed that the addition of 0.5% sodium dodecyl benzene sulfonate in soda pulping of wheat straw improved the penetration of the pulping liquor. Duggirala[3] has reported that the addition of 0.1% ethoxylated alcohol surfactant (on oven-dry wood) resulted in a 0.5-0.8% increase in total pulp yield, at a given kappa number, compared to control cooks; screen rejects also decreased and deresination was enhanced. Other researchers have shown that, when added to the kraft liquor, surfactants, such as ethoxylated alcohols or ethoxylated dialkylphenols, reduce the rejects and increase the screened yield through enhanced penetration of the pulping liquor into wood.[8] Chen[9] has reported that using a blend of surfactants can reduce cooking liquor usage and cooking time. It has been demonstrated that a blend of surfactants can often perform better than a single one, as it can improve parameters such as interfacial activity, solubilization and detergence.[10]

METHODS

Selection of surfactants

The optimum concentration of surfactant in the kraft pulping process can be determined by the measurement of critical micelle concentration (CMC). The measurement method applied has been described in a previous publication.[11] The surfactants used in this study were either commercial formulations supplied by the chemical manufacturers, or formulations described in literature. Anionic and non-ionic surfactants were used either individually or as blends (Table 1). The anionic surfactants used were ethoxylated alcohols or sodium dodecyl benzene sulphonate (SDBS), while the non-ionic surfactants were dimethylamides of unsaturated fatty acids. Three non-ionic surfactants of unknown composition were used, as recommended for kraft pulping of tropical hardwood species, here denominated as #1, #2 and #3. The penetration measurement data having led to the selection of these particular surfactants were also given in a previous publication.[11]

Penetration measurements

Figure 1 shows schematically the penetration measurement instrument used in the work. Prior to the experimental run, the middle glass tube was filled with pulping liquor, after which the liquor was released to the left and right tubes, until reaching the top of the left tube. A wood slice is placed on top of the left tube contacting the pulping liquor. The right tube is graduated and measures the volume of liquor absorbed by the wood slice.

The measurements are automated, due to a pressure transducer, which responds to the height of the liquor in the calibrated tube. More details on measurements can be found elsewhere.[11]

Table 1
Surfactant blends used

Surfactant blend	Anionic surfactant	Non-ionic surfactant
#1	SDBS	Dimethylamides of unsaturated fatty acid
#2	Ethoxylated alcohol	

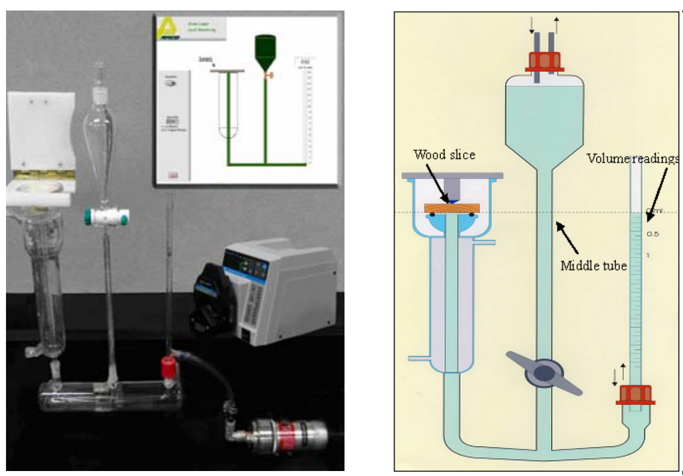

Figure 1: Photograph and schematic presentation of the penetration measurement instrument

Wood quality

Hardwood species

Eucalyptus Grandis, *Eucalyptus Globulus* and *Betula Pendula* were the three hardwood species used in the study. *Eucalyptus Grandis*, aged between 5 and 7 years, originated from either São Miguel or Mucuri forests in Brazil, while the 12 year-old *Eucalyptus Globulus* came from the Foradouro forest in Portugal. *Betula Pendula* was 67 year-old and originated from a Finish forest. The vessel size of *Betula Pendula* is about 50% greater than those of both *Eucalyptus Grandis* and *Eucalyptus Globulus*, which are relatively similar. The density of *Eucalyptus Globulus* was 0.63 g/cm^3, that of *Betula Pendula* – 0.51 g/cm^3, and that of *Eucalyptus Grandis* – 0.47 g/cm^3. The extractive contents[12] were 7.0% for *Betula Pendula*, 3.6% for *Eucalyptus Globulus* and 2.6% for *Eucalyptus Grandis*, respectively. To investigate the effect of resins on the penetration process, some wood slices of *Betula Pendula* were extracted, prior to penetration measurements, with an acetone-water mixture, according to a Tappi Standard Method (T 280 pm-99).

Black spruce wood

Black spruce wood is the predominant softwood species in Eastern Canada, the sample used in this project coming from a forest farm in the Eastern Townships of Quebec.

