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EFFECT OF FIBER SURFACE CHEMISTRY ON THE FIBER LOSS IN FLOTATION DEINKING

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ABSTRACT

The Wilhelmy principle was used to investigate the wettability of wood fibers in various aqueous solutions. The effect of surfactant and cationic polymer on the fiber surface hydrophobicity was studied. The relationship between fiber hydrophobicity and the fiber loss in flotation deinking was discussed. The results suggest that the adsorption of surfactant on wood fibers significantly reduces the advancing contact angle of fibers in aqueous solution, but the effect of cationic polymer on wood fiber hydrophobicity is insignificant. It was found that the fiber loss in flotation deinking depends not only on the fiber surface chemistry, but also strongly depends on the froth stability, froth structure, and fiber geometry. Experimental results suggest that both true flotation and physical entrainment will contribute to the total fiber loss, but physical entrainment is the dominating factor. The fiber loss in flotation deinking will also depend strongly on the type of fiber, i.e., old newsprint (ONP) showed the highest fiber loss compared to other fibers investigated in this study. The geometry of fibers is also an important factor affecting the fiber loss.

INTRODUCTION

Although the deinking efficiency is closely related to the brightness and cleanliness of the fibers, brightness figures without any information on the yield of the deinked fibers have only limited value because the achieved brightness strongly depends on the yield. Low yield caused by high fiber loss is one of the biggest problems in flotation deinking. Reported fiber loss is in the range of 4-24 wt% depending on the processes, equipment, and chemicals used in flotation deinking [1]. For highly sized or waxed fibers, fiber loss is even higher, and the flotation technique cannot be used for these paper products unless a new technique is established.

Many authors [2-4] believed that the fiber loss in flotation deinking is caused by air bubbles routinely adhering to the hydrophobic parts of fibers during the flotation process. The study conducted by Turvey [2,3] indicated that fiber loss in flotation deinking is solely caused by hydrophobic interaction between air bubbles and fibers. He also indicated that very hydrophilic fibers, such as unprinted newsprint fibers, will not float during the flotation. However, other researchers [4-7] indicated that unprinted fibers, even very hydrophilic bleached fibers, can still float during the flotation deinking process. In contrast to Turvey's study, some recent papers [5-7] indicated that the fiber loss in flotation deinking is solely caused by physical entrainment rather than true flotation. The conflicting experimental results obtained by different researchers suggest that the mechanism of fiber loss in flotation deinking has not been well understood. Obviously, in order to fully understand the mechanism of fiber loss in flotation deinking, the fiber wettability must be studied.

The recycling pulps used in flotation deinking include wood fibers, fines, ink particles, fillers, and other contaminants such as dissolved and dispersed polymers, and inorganic and organic materials. Many chemicals, such as surfactant and collector will also be added into the pulp slurry. All of the chemicals used in flotation deinking will affect the hydrophobicity of fibers and inks which will affect ink removal efficiency and fiber loss. Therefore, to understand the mechanism of fiber loss in flotation deinking, it is very interesting to know how adsorbed surfactants or polymers will affect the fiber surface chemistry and fiber flotation. However, no direct experimental measurement of the wettability of individual fibers in flotation deinking pulp suspension has been reported in the literature. Although it is important, the study of the surface chemistry of individual wood fibers in a flotation deinking pulp suspension is difficult because of the lack of an effective method to measure the contact angle of liquid on individual fibers. The contact angle measured from a liquid solution against a paper sheet may lead to a misunderstanding because of the pore structure of paper surfaces. The optical measurement of the contact angle of liquid against a single fiber has been attempted by Foote [8], Jones and Porter [9] and Grindstaff [10]. However, these methods are not satisfactory [11]. A new approach for determining fiber-liquid contact angles using a single wood fiber has been developed by Hodgson and Berg [12] and Krueger and Hodgson [13-14]. However, a poor reproducibility was observed because (1) the heterogeneity of wood fibers is high so that the data obtained using a single fiber may be significantly different from the average value of a pulp furnish, and (2) the wetting force is too small, which results in a large uncertainty. A new method that can be used for measuring a contact angle of individual wood fibers in aqueous solution was developed

recently in our laboratory [11]. In this method, a group of separated fibers was immersed and then removed from a liquid, and the advancing and receding wetting forces were measured, respectively.

In our previous study [6], it has been reported that both true flotation and physical entrainment will contribute to the fiber loss in flotation deinking. In this publication, the contact angle of flotation solutions against different wood fibers was directly measured, and the relationship among surfactant and polymer adsorption, wood fiber surface chemistry, and fiber loss in the flotation process was discussed.

EXPERIMENTAL

Triton X-100 (TX-100, a nonionic alkylphenoxy polyethoxy ethanol compound, analyze grade, J. T. Backer Inc.), sodium dodecylsulfate (SDS, BDH Inc., Specially pure), cetyltrimethylammonium bromide [$\text{CH}_3(\text{CH}_2)_{15}\text{N}(\text{CH}_3)_3\text{Br}$, CTMAB, Aldrich, 95%], sodium oleate (Aldrich, 98%), and water-soluble cationic poly(diallyl dimethylammonium chloride) (polyDADMAC, Polysciences Inc., 15% solid), alkyl ketene dimers (AKD) sizing emulsion (Hercon 70, Hercules Inc.) were used as received.

Wood fibers used in this study include repulped bleached softwood kraft (BSK) pulp, old newsprint (ONP, *Atlanta Journal-Constitution*), and xerographic paper. In order to study the effect of surface chemistry on the fiber flotation, AKD-sized BSK fibers were also used. The sized fibers were made by the reaction of fibers with varying amounts of a cationic AKD sizing emulsion in ~3% fiber consistency for 5 minutes. The furnishes were filtered and air dried for 2 hours. The air-dried fibers were then heated to $100 \pm 5^\circ \text{C}$

in a vacuum oven for ~30 minutes. Because AKD-sized BSK has the same fiber length as unsized BSK, the effect of fiber surface chemistry and fiber geometry on the fiber loss can be studied separately.

The pulp properties used in this study are given in **Table 1**.

