Water release from fractionated stock suspensions. Part 1 – Effects of the amounts and types of fiber fines

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ABSTRACT: Cellulosic fines produced varying resistance to dewatering in tests with a gravity-based freeness device. Fines at low to moderate levels had little effect on gravity dewatering, but fines slowed drainage considerably as their concentration increased beyond a threshold. Fines created by refining (secondary fines) slowed drainage to a much greater extent than did those originally present in bleached hardwood kraft pulp (primary fines). The results were consistent with a mechanism in which unattached fines can migrate within a wet web to choke points, where they tend to block the flow of water.

Application: This report shows how and why fiber fines can slow the rate of dewatering of furnish, especially when they are present at relatively high levels.

The presence of cellulosic fines in a papermaking furnish can significantly affect the rate of dewatering, sometimes limiting the overall production rate on a paper machine. By more effectively removing water during forming and pressing, mills can potentially reduce the energy required for drying paper. Higher levels of fines can result from increased use of mechanical pulp, from increased refining, and from recycling paper without deinking. These issues are of increasing economic importance as papermakers attempt to produce more tons without increasing fixed costs.

Especially since the 1950s, important theoretical work has revealed factors affecting the rate of dewatering of papermaking fiber suspensions [1-7]. The resistance to dewatering has been successfully modeled as a function of the sizes, surface areas, and flexibility of fibers in wet mats. Few of these studies have dealt with issues related to fiber fines [8-13] or the effects of papermaking chemicals [14-15]. A recent review noted that the traditional explanations of resistance to dewatering do not correctly account for effects related to fiber fines content, slurry consistency, or the addition of drainage-promoting additives [7]. The external surface area per unit mass is much higher for fines than for fibers, which might account for the effects of fines on drainage. In that case, the Kozeny-Carman equation can be applied to predict the effects of the fines on dewatering rates. However, this approach fails to properly account for effects of increasing fines content and increasing basis weight on the resistance to dewatering.

An alternative explanation suggests that fines increase resistance to flow through a fiber mat as choke points become plugged within the wet web of paper [5,7,12,14,16-19]. Unattached fiber fines may be able to follow channels in a wet web during drainage. Such fines may become trapped at constricted locations and then have a disproportionate effect on reducing the rate of flow.

To begin to address these issues, we examined the effects of two types of cellulosic fines on the dewatering of a bleached kraft fiber suspension under the influence of gravity.

EXPERIMENTAL SYSTEM

Materials

We prepared and refrigerated separate fractions of fiber fines and long fibers for later use. The fiber portion was obtained by dispersing a 20 lb, 84 brightness, 35% recycled content xerographic copy paper and then collecting the fiber fraction using a Bauer-McNett classifier with a 100-mesh screen (TAPPI T 233 "Fiber length of pulp by classification"). The classifier was run for 15 min during each batch treatment to reduce total fines content.

Primary fines came from bleached hardwood kraft pulp obtained in dry-lap form from a local southern U.S. paper mill. The pulp was dispersed with 15,000 revolutions of a TAPPI disintegrator (TAPPI T 205 "Forming handsheets for physical tests of pulp"). The fraction of pulp that would then pass through a 100-mesh screen in the classifier was collected in large drums. After the solids had been allowed to settle overnight, the liquid on top was siphoned off. The fines suspension subsequently was transferred to smaller containers, where additional settling and siphoning of liquid was carried out until the solids content was about 0.1%.

Secondary fines were produced by taking the material from the preceding step that was retained by the 100-mesh screen (i.e., the R100 fraction), and refining it extensively with a laboratory Hollander beater (TAPPI T 200 "Laboratory processing of pulp") for 30 min. Batches of the refined suspension were then placed in the final vessel of the classifier, using a 200-mesh screen. The fraction that passed through the screen was collected in large drums and concentrated by settling, as before.

1. Optical micrographs of (A) primary fines from unrefined bleached hardwood kraft pulp, (B) secondary fines from refining of bleached hardwood kraft fibers, and (C) fibers obtained by repulping and fractionating unprinted xerographic copy paper.

