Acid-insoluble and acid-soluble lignin characteristics in kraft pulping of hybrid *salix* clones

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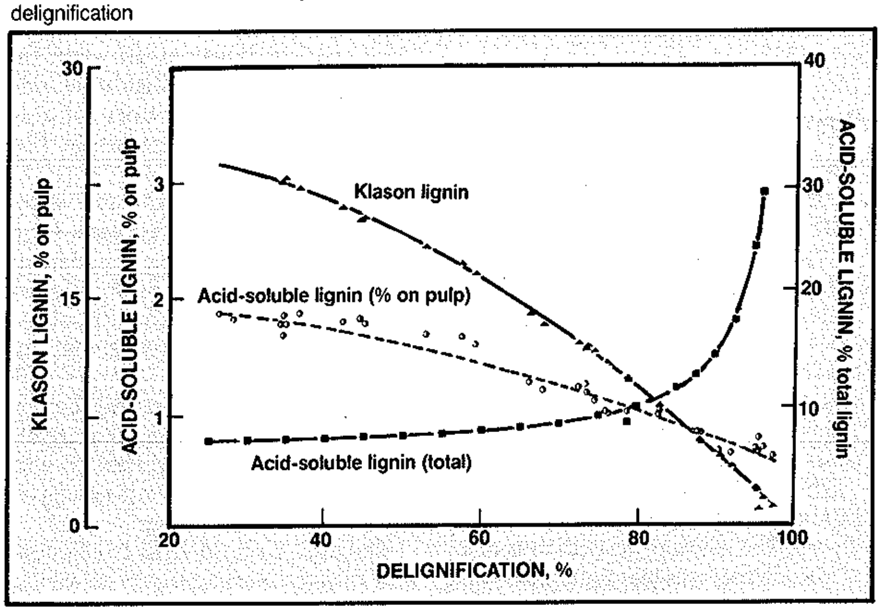
One of the potentially promising concepts that is capable of challenging the impending shortage of raw material for the pulp and paper industry is that of short-rotation forestry. In this method, hardwood species such as *Populus* and *Eucalyptus* and softwoods such as southern pines and larch are grown at relatively high density on prepared sites.

To bring the concept to fruition, the species must be suitable, which depends on various factors. Such factors include the rate of value increment, the species' predominance in existing forests, its value for uses other than timber production, ease of planting, acreage for artificial regeneration, and the success and cost of producing improved stock (*1*).

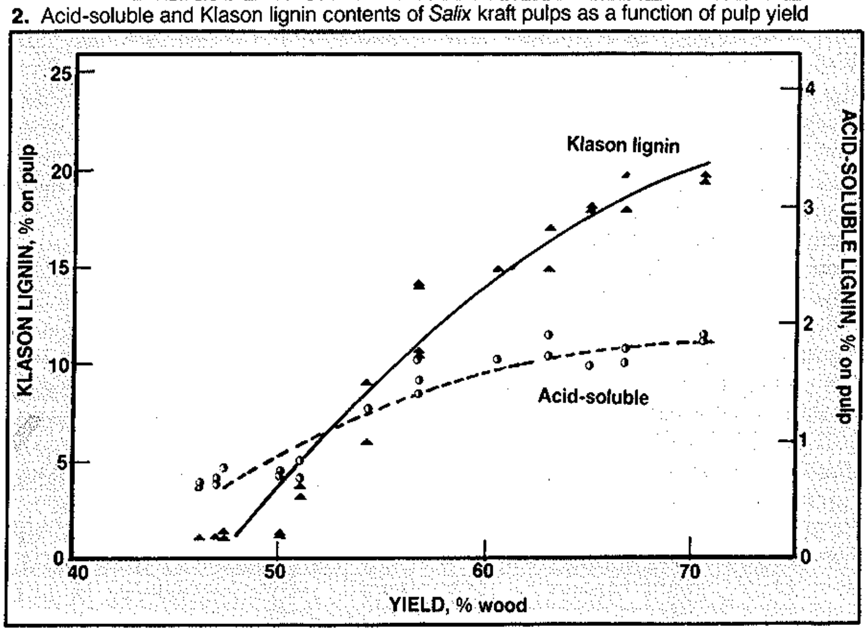
The recoppicing characteristics of the *Salix* species, the possibility of rapid genetic improvement, clonal propagation, relatively short rotations, and the relative uniformity of the physical properties of the trees make selected hybrids of this species attractive for study.