The fiber lengths were determined by image analysis. The width and lumen diameter of fibers were measured using 400× magnification with the aid of OPTIMAS image analysis software. The fiber perimeter was calculated from average fiber width and lumen diameter. The ash content was obtained at 550°C according to the TAPPI standard method T211 om-93.

The adsorption of a nonionic surfactant, TX-100, on the fiber surface was carried out at various surfactant concentrations at a fixed fiber consistency (5 wt-% based on total weight of solution). The required surfactant solution was added into a 50-mL beaker containing 1.5 g fibers, and the final volume of fiber suspension was adjusted to 30 mL by distilled water. The mixture of fiber and TX-100 was gently agitated by a magnetic stirrer at room temperature for 8 hours. The fibers and fines in the suspension were removed by centrifugation. The supernatants were analyzed by the absorbency of the TX-100 solution at a wavelength of 275 nm using an HP 8452 Diode Array UV/VIS spectrophotometer (Hewlett Packard) at room temperature. The calibration curve of TX-100 solutions were made by a series of TX-100 solutions in the concentration range between 10-45 mg/L before analysis. In this concentration range a reproducible linear curve of absorbency against TX-100 concentration was obtained.

The flotation unit includes a polyacrylate column (12 cm in diameter; variable in height) and a gas inlet filter. Nitrogen was blown into the pulp at a required rate through the inlet filter. The ultra high pure (UHP) nitrogen was run through a digital flowmeter (Omega) before the flotation cell. The flow rate was first adjusted to a required value before blowing into the flotation cell. The foam that spilled over the column was collected and weighed, then the water loss was calculated. Both the fibers that were removed (fiber loss) and those that remained in the cell (residue) were filtered, oven dried, and weighed. The technique used in this study is different from previous studies [5,7]. In this study, the water loss was controlled by varying the distance between the surface of pulp slurry and top of the flotation cell (adding extra columns to the top of the flotation cell) at fixed nitrogen flow rate and flotation time. However, in previous studies [5,7] the water loss was controlled by varying the flotation time at fixed froth height. We believe that the method for studying the fiber loss mechanism used in previous studies is incorrect. The details about the difference between our method and the previously reported one can be found in reference [6].

The froth stability was measured by the half-life time of froth decay in the flotation cell. The volume of surfactant solutions used for froth stability measurement was 0.5 L. The UHP nitrogen was blown into the solution through the gas inlet filter at a flow rate of 1500 cm³/min. Once the froth height reached 80 cm, the air flow was turned off. The half-life time of froth decay in the column (reduced from 80 to 40 cm) was recorded.

A dynamic contact angle analyzer (Cahn DCA 312) was used to measure the surface tension of liquid and the contact angle of liquid on individual fibers. The technique for

measuring the dynamic contact angle of aqueous solution on a group of separated fibers was developed in our laboratory [11]. The equipment used for contact angle measurement is schematically shown in **Figure 1**, and the advancing contact angle, θ_A , was calculated using equation

$$\cos\theta_A = F_A / F_R \quad (1)$$

assuming the receding contact angle for all wood fibers in aqueous solution is zero [11-14], where F_A and F_R are the advancing and receding dynamic wetting forces, respectively.

RESULTS AND DISCUSSION

1. Contact Angle of Different Fibers in Surfactant and Polymer Solutions

The typical curves of receding and advancing dynamic wetting forces measured using a group of separated fibers are shown in **Figure 2**. During the measurement, the fibers were immersed in (advancing) or pulled out (receding) of the liquid at a constant velocity. The detailed explanation of the traces of dynamic wetting force was discussed previously [11]. **Figure 2** indicates that a) both constant advancing and receding wetting forces of wood fibers in a liquid solution can be obtained using a group of wood fibers (**B** to **C** for advancing, and **D** to **E** for receding); b) the advancing force of the first cycle is smaller than that of the second, but the receding force is the same for the first and the second cycles. The difference in the advancing wetting forces between the first and second cycles is due to the swelling of fibers after the first cycle, i.e., the wetting force of

the first cycle was obtained by dry fibers, but that of the second cycle was obtained by wetted fibers.

It has been reported [8-14] that the receding contact angle of wood fibers in aqueous solutions is zero. However, the advancing contact angle of wood fibers against aqueous solution could be significantly different for different systems, which strongly depends on both the fiber surface chemistry and the liquid properties [11-14]. It is known that the attachment of a solid particle to an air bubble is a receding process (from liquid to air), and the detachment is an advancing process (from air to liquid). Because wood fibers have a zero receding contact angle in water, the fibers cannot adhere to air bubbles by the hydrophobic attractive force. However, it should be noted that both air bubbles and wood fibers in a liquid solution are continually moving under agitation. The collision between air bubbles and fibers caused by agitation may overcome the energy barrier between air bubbles and fibers, resulting in some fibers extruding into air bubbles. Once part of the fiber get in an air bubble, the detachment of fibers from the air bubble will be dominated by the advancing rather than receding contact angle of fibers in the solution. If the wood fibers have a zero-advancing contact angle, they can detach from the air bubble freely and cannot float to the surface with the air bubble. However, if the fibers have a nonzero-advancing contact angle, they cannot detach from the air bubble. Therefore, true flotation occurs. This suggests that even though all wood fibers have a zero-receding contact angle in aqueous solution, the true flotation of fibers is still possible if they have a nonzero-advancing contact angle.

According to the above discussion, it can be known that the advancing contact angle of wood fibers in aqueous solution is an important factor affecting the true flotation during flotation deinking. Therefore, the advancing contact angle of wood fibers used in this study against different surfactant and polymer solutions was first measured. **Figure 3** shows the advancing contact angle of BSK fibers in aqueous solution as a function of surfactant and polymer solutions. It can be seen that the advancing contact angle of BSK fibers in water decreases with the increase of surfactant concentration for all three surfactants used in this study, but the effect of nonionic TX-100 and cationic CTMAB are more significant than that of anionic SDS. It is interesting to note that the advancing contact angle of BSK fibers in aqueous solution is close to zero at high concentrations of TX-100, which may suggest that the adsorption of this surfactant on the liquid and fiber surfaces will significantly affect the wettability of wood fibers. The adsorption of TX-100 on BSK fibers will be further discussed in this paper. In contrast to surfactants, cationic polyDADMAC did not significantly affect the advancing contact angle of wood fibers in water. Although it is well known that cationic polyDADMAC will strongly bond to negatively charged wood fiber surfaces, it may not effectively adsorb on the surface of aqueous solutions. As a result, both the surface tension of aqueous solution and the contact angle of wood fibers against aqueous solutions will not be significantly decreased by adding polyDADMAC.

