

Using a kraft pulping model to improve pulp uniformity

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ABSTRACT *The penetration of kraft liquor into Douglas fir chips is measured as a function of digester heat-up time, chip thickness, and chip moisture. Results of the penetration study are input to a kraft pulping model to study the consequences of incomplete penetration on pulping uniformity. Simulation results show that uniform pulping is achieved with moderately sized commercial chips if the digester heating time is longer than one hour.*

KEYWORDS

Diffusion
Kinetics
Kraft pulping
Penetration
Process
simulation
Pulps

When nonuniform pulp is produced, inferior paper products and operation difficulties may occur downstream. The relationship between pulp uniformity and ease of operation in the bleach plant is particularly close. Wide variations in pulp kappa number require higher bleach plant loadings to maintain a specified brightness. Bleaching pulps with a wide kappa range and using excess bleach will increase the effluent toxicity and may increase the concentration of toxins in the pulp (1-3).

Pulp variability comes from a variety of sources. Incorrect chemical charges caused by chip moisture variations or disturbances in causticization (4) will result in batch-to-batch deviations. Within a single batch, temperature gradients or liquor channelling can yield nonuniform pulp (5, 6). Pulping nonuniformity also results from heterogeneities in the chips. Knots, oversized chips, and dry chips will produce partially reacted chip cores and will liberate fibers that have a wide range of kappa numbers (7).

These sources of variation will adversely affect pulp quality. The difficulty is to quantify the effect of these sources, particularly when there are multiple variables to consider. For example, a digester with temperature

gradients pulping oversized chips will produce pulp of low quality. Which factor contributes most to the nonuniformity and how much improvement in uniformity will be achieved by eliminating one or both of these sources of variation is difficult to know *a priori*. It is essential to know this, however, before spending capital to improve digester performance.

Experiments can and should be performed to help answer pulp nonuniformity questions. Unfortunately, experiments are time-consuming and expensive, and conditions that occur commercially may be difficult to reproduce in the laboratory. An accurate, theoretical pulping model provides a quick and inexpensive means of studying the effects that sources of variation have on pulp properties. A large number of sources may be studied simultaneously, or one at a time, to ascertain the primary disturbances in a mill. Once the major source of variation has been identified, the efficacy of corrective measures may be studied. Experiments may be performed in parallel with the simulations to confirm simulation results and to fine tune the model.

Here, we illustrate how a pulping model may be used to determine the effect of one cause of pulp variability—

incomplete penetration of pulping liquor. We discuss experimental penetration studies first and then modeling work performed to study the effect of incomplete penetration on pulping behavior.

Penetration experiments

Liquor penetration curves for commercial chips are required before the effect of incomplete penetration on pulping properties can be thoroughly studied. Penetration into handcut chips has been studied (8), but these chips serve as poor models for the highly fissured commercial chips (9). Previous studies were performed in our laboratory to determine the mode by which pulping liquor penetrates a commercial chip (10). The results reported here are a continuation of those qualitative studies. The objective of this research is to measure quantitatively the penetration of kraft liquor into commercial Douglas fir chips as a function of chip thickness, chip moisture, and digester heating rate.

Experimental methods

Douglas fir chips obtained from the Weyerhaeuser Longview mill are pulped with the conditions shown in Table I. Chips that are 5 mm and 10

mm thick represent average accepts and oversized chips, respectively. After pulping, chips are removed from the digester and are immediately frozen in liquid nitrogen to stop the penetration. The frozen chips are then split open and photographed. **Figure 1** shows a typical photograph of partially impregnated chips.

Photographs of the split chips are digitized and analyzed to determine the extent of liquor penetration. (The extent of penetration is defined as the fraction of a chip that is impregnated with pulping liquor.) This experimental method for determining the extent of penetration is somewhat tedious; however, other methods that we tried—gravimetric separations or titrations of residual alkali—were too confounded by pulping reactions and chemical diffusion to be used.

Experimental results

Figure 2 shows the extent of liquor penetration into 10-mm air-dried chips when pulped with different heat-up times. Each datum in **Fig. 2** represents an average of about ten penetration measurements. The figure shows that the penetration is initially rapid, but then it slows markedly at high extents of penetration. Penetration curves similar to those in **Fig. 2** have also been reported by other researchers (11–13). The surprising result in **Fig. 2** is that the penetration rate is independent of heat-up time for the heating rates used in this study. This result was observed for all chip moistures and thicknesses.