Methods

Micrographs were obtained with an Olympus BH2-UMA optical microscope that was fitted with a Sony Power HAD DXC-97OMD video camera.

Fraction	Length (mm)	Width (mm)	Percent Fines
Primary fines	0.050 to 0.092	0.014 to 0.030	50.6 to 66.4
Secondary fines	0.121 to 0.179	0.009 to 0.018	45.4 to 47.5
Recycled fibers	0.560 to 0.819	0.021 to 0.028	20.23

I. Attributes of fines and fiber samples.

Samples for each dewatering test had 5.0 g of oven-dry contents in 1000 g of suspension and an electrical conductivity of 1000 μS/cm. To achieve this, we prepared a submaster batch, having a consistency of 1% to 2%, from standard recycled fibers (R200) from the copy paper sheets. Sufficient sodium sulfate was added to achieve the target electrical conductivity. Calculated amounts of fiber suspension and fines suspension were combined in advance of each test.

Dewatering tests were carried out with a modified Schopper-Riegler device provided by Buckman Laboratories, Inc. The device was cleaned before each test, and a 1000 mL beaker was placed on a balance below the outlet and tared. The 1000 mL contents of the mixture was poured into the beaker by depressing a plunger. When the plunger was released, a timer started simultaneously. The filtrate mass was recorded at specific times after the start of dewatering (e.g., 5 s, 10 s, 20 s, etc.). The turbidity of the filtrate was measured using a DRT-15CE turbidimeter from HF Scientific (Ft. Meyers, Florida, USA). Duplicate tests were conducted using the same sample mixture, obtained by briefly inverting the vial between repeat measurements.

RESULTS AND DISCUSSION

Dimensions of fines and fibers

The primary fines mainly consisted of elongated, approximately rectangular objects having lengths of 30 μm to 60 μm and widths of 10 μm to 30 μm (**Fig. 1A**). These dimensions are consistent with what can be expected for hardwood parenchyma cells [20-21]. The secondary fines, obtained by refining the hardwood fraction of bleached hardwood kraft pulp, did not show up as well in the micrographs. A portion of those fines, which are slender and relatively transparent, likely were below the resolution of the microscope of about 5 μm. The objects most visible in Fig. 1B are fibers and primary fines. The primary fines are mainly in the background of the figure and not well resolved. Figure 1C shows a typical fiber obtained by fractionating the xerographic copy paper.

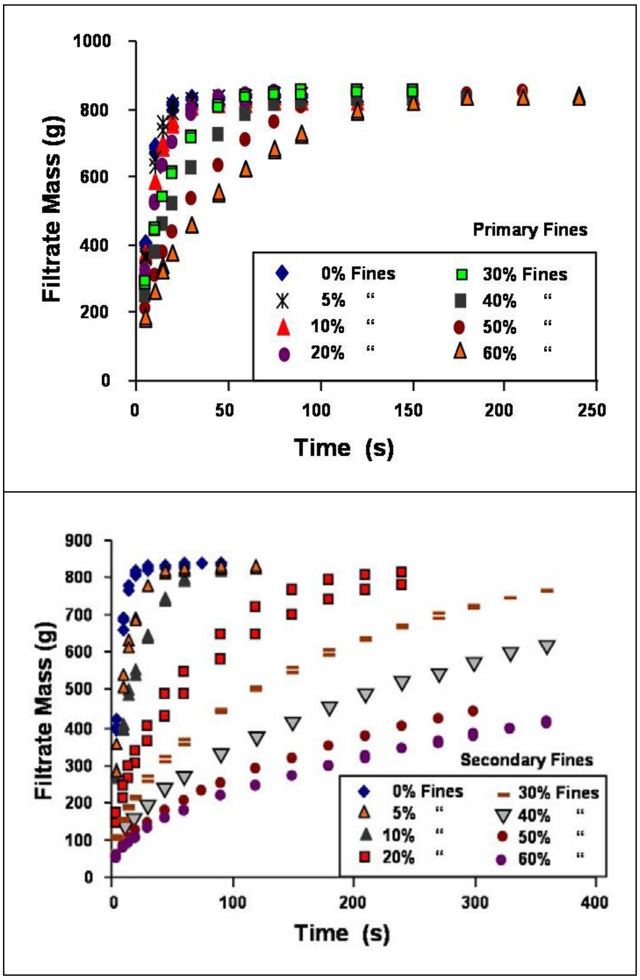
Table I shows the results from image analysis using a fiber quality analyzer (FQA) device. In the case of primary fines, the tabulated results generally agreed with what is shown in Fig. 1A. In particular, the relatively short, blocky shapes of parenchyma cells from hardwood pulp are clearly evident. By contrast, the maximum length of secondary fines was much greater, and the widths included much lower values than was true for the primary fines. Results from the FQA device for the fiber fraction obtained from repulped xerographic paper were typical for furnish composed mainly of hardwood kraft fibers.