Lodgepole pine

The samples of Lodgepole pine trees, which had been attacked by the mountain pine beetle, were obtained from British Columbia. The samples were collected from trees, at different stages of response to the attack. The green stage sample was taken from a 5 year-old tree not infested by the beetle yet; the red stage sample was from a 10 year-old tree having a high level of extractives and a reduced moisture content; finally, the grey stage sample was from a dead tree with very low moisture and extractive contents (Table 2). The initial increase in extractives and then the decline in both extractive and moisture contents can cause operational mill problems.[13]

Table 2
Details of Lodgepole pine tree samples[14]

Stage	Moisture content (%)	Extractive content (%)
Green	54	1.6
Red	24	5.3
Grey	18	1.8

RESULTS AND DISCUSSION

Penetration experiments with hardwoods

The changes in the rate of liquor penetration for *Betula Pendula*, *Eucalyptus Globulus* and *Eucalyptus Grandis* were measured with three non-ionic surfactants and two blends of anionic and non-ionic surfactants.

Effect of wood structure on liquor penetration

Figure 2 shows the penetration rates of the three hardwood species without surfactants. The penetration rate of *Betula Pendula* was the fastest, that of *Eucalyptus Grandis* being considerably slower and only slightly faster than that of *Eucalyptus Globulus*. Such differences[12] in the penetration rates are explained by the lumen size of *Betula Pendula*, which is about 50% larger than those of the *Eucalyptus Grandis* and *Eucalyptus Globulus*. Although *Betula Pendula* has the highest extractive content among the three species, the rate of penetration into it is still the fastest, due to the large diameter of the vessel lumens.

Effects of surfactant blends on the deresination of Betula Pendula

Penetration experiments were done with *Betula Pendula*. Figure 3 shows the results of 4 penetration measurements, performed with the same surfactant blend. Apparently, the surfactant blend can improve the penetration rate. However, as shown by the upper two curves, when the extractives were removed from the wood, the penetration rate was very high and independent of the presence of the surfactant. This result implies that, although *Betula Pendula* has large vessels, the surfactants improved the rate of penetration, as a result of deresination.

Effects of surfactant concentration on wood penetration rate

Figures 4 and 5 show that the surfactant charge is a critical performance parameter. It is disconcerting to see that the addition of surfactants, to give a liquor concentration of 1250 ppm, as recommended by the supplier, greatly decreased the penetration rate of *Betula Pendula* and *Eucalyptus Globulus* – compared to that of the control. This result indicates that adding surfactants at concentrations considerably higher than that of their CMC (4 ppm) can hinder liquor penetration, probably by blocking the vessel lumens. It appears that, at higher concentrations, the surfactant may combine with the extractives and block the lumen. *Eucalyptus Grandis* (Fig. 6) was less affected by a high surfactant concentration, at a penetration rate similar to that of the control. This result is likely caused by the lower content of resins in this sample. Only when surfactants were added at critical micelle concentrations was the penetration rate appreciably improved for all three wood species.

Efficiency of non-ionic surfactants in liquor penetration

Figures 7 to 9 show that non-ionic surfactant #3 at CMC improved the penetration rate of all three species, while surfactant #1 at CMC did not improve it beyond that of the control. The figures also show that the addition of surfactant #2 to CMC caused a similar or slightly slower penetration rate with *Betula Pendula* and *Eucalyptus Globulus versus* that of the control, while it greatly improved the penetration rate with *Eucalyptus Grandis*.

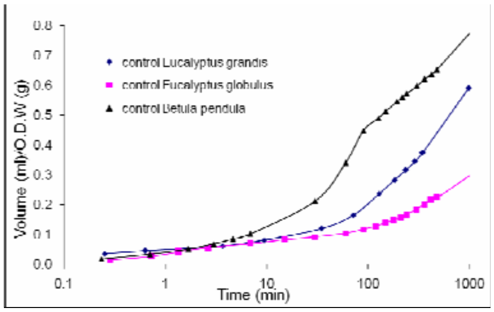

Figure 2: Effect of the wood structure of tropical species on liquor penetration

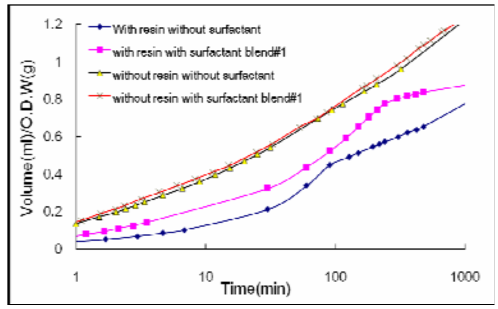

Figure 3: Effects of surfactant blend #1 on deresination of *Betula Pendula*

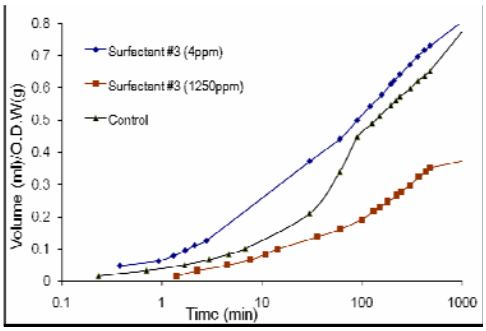

Figure 4: Penetration rates at different concentrations of non-ionic surfactant #3 for *Betula Pendula*