Figure 3 shows the penetration curves for all the pulping conditions; the results from the different heat-up times are averaged together to yield each curve. As anticipated, thinner chips penetrate faster than thick chips, and a reduction in chip moisture retards penetration. The 5-mm, never-dried chips are completely impregnated in 1 h, whereas the 10-mm, air-dried chips take almost twice that long. This result is consistent with the theory that penetration is controlled by the dissolution and diffusion of air trapped in a chip (8). Thinner chips have shorter diffusion paths and hence will penetrate faster. Lower chip moisture means more air is trapped in the chip and less water is evaporated when the chip is heated. Vaporization of water displaces trapped air.

Most of the chips in a commercial

digester are 3–8 mm thick and are quite wet. **Figure 3** shows that under these conditions, the impregnation will be essentially complete before the digester reaches the top temperature if the heating time is greater than 1 h. Simulation results have shown that achieving complete penetration before the top cooking temperature is reached significantly improves pulping uniformity (14).

Simulations

Simulations with the University of Washington Pulping Model were run to study the consequences of incomplete liquor penetration. The pulping model, described in detail elsewhere (14), predicts the intra-chip lignin, carbohydrate, and effective alkali profiles. It also predicts the bulk alkali concentration as a function of pulping time. The pulping conditions described in **Table I** with the penetration curves shown in **Fig. 3** were input to the model for the simulations.

Simulation results are shown in **Figs. 4–7**. The pulp kappa numbers as a function of H-factor for the 12 cooks are shown in **Figs. 4** and **5**. **Figures 4** and **5** reveal that the heating rate has a small effect on the kappa H-factor curve when pulping thin chips to bleachable grades, but it becomes significant at higher kappa numbers. In thicker chips, the effect of heating rate on the pulp properties is evident at all lignin contents: faster heating leads to higher kappa numbers. Such behavior is a consequence of pulping reaction retardation by penetration and diffusion limitations when the digester is heated rapidly. **Figures 4** and **5** also show that the 10-mm chips pulp much slower than the 5-mm chips at all digester heating rates but that the differences between air-dried and never-dried chips is less dramatic, especially for 5-mm chips. The greater effect of chip thickness on pulping rate might be anticipated, since penetration and diffusion rates are a function of chip thickness but only the penetration rate is a function of the initial chip moisture.

The uniformity of pulp within a given chip may also be examined with the model. In **Figs. 6** and **7**, the intra-chip kappa profiles for chips pulped to H-factor 1400 are shown. In these figures, all the 5-mm chips display

I. Pulping conditions for penetration experiments and pulping simulations

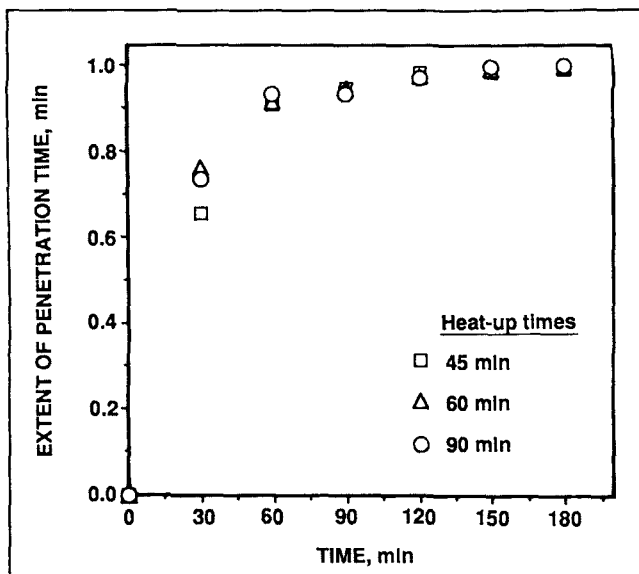
Effective alkali, % on wood as NaOH	22
Sulfidity, %	25
Liquor/wood, L/kg	4/1
Initial temp., °C	25
Max. temp., °C	170
Heat-up times, min	45 60 90
Pulping times, min	30–180
Chip thickness, mm	5, 10
Species, Douglas fir.	