Effects of fines on dewatering

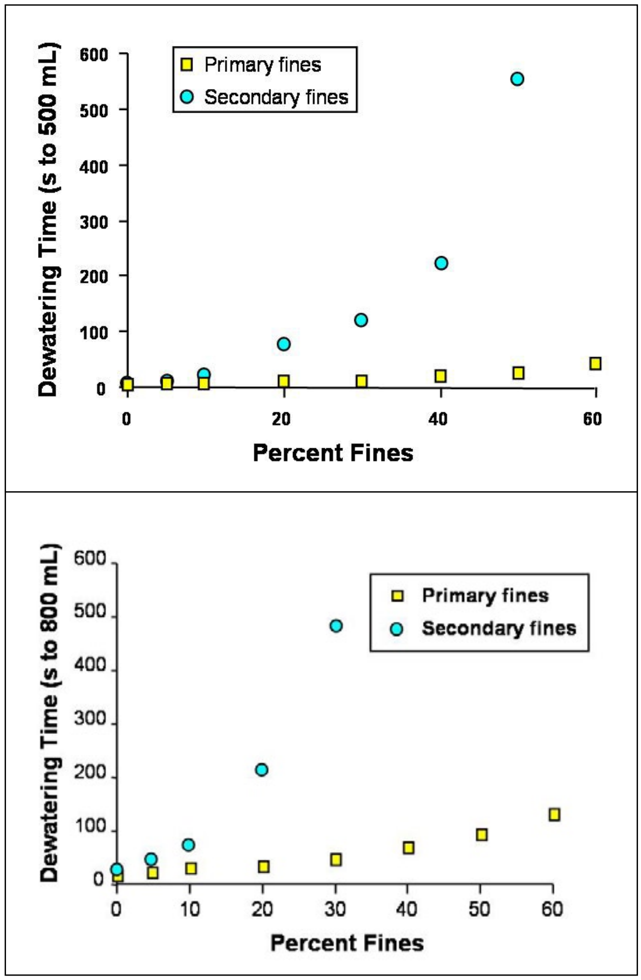
Figures 2A and 2B show the dependency of gravity dewatering on the content of primary fines (left-hand plot) and secondary fines (right-hand plot), respectively. As shown in Fig. 2A, primary fines did not significantly affect the freeness of the suspension until the content of fines was about 30% or greater by mass. The effects on dewatering were nonlinear with respect to fines content. For example, the presence of primary fines at 60% had an effect that was much more than twice that of the same kind of fines at 30%.

The observed nonlinear effect of fines content on resistance to dewatering agrees with certain earlier findings [9,12,22], but is not consistent with straightforward application of the Kozeny-Carman equation [23-24]. A tentative explanation of these results is that the unattached fines migrate within a wet pad of fibers and tend to get trapped at choke points within the mat [7,12].