The effect of TX-100 surfactant on the advancing contact angle of AKD-sized fibers in aqueous solution was studied and the results are shown in **Figure 4**. It is interesting to note from **Figure 4** that although the AKD-sized BSK fibers have a very high advancing

contact angle in water ($>90^{\circ}\text{C}$), it decreases sharply as the TX-100 concentration is increased. For example, the advancing contact angle of liquids on 0.6% AKD-sized fibers drops from 110 degrees in pure water to less than 20 degrees in a 200 mg/L TX-100 surfactant solution. It is believed that the decrease in the advancing contact angle of wood fibers against surfactant solutions is mainly caused by the decreases in the surface tension of the solution and the interfacial energy between fibers and water.

It is interesting to note that the advancing contact angle of unsized BSK fibers in aqueous solutions is close to 0 degrees when the TX-100 concentration is higher than ~ 30 mg/L. However, for AKD-sized fibers, the advancing contact angle could not reach zero even at the concentration higher than the critical micellization concentration of TX-100 (CMC = 195 mg/L). When the TX-100 concentration was further increased, the advancing contact angle of AKD-sized fibers in aqueous solution remained almost constant. This is not surprising because the surface tension of the solution, the concentration of free surfactant, and the adsorption of the surfactant on both the liquid and wood fiber surfaces should be constant at TX-100 concentration higher than its CMC.

The adsorption of TX-100 on BSK was directly measured and the results are shown in **Figure 5**. It can be seen that the adsorption of TX-100 on sized BSK fibers is higher than on unsized fibers, and the adsorption by both sized and unsized BSK fibers increased with the increase in TX-100 concentration, then remained constant (at saturated adsorption) as further increase in the TX-100 above its CMC. The adsorption isotherms shown in **Figure 5** is in consistent with contact angle measurements shown in **Figure 4**,

i.e., no further increase in adsorption amount and decrease in contact angle when the surfactant concentration is higher than its CMC.

The advancing contact angles of different fibers in different solutions are summarized in **Table 2**. It can be seen that ONP fibers has a higher advancing contact angle in water than BSK. Two factors may contribute to the high contact angle of ONP. First, the fibers used in the newsprint may be sized by a hydrophobic sizing agent, such as AKD, during the papermaking process. Second, the hydrophobic materials in the printing ink may contaminate the wood fibers.

2. The Relationship Between Fiber Surface Chemistry and Fiber Loss in Flotation

It has been reported in previous studies [11-14] that the receding contact angle of wood fibers in all aqueous solutions is zero. This study shows that the advancing contact angle of aqueous solution on unsized BSK fibers is almost zero if the TX-100 concentration is higher than 30 mg/L. All of these results suggest that the unsized BSK fibers are very hydrophilic in TX-100 surfactant solution and they should not adhere onto the air bubble surface during flotation. In other words, these very hydrophilic fibers should not float during flotation if the fiber removal is solely caused by true flotation. However, the flotation results shown in **Figure 6** clearly indicates that a significant amount of these hydrophilic BSK fibers were removed during flotation. It can also be seen that the fiber loss is linearly proportional to the water loss. Because these floated BSK fibers can only be caused by physical entrainment rather than true flotation, it strongly

suggests that the physical entrainment is one of the important mechanisms of fiber loss in flotation deinking.

The removal of AKD-sized BSK fibers as a function of water loss is also shown in **Figure 6**. It can be seen that the total loss of AKD-sized fibers is consistently higher than that of unsized fibers, and 0.6% AKD-sized fibers gave the highest loss. Because sized and unsized fibers have exactly the same fiber length, the difference in the fiber loss between sized and unsized fibers can only result from the fiber hydrophobicity if other parameters remain constant. From **Table 2** we know that the advancing contact angles of 0.6% AKD-sized and unsized fibers in 100 ppm TX-100 solution are 36 and 0 degrees, respectively. The higher fiber loss for hydrophobic fibers suggests that fiber surface chemistry also plays an important role in total fiber loss.

If we assume that the true flotation of hydrophilic unsized BSK is zero, the contribution of true flotation to the total fiber loss for AKD-sized fibers can be calculated by

$$F_{\text{true}} = (T_{\text{sized}} - T_{\text{unsized}})/T_{\text{sized}} \quad (2)$$

Where T_{sized} and T_{unsized} are total losses of AKD-sized and unsized fibers, respectively.

From **Figure 6** it can be estimated that the average F_{true} is only about 6% and 20% for 0.2% and 0.6% AKD-sized fibers, respectively. The low value of F_{true} even for highly sized fibers strongly suggests that the physical entrainment is the dominating factor for the total fiber loss during flotation. The fractions of the true flotation fibers and physically entrapped fibers can be obtained by the slope and the intercept of the curve of fiber loss

against water loss shown in **Figure 6**. This has been discussed in detail in our previous paper [6].

The effect of fiber types on the total fiber loss was also examined and the results are shown in **Figure 7**. The experimental conditions are the same for all of the experiments except that different fibers were used. It can be seen that at the same water loss volume, the ONP gave the highest fiber loss. The single fiber wettability measurement indicates (see **Table 2**) that the advancing contact angle of ONP in water is 52.2° , which is much higher than xerographic paper (28°) and unsized BSK (32°) fibers. Even in a 100 mg/L TX-100 solution (the same concentration used in the flotation experiments), the advancing contact angle of ONP fibers is still higher than unsized BSK and xerographic fibers. Because of this high contact angle, it is expected that ONP should give a higher fiber loss than BSK and bond paper fibers. This was confirmed by the experimental results shown in **Figure 7**. However, it is surprising that ONP gave a higher fiber loss than AKD-sized BSK fibers even though its advancing contact angle is smaller than that of 0.6% AKD-sized fiber in both pure water and 100 mg/L TX-100 solution (see **Table 2**). This suggests that the higher fiber loss of ONP compared to other fibers cannot be explained simply by the fiber hydrophobicity alone. As was noted in the above discussion, the physical entrainment, rather than true flotation, is the major contributor to the fiber loss. The difference in the fiber length between these fibers has to be considered because the physical entrainment depends strongly on the fiber geometry and froth structure. It can be seen from **Table 1** that the fiber length of ONP is much shorter than that of BSK. The higher fiber loss of ONP over AKD-sized fibers may suggest that short ONP fibers can be

entrapped into the foam network more easily than long BSK fibers. However, more work is needed for a full understanding of the relationship among fiber geometry, foam structure, and fiber loss. It is expected that there may be an optimized fiber length that will cause the highest fiber loss under a fixed foam structure.