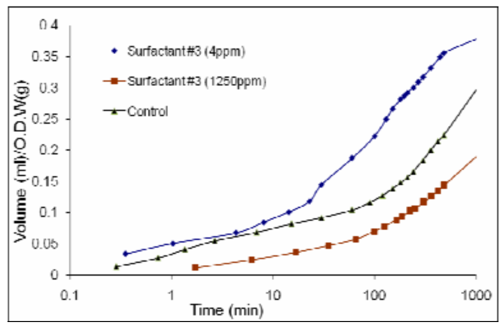

Figure 5: Penetration rates at different concentrations of non-ionic surfactant #3 for *Eucalyptus Globulus*

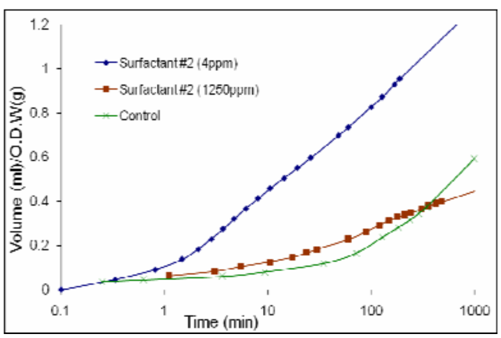

Figure 6: Penetration rates at different concentrations of non-ionic surfactant #2 for *Eucalyptus Grandis*

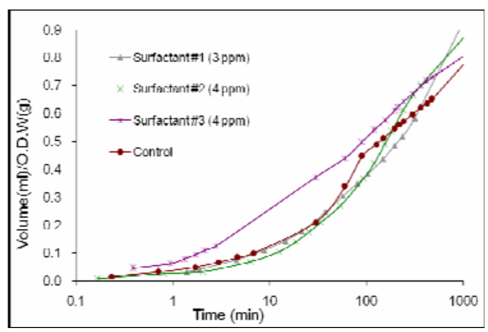

Figure 7: Penetration rates *versus* different surfactants for *Betula Pendula*

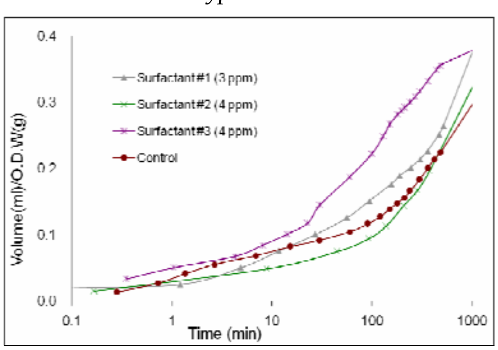

Figure 8: Penetration rates *versus* different surfactants for *Eucalyptus Globulus*

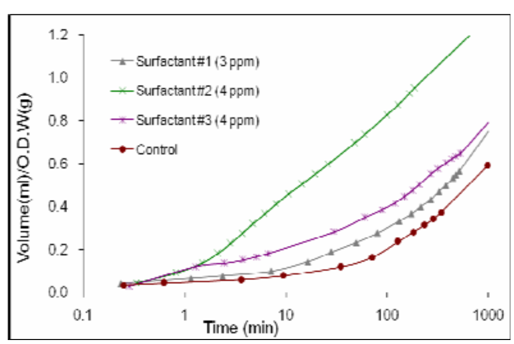

Figure 9: Penetration rates *versus* different surfactants for *Eucalyptus Grandis*

As the extractives contain different chemical compounds in different wood species, the results obtained suggest that the surfactant needs to be tailored to the specific extractive composition.

Penetration experiments with beetle infested Lodgepole pine

Effects of surfactants on the penetration rate of Lodgepole pine

Samples presenting 3 response stages were tested, using two blends of anionic and non-ionic surfactants (Table 1). Figures 10 to 12 show that, whereas surfactant blend #2 could not improve the penetration rate, surfactant blend #1 considerably improved it, for the samples presenting all three response stages. The improvement in the penetration rate was appreciably higher for the grey stage sample; the penetration rate was nearly three times faster than that of the control without surfactants. The green stage sample showed less improvement with the surfactant, while the red stage sample showed negligible improvement in the penetration rate, with any blend of surfactants. This result is surprising because the red stage sample had the highest content of extractives. However, the chemical composition of the extractives varies with the response stage; for example, the concentration of 2', 6'-dihydroxy-4'-methoxy chalcone increased from the grey stage to the green stage and to the red stage.[14] More specifically, the ratio between the resin and the fatty acids in the samples is changed, namely more resin acids than fatty acids remain in the grey stage wood. Such results suggest that the resin acids are more problematic, their removal being considerably improved when the fatty acids are removed by surfactant treatment.