1. Partially impregnated Douglas fir chips

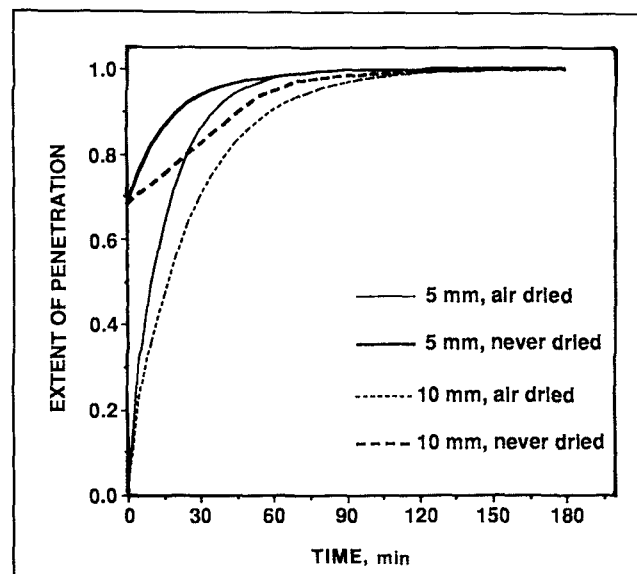
uniform pulping except at the centers of those chips heated quickly in the digester. Pulps produced from the 5-mm chips heated in 45–60 min might produce rejects, but the lignin contents of fibers liberated from the cook would be uniform. A comparison of 5-mm intra-chip lignin profiles between **Figs. 6** and **7** also demonstrates that air drying these chips moderately reduces pulp uniformity.

The centers of the 10-mm chips, in contrast to the 5-mm chips, have high kappa numbers, and the variation in lignin content across the chip is broad. The 10-mm chips will yield high reject levels and liberate fibers with an

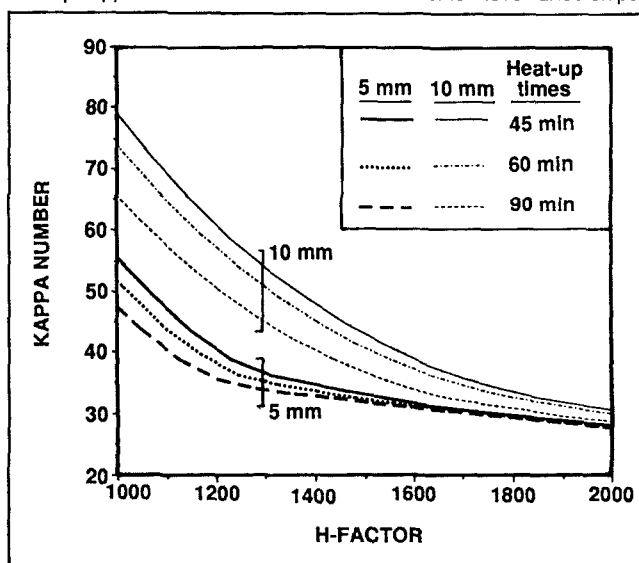
2. Penetration into 10-mm air-dried chips for three heat-up times



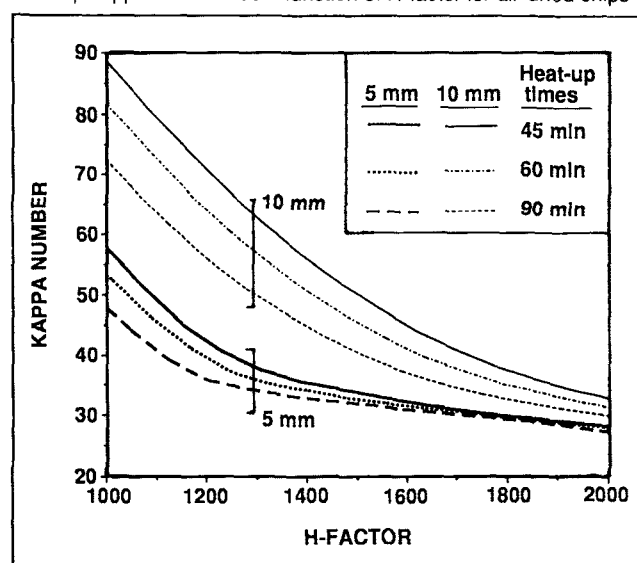
3. Liquor penetration into commercial Douglas fir chips



4. Pulp kappa numbers as a function of H-factor for never-dried chips



5. Pulp kappa numbers as a function of H-factor for air-dried chips



extensive kappa range. Such fibers will be difficult to bleach and will result in an inferior paper product. The impact of chip moisture on pulping uniformity is more drastic in the 10-mm case than for 5-mm chips. Figure 7 shows that the centers of air-dried, 10-mm chips barely get cooked, especially when a rapid heating rate is used.