The fiber loss as a function of TX-100 concentration for BSK fibers is shown in **Figure 8**. In order to understand the relationship between fiber hydrophobicity and fiber loss in flotation, the advancing contact angle of BSK fibers as a function of TX-100 is also re-plotted. It can be seen that although the advancing contact angle is decreased, the fiber loss is increased as the concentration of TX-100 is increased. The opposite change trends between fiber hydrophobicity and fiber loss may suggest that the fiber surface chemistry plays only a minor role in fiber loss under these conditions. Because the physical entrainment of fibers in a foam network must have a close relationship with the foam stability and structure, the half-life time of the froth decay as a function of surfactant concentration was measured. **Figure 9** shows that the half-life time of the froth decay increased as the concentration of TX-100 was increased in both the absence and presence of fibers, which suggests that the froth stability was increased. The results indicate that the froth stability is higher in the presence of 0.52% BSK fibers than without fibers. The increase in the froth stability when fibers are present may be due to two factors. First, the wood fines will adsorb onto the air bubble surface and act as a particle stabilizer. Second, the fiber network in the froth phase may hold the foam and prevent the decay of the foam in the flotation cell. It is interesting to note that the froth stability continually increases with surfactant concentrations up to 300 mg/L, which is far above the CMC of TX-100

(195 mg/L). This is surprising because from the principle of surface chemistry, it is well known that the surface tension of the solution should be constant above the CMC, and the froth stability should not continually increase as the surfactant concentration further increases. There is no clear explanation for this phenomena and more work needs to be done for a full understanding of froth stability.

Although the hydrophobicity of wood fibers in an aqueous solution will decrease as the surfactant concentration is increased, the froth stability will increase. Obviously, the decrease in the fiber hydrophobicity will reduce the true flotation of fibers, but the increase in froth stability will increase the physical entrainment. As a result, the fiber loss continually increases as the surfactant concentration is increased. This may also suggest that the physical entrainment is more important than true flotation for the fiber loss, as we have seen in **Figures 6 and 7** and the related discussion.

In order to know whether physical entrainment is a general mechanism for fiber loss if the experimental condition are varied, the fiber loss for both sized and unsized AKD fibers were also measured under different flotation conditions (different surfactant concentrations, fiber consistencies, and froth heights), and the results are shown in **Figure 10**. It can be seen from **Figure 10** that although the experimental conditions varied significantly, the fiber loss increased consistently with the increase in water loss regardless of the cause of the water loss. This is very interesting because it suggests that the entrapped water in the froth network must cause a physical entrainment of wood fibers, and the physical entrainment is a general mechanism for fiber loss in flotation deinking irrespective of the experimental conditions. This also suggests that in order to reduce the

fiber loss in flotation deinking, one must reduce the water loss by controlling the froth structure and stability. It can also be seen that AKD-sized fibers produced a consistently higher fiber loss comparing to the unsized fibers, but the difference in the fiber loss between hydrophobic (AKD-sized) and hydrophilic (unsized) fibers is insignificant.

CONCLUSIONS

1. The hydrophobicity of wood fibers in an aqueous solution decreases as surfactant concentration increases because the surfactant will adsorb to both water and fiber surfaces to reduce the surface tension and interfacial energy between water and fibers.
2. Both true flotation and physical entrainment will contribute to the total fiber loss in flotation deinking, but the physical entrainment is a dominating factor in most cases.
3. The fiber length, froth stability, and froth structure play important roles in fiber floating. ONP used in this study gave the highest fiber loss compared to other fibers because of its relatively higher hydrophobicity and shorter fiber length.

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FIGURE CAPTIONS

Figure 1. Schematic diagram of dynamic wetting force measurement using fiber group technique. A: electronic microbalance, B: fibers, C: wetting liquid, D: traveling elevator system, and E: computer.

Figure 2. The traces of dynamic wetting forces of distilled water on a group of 5 separated fibers.

Figure 3. The effect of surfactant and polymer concentrations on the advancing contact angle of aqueous solution against unsized BSK fibers.

Figure 4. The effect of TX-100 concentration on the advancing contact angle of aqueous solution against unsized and AKD-sized BSK fibers.

Figure 5. The adsorption isotherm of TX-100 on unsized BSK fibers at room temperature. pH = 6.8.

Figure 6. Fiber loss as a function of water loss for unsized and AKD-sized bleached softwood fibers. The water and fiber losses were measured at different froth heights. Pore size of air inlet filter: 10 μm ; fiber consistency: 0.52%; concentration of TX-100: 100 mg/L; nitrogen flow rate: 1800 cm^3/min ; flotation time: 2 minutes.

Figure 7. Fiber loss as a function of water loss for different fibers. Fiber consistency: 0.52%; Surfactant: 100 mg/L TX-100; Nitrogen flow rate: 1800 cm^3/min ; flotation time: 2 minutes.

Figure 8. Advancing contact angle and fiber loss of unsized BSK fibers as a function of TX-100 concentration.

Figure 9. Half-life of froth decay in the flotation column in the presence and the absence of BSK fibers at room temperature. BSK fiber consistency: 0.52%.