Penetration experiments with black spruce

Figure 13 demonstrates that the penetration rate of black spruce sapwood was much faster than that of heartwood, and also that surfactants improved liquor penetration neither in sapwood nor in heartwood samples.

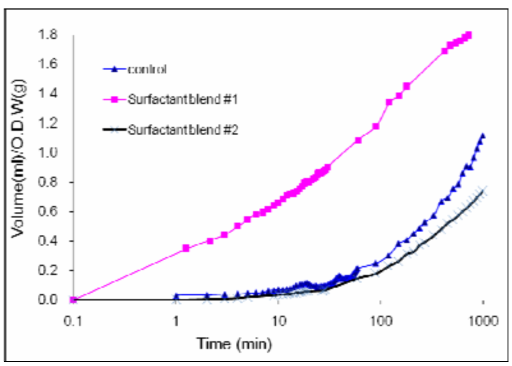

Figure 10: Effects of surfactant blends on the penetration rate of grey stage Lodgepole pine tree

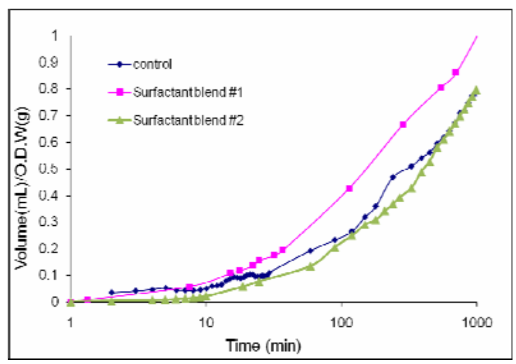

Figure 11: Effects of surfactant blends on the penetration rate of green stage Lodgepole pine tree

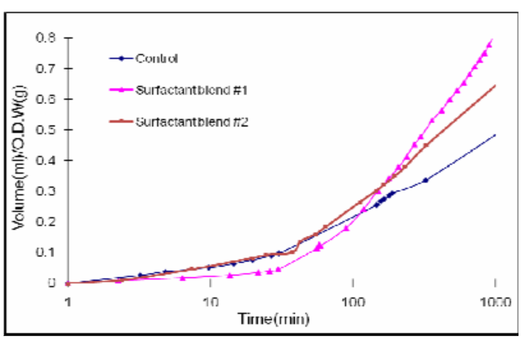

Figure 12: Effects of surfactant blends on the penetration rate of red stage Lodgepole pine tree

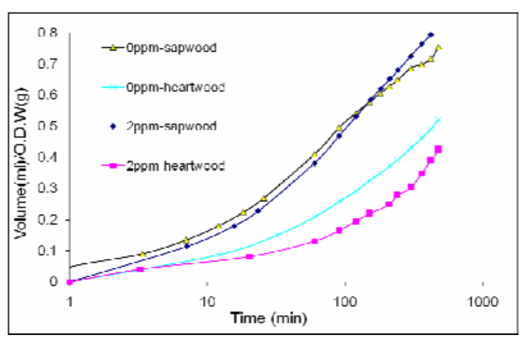

Figure 13: Penetration rates of black spruce sapwood and heartwood with non-ionic surfactant at CMC

CONCLUSIONS

The liquor penetration measurement instrument, previously developed and tested with aspen wood, is effective for the evaluation of the liquor penetration rate of different wood species.

The experiments carried out with three resinous species, *Betula Pendula*, *Eucalyptus Globulus* and *Eucalyptus Grandis*, showed that the amount and the chemical composition of extractives play an important role in the efficiency of surfactants, and also that liquor penetration is considerably improved by surfactant addition with highly resinous wood samples. Surfactant concentration was also found as critical, once the application of values higher than the critical micelle concentration may inhibit rather than improve liquor penetration.

The Lodgepole pine samples presenting different stages of response to the mountain pine beetle attack showed that surfactants considerably improved the liquor penetration of the grey stage samples, but not that of the red stage ones; a possible reason for this might be the different resin-to-fatty acids ratio found in different infestation stages.

Another conclusion was that the rate of penetration into non-resinous softwood species could not be improved by surfactants.

ACKNOWLEDGEMENTS: The authors are grateful to NSERC and FPInnovations (Paprican) for the generous financial support. They also wish to thank Mr. Henrique Siminoto Robortella from the University of São Paulo for his careful experimental work.

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