A comparison between results in Figs. 2 (top) and 2 (bottom) reveals that the secondary fines had a much greater effect on dewatering than did the primary fines. This observation is in agreement with some earlier studies [12,25-27]. The rate of dewatering also tended to decrease with the pas-



2. Filtrate mass as a function of time during gravity dewatering of 1000 mL samples of 0.5% consistency slurries with different levels of primary (top) and secondary (bottom) fines as a percentage of the filterable solids.



3. Amount of time required for drainage of 500 mL (top) or 800 mL (bottom) filtrate by gravity dewatering of a 1000 mL suspension of 0.5% solids cellulosic material with 30% content of either primary (squares) or secondary fines (circles).

sage of time, to a greater degree than could be explained by the decrease in hydrostatic head. This nonlinear dependence of time is shown, for instance, by the curved nature of the mass-time trends (Fig. 2). The Kozeny-Carman equation predicts a nonlinear effect when the consistency of the mixture changes, which would be expected, particularly near the end of each dewatering test. Strong curvature is apparent even near the beginning of the dewatering experiment, especially when 30% or more of secondary fines were present.

Figure 3 shows further nonlinearity in the data. Figure 3 (top) shows how the time required to collect 500 g of filtrate depended on the content of fines. Figure 3 (bottom) shows an even greater degree of nonlinearity when comparing the times required to collect 800 g of filtrate from suspensions containing different quantities of fines. Even in the case of primary fines, the resistance to dewatering increased out of proportion to the amount of fines present.

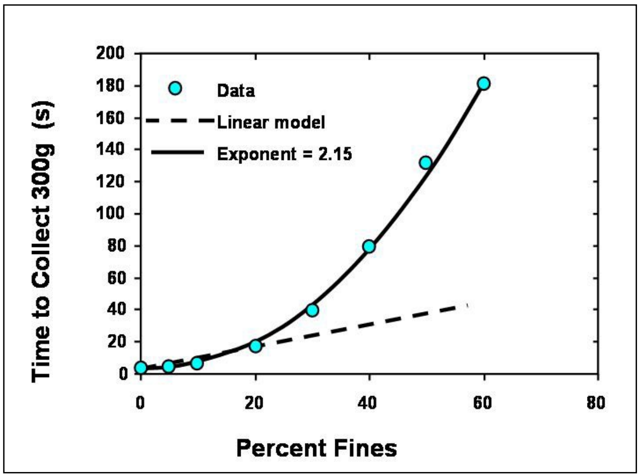
To quantify the observed nonlinearity with respect to fines content, **Fig. 4** shows a calculated fit to data related to secondary fines. The circular symbols correspond to the times required for collection of 300 g of filtration in Fig. 2 (bottom). In calculating the fit, we assumed that the time required to collect a certain amount of filtrate can be used as a measure of the resistance to dewatering. Resistance to dewatering, *R*, was assumed to be related to the percent fines content, *F*, according to

$$R = \mathrm{A}\, F^{\,\mathrm{n}} + \mathrm{B}\,(100 - F),$$

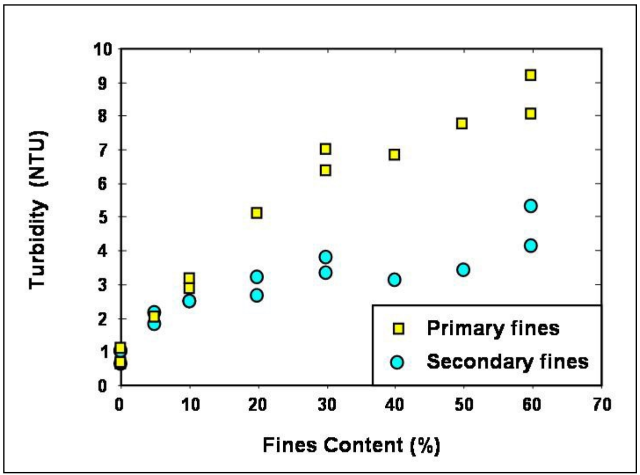
where A and B are constants, and n is an exponent. The constant A is related to the contribution to flow resistance by the fines, whereas B is related to the flow resistance caused by the fibers. As indicated in Fig. 4, an exponent of 2.15 yielded a good fit of the data. The values of the fitting coefficients A and B were 0.027 and 0.0351, respectively.