Figure 10. Fiber loss as a function of water loss for AKD-sized BSK (open symbols) and unsized BSK (solid symbols) fibers obtained at different conditions. The amount of AKD used for fiber sizing is 0.6% based on dry fibers. Δ : AKD-sized fibers, 0.52% consistency, 100 mg/L TX-100, varied froth height (in the range of 4-80 cm); \square : AKD-sized fibers, 100 mg/L TX-100, fixed froth height (20 cm), varied fiber consistencies (0.2 to 1.1%); \bullet : Unsized BSK, 0.52% consistency, 100 mg/L TX-100, varied froth height (in the range of 4-80 cm); \blacksquare : Unsized BSK, 100 mg/L TX-100, fixed froth height (20 cm), varied fiber consistencies (0.2 to 1.1%); \blacktriangle : Unsized BSK, 0.52% consistency, fixed froth height (20 cm), varied TX-100 concentration (10-100 mg/L).

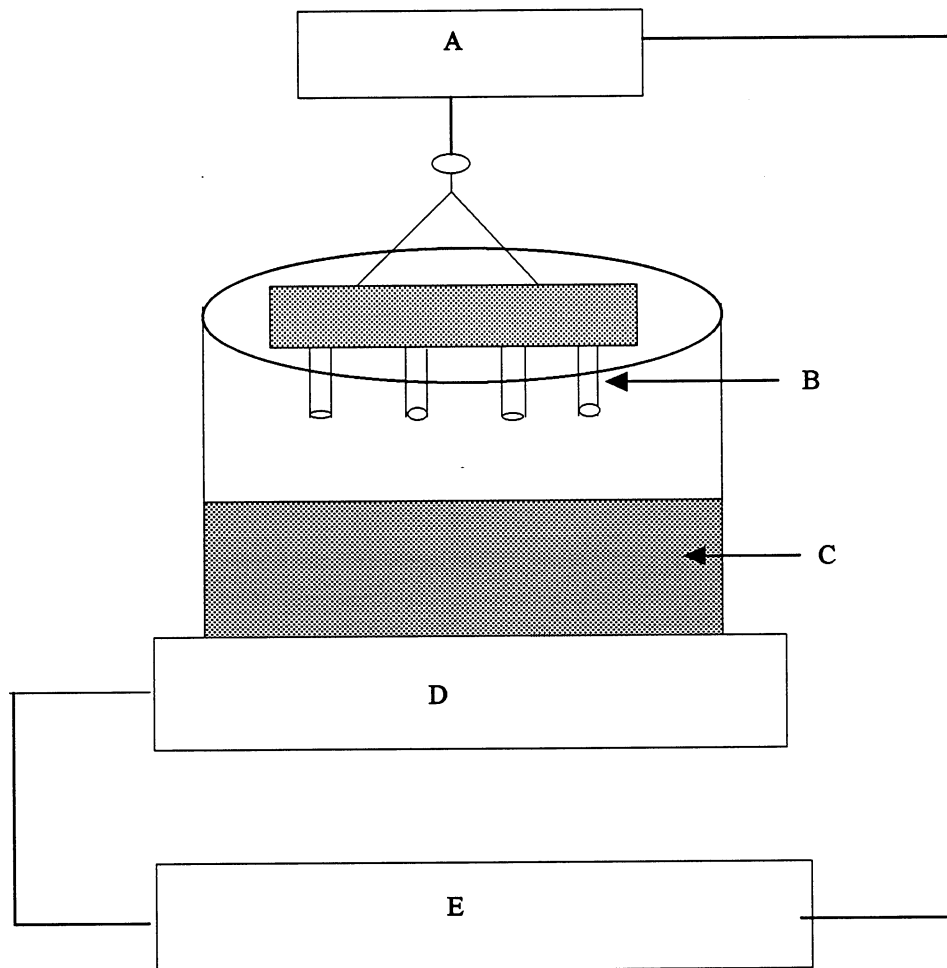
Table 1. Fiber properties.

Fiber*	Ash Content (%)	Fiber length (mm)
ONP	0.93%	1.60
Xerographic paper	16.24%	1.79
BSK	0	2.83
0.2% AKD emulsion-sized BSK	0	2.83
0.6% AKD emulsion-sized BSK	0	2.83

*: ONP: Old newsprint; BSK: Bleached softwood kraft fiber.

Table 2. Fiber advancing contact angle of different fibers in water and TX-100 surfactant solutions.

Fiber*	Advancing contact angle in water (degree)	Advancing contact angle in 100 g/L TX-100 (degree)
ONP	52	26
Xerographic paper	28	4
BSK	28	0
0.2% AKD emulsion-sized BSK	76	28
0.6% AKD emulsion-sized BSK	106	34



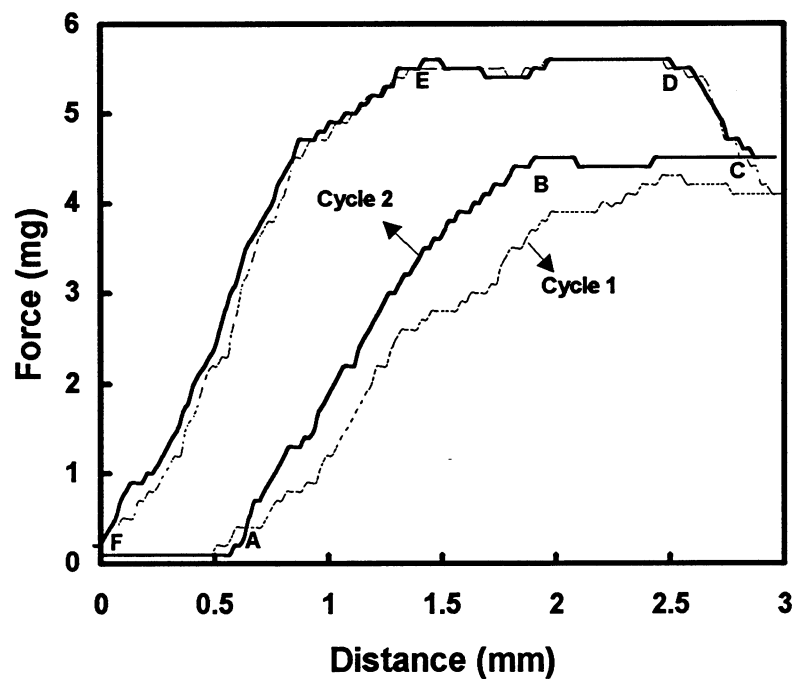


Figure 2. The traces of dynamic wetting forces of distilled water on a group of 5 separated BSK fibers.