Note that the pulping behavior leading to the kappa profiles in Figs. 6 and 7 is complex and, as such, is difficult to predict with absolute accuracy. Simulation results should be viewed as representing typical behavior and not as absolute predic-

tions of pulping performance.

Conclusions

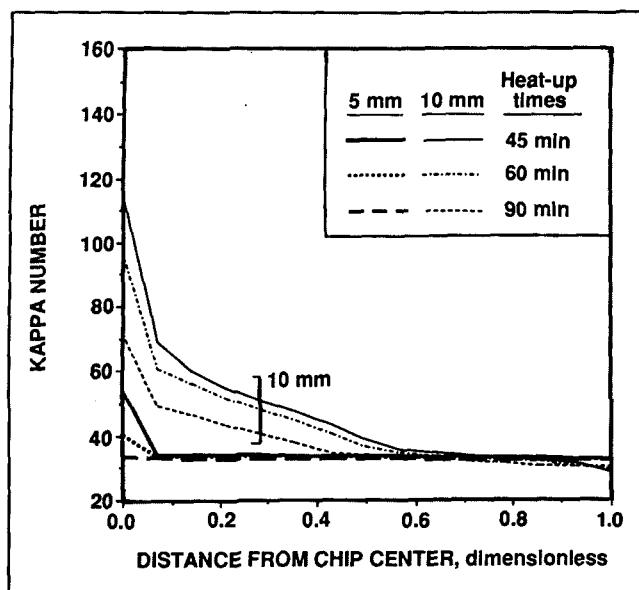
Results of experimental penetration studies on commercial Douglas fir chips show that the rate of liquor impregnation is independent of digester heating rate. Liquor impregnation was faster in thin chips, and a low moisture content led to slower penetration. Penetration into moderately sized, 5-mm-thick, commercial, never-dried chips is sufficiently rapid to avoid significant pulp variability if heat-up times longer than 1 h are used. Simulation results show that the

effect of chip thickness on pulping uniformity is greater than the effect of initial moisture content. However, the effect of moisture content becomes more important in thick chips. Pulp uniformity is improved, particularly in thick chips, if longer heating times are used. For thick chips, however, it appears that pulping will be nonuniform even with long digester heat-up times. □

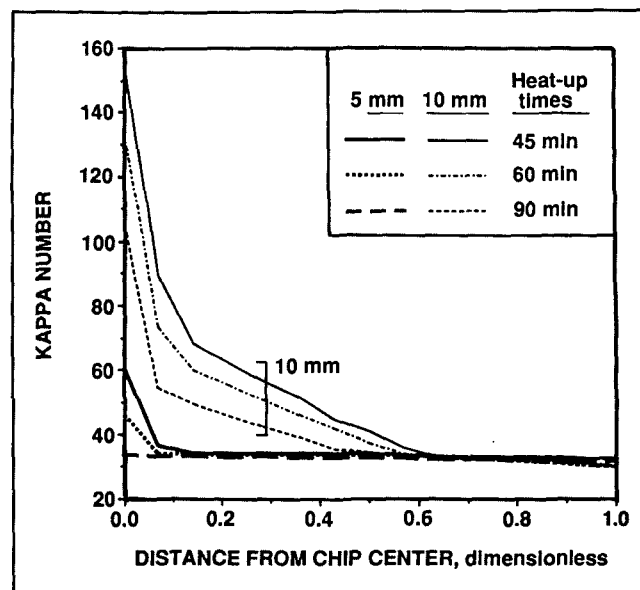
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6. Intra-chip kappa profiles for never-dried chips pulped to 1400 H-factor



7. Intra-chip profiles for air-dried chips pulped to 1400 H-factor



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The authors wish to thank the Weyerhaeuser Co. and the USDA Competitive Grant Program (Grant No. 85-FSTY-9-0099) for their support of this research.

Received for review June 18, 1989.

Accepted Feb. 23, 1990.

Presented at the TAPPI 1989 Process and Product Quality Conference.