Turbidity test results

The results of turbidity tests (**Fig. 5**) support the explana-



4. Exponential fit and linear trend based on initial points in collection of 300 g of filtrate in the presence of different amounts of secondary fines.



5. Effect of fines content on the turbidity of filtrate obtained by gravity dewatering of cellulosic fiber suspensions containing primary (squares) or secondary fines (circles).

tions just given. The proposed mechanism involves a filtration of cellulosic fines by the mat of fibers. Because secondary fines tend to be long and slender, we would expect the mat to become increasingly effective as a filtration medium with increasing content of secondary fines.

Figure 5 shows a nonlinear dependence of filtrate turbidity on the content of fines of each type. In the case of primary fines, turbidity increased linearly as fines content was increased to about 30%, followed by a lesser slope. In the case of secondary fines, filtrate turbidity generally increased little after about 20% fines content. As an exception to this rule, samples prepared with 60% content of secondary fines showed some further increase in turbidity. The effect at 60% fines content might result because the long-fiber content was very low, reducing the thickness of the long-fiber mat available for filtering.

CONCLUSIONS

In this study, we saw that the addition of primary and secondary fines to a fiber suspension increased resistance to gravity dewatering in a nonlinear manner. The addition of up to 20% primary fines or up to 5% secondary fines had only minor effects on results of modified Schopper-Riegler drainage tests. Incremental increases at greater quantities of either type of fines slowed drainage considerably. Secondary fines, obtained by refining of bleached hardwood kraft fibers, had much greater effects on dewatering in comparison with primary fines obtained from unrefined bleached hardwood kraft pulp. Data from drainage tests with secondary fines could be fitted to an exponential equation. The time to collect a certain volume of filtrate was proportional to an exponent of 2.15 of fines content. The results suggest that secondary fines act as effective aids to mechanical filtration. **TJ**

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INSIGHTS FROM THE AUTHORS

We chose this area because not only does it have a big economic input, but also it seemed like a good summer undergraduate research project. Though others have done related work, this is the first careful study involving fractionated suspensions in which fines levels were varied and retention aids were used, with a focus on dewatering rates.

It is always quite challenging to get reproducible results with this kind of study. It is striking how dominant fiber fines are relative to the rates of dewatering, and also the extent to which polymeric additives can affect gravity dewatering.

Papermakers already know a lot about retention and dewatering, but a lot of questions remain, and there is a need for an improvement in the practical understanding of how dewatering aids work. We anticipate that further work will focus on developing equations to explain the effects of fines and polymeric additives on dewatering rates.

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Editor's Note

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EPE, IBBC offer double opportunity

As we go to press with this issue of *TJ*, the hottest industry news is the DOE's approval of two major grants in the U.S. biorefinery arena. Wisconsin's Flambeau River BioFuels will get more than US$30 million to advance its biodiesel project; and Verenium has received grant approval to expand capacity at its Jennings, La. ethanol biorefinery, and to broaden its cellulosic raw material reach to include wood chips.

For industry thought leaders, keeping up with forest biorefining developments like these has become an imperative. TAPPI's 2008 International Bioenergy & Bioproducts Conference (IBBC) will be an intensive two-day event exploring not only the latest biorefinery technologies, but also developing markets and legal-legislative-investment issues. It will take place August 27-29, 2008 at the Doubletree Hotel in Portland, Oregon (get full details at www.tappi.org/08IBBC.)

Checking your calendars, you'll notice that IBBC is scheduled immediately following TAPPI's 2008 EPE Conference (www.tappi.org/08EPE), at the same venue. For EPE "regulars," we couldn't have made it easier for you to also take part in this year's IBBC; we even offer dual-event registration discounts. If you haven't yet made plans to attend either event, why limit yourself and your knowledge? Attend both, and take advantage of this outstanding scheduling synergy.