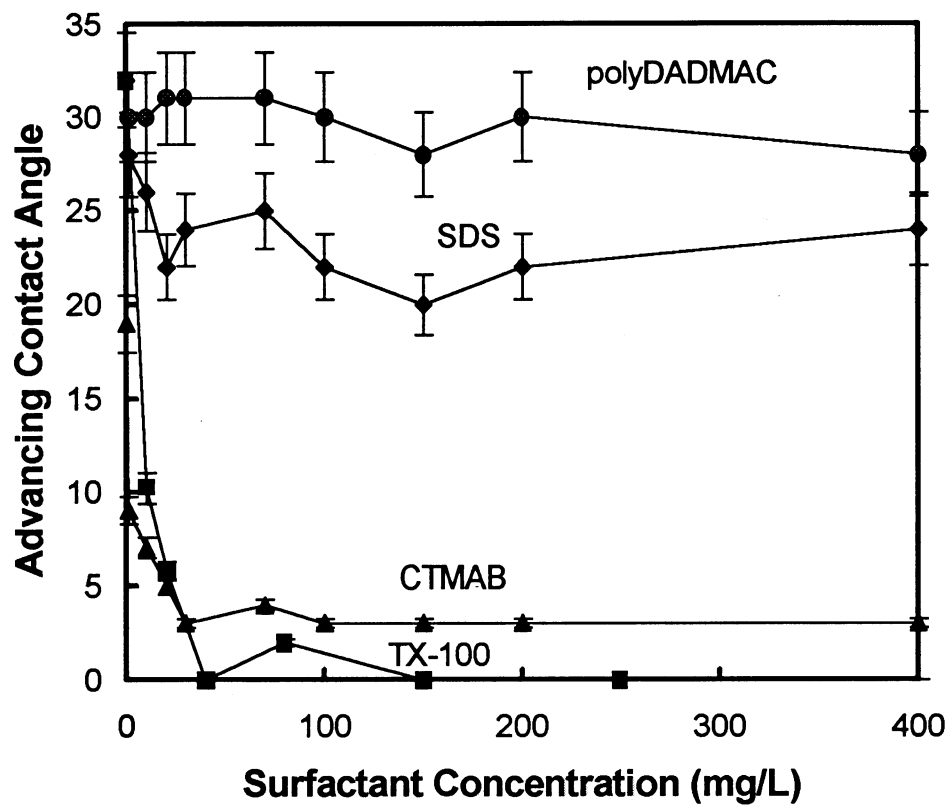


Figure 3. The effect of surfactant and polymer concentrations on the advancing contact angle of aqueous solution against unsized BSK fibers.

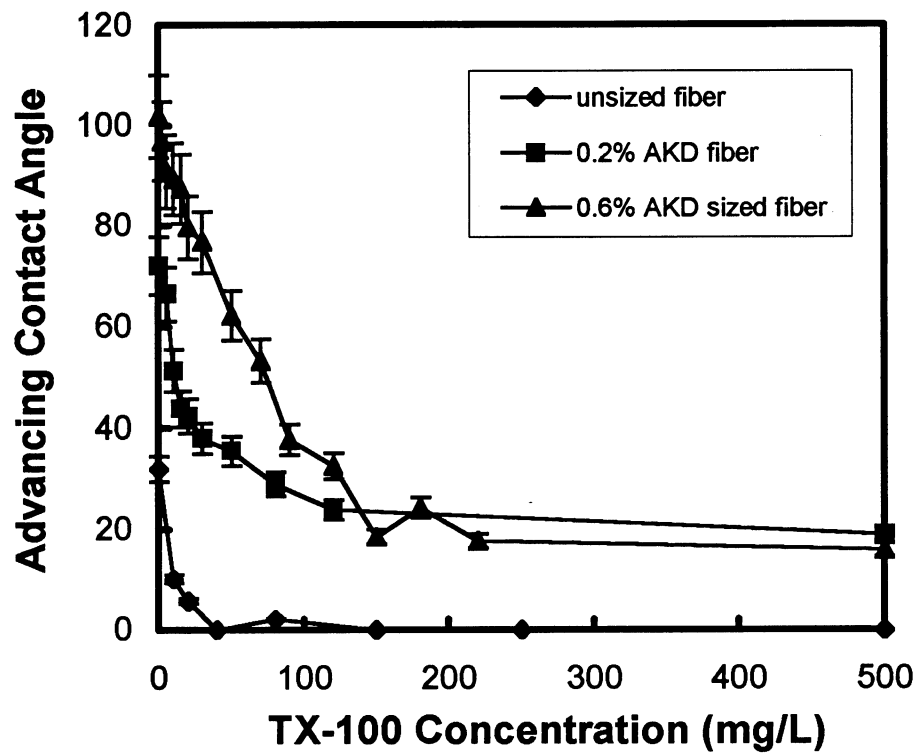


Figure 4. The effect of TX-100 concentration on the advancing contact angle of aqueous solution against unsized and AKD-sized BSK fibers.

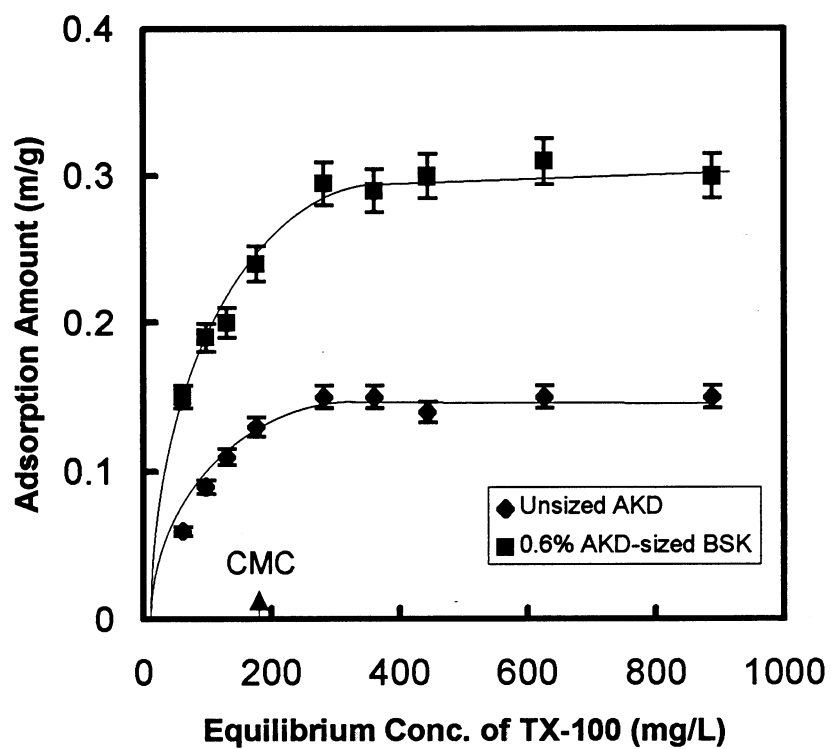


Figure 5. The adsorption isotherm of TX-100 on 0.6% AKD-sized and unsized BSK fibers at room temperature. pH = 6.8.