Earlier research provided some information on pulping properties of juvenile *Salix* stems (*2–4*). However, the pulping properties of different species of *Salix* that can be grown on short rotations have not been studied. In our study, we characterized pulping properties among clones from different species and within species, using current shoots from stools that

1. Acid-soluble and Klason lignin contents of *Salix* kraft pulps as a function of percent delignification



2. Acid-soluble and Klason lignin contents of *Salix* kraft pulps as a function of pulp yield



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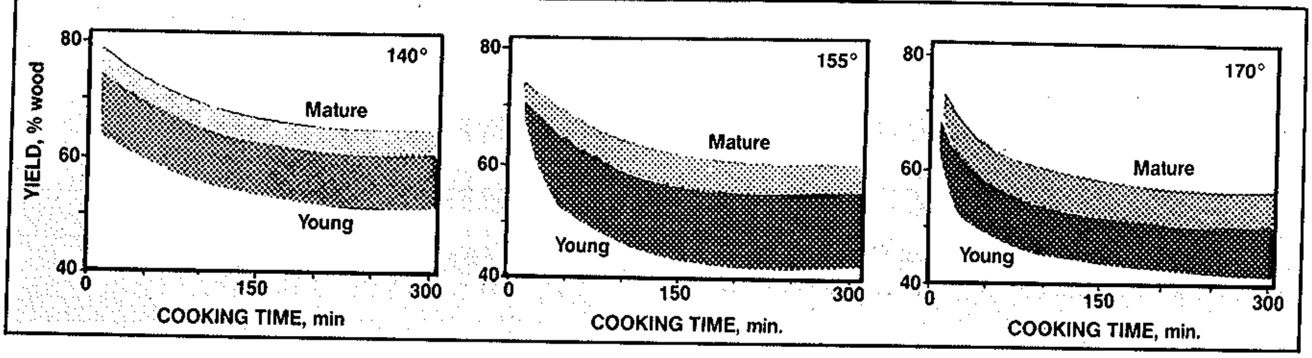
3. Kraft pulp yields of young and mature *Salix* at pulping temperatures of 140°, 155°, and 170°C



were one year old in 1982. Thirteen young clones from within and between species were used in the study. Three other *Salix* clones, 14 years old, were also included for additional comparisons.

Results and discussion

The activation energies of bulk lignins ranged from 98 to 120 kJ/mol, a difference in activation energy that is statistically significant. From the reaction rates, say at 155°C, the rate of bulk lignin dissolution was high for clone SH3 (*Salix hastata*). Similarly, the lowest activation energy from among the young clones was for SH3. Therefore, SH3 would be an ideal clone for pulping.

The activation energy for bulk lignins is slightly higher for mature clones. The average activation energy of 107 kJ/mol was less than that of the 132-kJ/mol average reported for species such as *Eucalyptus regnans* by Nelson and Gniel (*5*). The activation energy is higher than Obiaga and Wayman obtained for *Gmelina arborea* (*6*) but lower than Wilder and Daleski obtained for kraft delignification for loblolly pine (*7*).

A typical result obtained for acid-insoluble (Klason) and acid-soluble lignin contents in pulp at various degrees of delignification is shown in **Fig. 1.**

Regardless of clones, acid-insoluble lignin contents in pulp correlate with the percentage of delignification and could be expressed by a second-order polynomial. Alkali treatment of wood dissolves the acid-insoluble portion of lignin gradually during the entire delignification process. Up to about 50% delignification, the percentage of acid-soluble lignin content in pulp remains almost constant.

Between 70-95% delignification, the percentage of acid-soluble lignin based on total lignin increases, and this increase is exponential after about 80% delignification. The trends were also not linear at all when the percentages of acid-insoluble and acid-soluble lignins were plotted against pulp yield, as shown in **Fig. 2.**

This plot may be the result of the fact that the data incorporate a large enough range to show the nonlinearity of the trend. Therefore, over the entire range of pulp yield, the acid-insoluble and acid-soluble lignin dissolution trends are not linear. These trends may arise from the structural changes in the residual lignin caused by severe alkali treatment in combination with prolonged time and temperature, in the case of kraft pulping.

The data on pulp yield from young and mature clones pulped at various temperatures (**Fig. 3**) indicate that regardless of temperature, a mature clone would result in higher yield than could be achieved from a young clone. This higher yield would result from the greater amounts of hemicellulose in young wood than in mature wood. Therefore, in predicting the expected yield from young clones, a 5-6% lower yield also needs to be considered.

Conclusions

The apparent activation energy for kraft pulping of wood from different hybrid *Salix* clones ranges from 98 to 120 kJ/mol. The average activation energy is less than reported for species such as *Eucalyptus regnans*, revealing it as an ideal species for pulping.

Among the species, wood from clone SH3 (*Salix hastata*) requires the lowest activation energy in bulk delignification.

Acid-insoluble and acid-soluble lignin contents in pulp are strongly related to percent delignification; the relationship could be fitted by a second-order polynomial. This finding is contrary to the straight-line relationship found by earlier researchers. Similar nonlinear relationships were also evident when these contents were plotted against pulp yield.

In pulping young and mature wood by the kraft process, a 5-6% difference in yield could be expected in normal operating conditions. Therefore, in any economic justification for using young wood, this drop in expected yield must be taken into account.

Material preparation and details of kraft pulping

For a complete discussion, please refer to our paper in TAPPI conference proceedings (*8*).

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