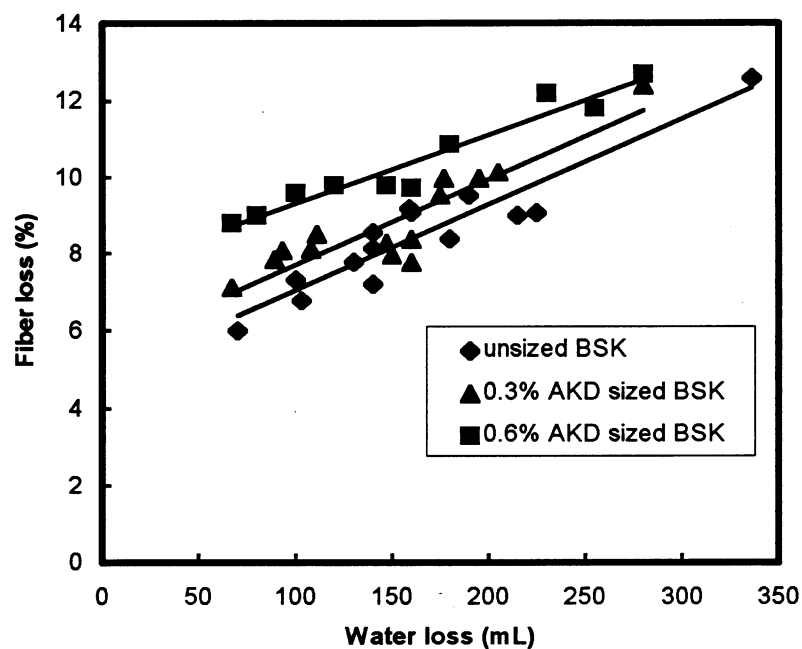


Figure 6. Fiber loss as a function of water loss for unsized and AKD-sized bleached softwood fibers. The water and fiber losses were measured at different froth heights. Pore size of air inlet filter: 10 μm ; fiber consistency: 0.52%; concentration of TX-100: 100 mg/L; nitrogen flow rate: 1800 cm^3/min ; flotation time: 2 minutes.

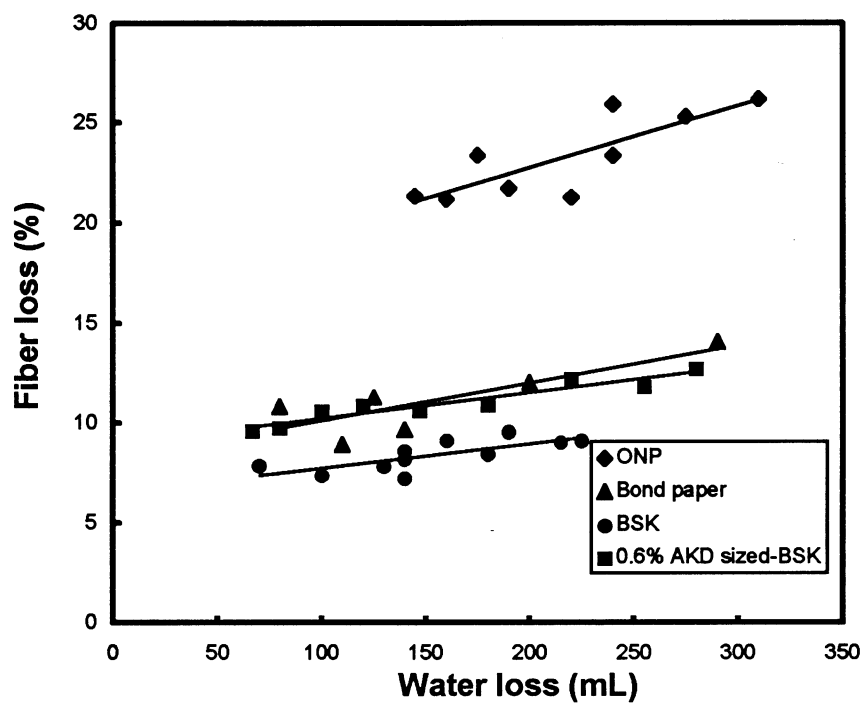


Figure 7. Fiber loss as a function of water loss for different fibers. Fiber consistency: 0.52%; Surfactant: 100 mg/L TX-100; Nitrogen flow rate: 1800 cm³/min; flotation time: 2 minutes.

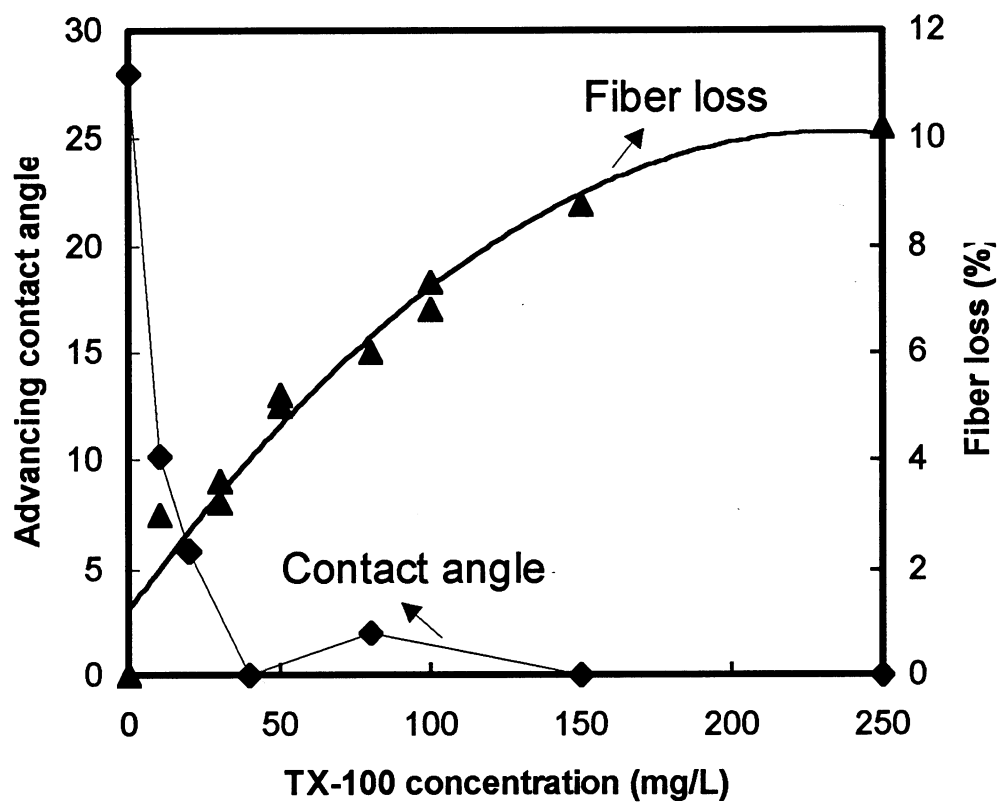


Figure 8. Advancing contact angle and fiber loss of unsized BSK fibers as a function of TX-100 concentration.

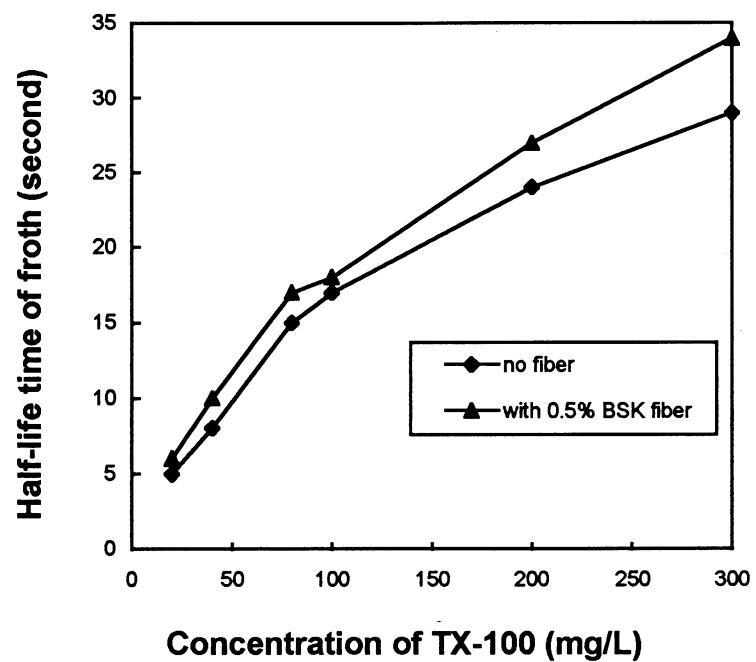


Figure 9. Half-life time of froth decay in the flotation column in the presence and the absence of BSK fibers at room temperature. BSK fiber consistency: 0.52%.

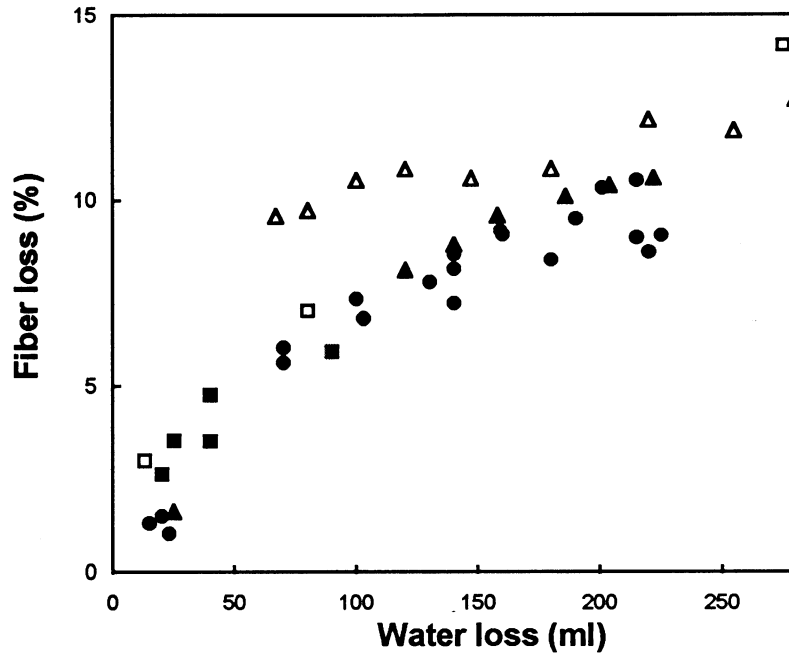


Figure 7. Fiber loss as a function of water loss for AKD-sized BSK (open symbols) and unsized BSK (solid symbols) fibers obtained at different conditions. The amount of AKD used for fiber sizing is 0.6% based on dry fibers. Δ : AKD-sized fibers, 0.52% consistency, 100 mg/L TX-100, varied froth height (in the range of 4-80 cm); \square : AKD-sized fibers, 100 mg/L TX-100, fixed froth height (20 cm), varied fiber consistencies (0.2 to 1.1%); \bullet : Unsized BSK, 0.52% consistency, 100 mg/L TX-100, varied froth height (in the range of 4-80 cm); \blacksquare : Unsized BSK, 100 mg/L TX-100, fixed froth height (20 cm), varied fiber consistencies (0.2 to 1.1%); \blacktriangle : Unsized BSK, 0.52% consistency, fixed froth height (20 cm), varied TX-100 concentration (10-100 mg/L).

