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FLOTATION DEINKING OF TONER-PRINTED PAPERS USING FROTHER SPRAY

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ABSTRACT

We experimentally studied a novel approach using a simple frother delivery device, i.e., a spray atomizer, in flotation deinking of toner printed papers to control several key process variables that affect ink removal, froth stability, fluid dynamics in froth, fiber contamination, fiber and water losses, and frother consumption. Instead of adding frother into the pulp slurry directly before flotation in the conventional process, a pressure atomizer was used to spray the frother solution from the top of the flotation column during flotation. Results obtained in a laboratory column flotation cell indicated that the frother spray approach can reduce fiber loss by 50%, water loss by 75%, and frother consumption by 95% without sacrificing deinking efficiency. The proposed approach can also prevent fiber from contamination by the process frothing agent. More importantly, this study developed a simple method to mechanically control froth stability when the physicochemical properties of the pulp source vary.

INTRODUCTION

Flotation deinking is a common practice for the removal of ink from wastepaper in many recycling paper mills. The application of flotation was successfully introduced to the paper recycling industry in the 1980s, and its applications in wax removal, sticky control, and fiber fractionation have attracted great research interest. The chemistry of the flotation process has been reviewed in literature [1-3]. However, the deinking chemistry and the physicochemical interactions among air bubbles, fibers, fines, fillers, and ink particles are very complex. Existing technologies and process designs of flotation deinking are based on experiences obtained from mineral flotation processes. Limited process control mechanisms are available. Many problems remain unsolved such as high fiber and water losses [4-9], fiber contamination by deinking chemicals, adverse chemistry modification of fibers due to the adsorption of surfactant [1,2,10,11], low efficiency in the removal of small ink particles [12-14], etc. Therefore, new technologies based on the mechanistic understanding of flotation processes are greatly needed to solve or alleviate the above problems. Recently, Gomez et al. [15] conducted a preliminary study to increase flotation deinking selectivity and collection kinetics using packed columns. In this study, we present an innovative concept and technology for flotation of toner-printed papers using surfactant spray.

Surfactants play three roles in flotation deinking: as a dispersant to separate the ink particles from the fiber surface and prevent the redeposition of separated particles on fibers, as a collector to agglomerate small particles to large ones and change the surface of particles from hydrophilic to hydrophobic, and as a frother to generate a foam layer at the top of the flotation cell for ink removal [1,2]. However, all three types of surfactants may not always be necessary in flotation deinking. For instance, some ink particles, such as xerographic toner, are hydrophobic in nature. Therefore, collector is not necessary in deinking toner-printed papers. The dispersant may also be unnecessary if the ink particles can be removed from fibers by other chemicals, such as sodium silicate, sodium hydroxide, and enzyme; mechanical actions, such as magnetic and electrical fields; or and ultrasonic irradiation. However a frother has to be used to obtain a stable foam layer for removing ink particles. Traditionally, the frother and other deinking chemicals are directly added to the pulp suspension during pulping or flotation, which may cause some adverse effects. For example, both the surface hydrophobicity and removal efficiency of ink particles will decrease by the adsorption of dispersant and frother [10,11,16]. The remaining surfactant in recycled fibers can decrease fiber-fiber bonding, increase paper machine foaming, affect printing quality, etc. Furthermore, the control of froth stability is very difficult once the surfactant has been directly added into the pulp slurry in current industry practice. Because surfactants have both positive and negative effects, it is of interest to separately apply and control dispersant, frother, and collector in flotation deinking processes to minimize the negatives and maximize the positives.

Ink removal efficiency depends on several factors such as the ability to separate the ink particles from the fibers, the collision probability between ink particles and air bubbles, the interfacial energy between ink particles and the air bubble surface, the specific contact surface area between ink particles and air bubbles, the stability of the froth for final ink removal, etc. It has also been identified that the froth stability is critical for ink removal [10,11,17]. Ink removal efficiency increases with an increase in froth concentration at low frother concentration due to the increase of froth stability. Further increases in frother concentration will increase the adsorption of surfactant onto ink particles, resulting in a reduction of the surface hydrophobicity of ink particles and ink removal [10]. Therefore, there must be an optimum surfactant concentration and ink removal efficiency as observed by Epple et al. [10] and in our previous study [16]. However, it is difficult to optimize the surfactant concentration in a paper recycle mill because of the variability in the secondary fiber sources. This indicates that good control of the concentrations and distributions of various surfactants within a flotation cell can significantly improve flotation deinking operation.

The understanding of fiber loss in flotation is very limited. Turvey [5,6] indicated that fiber loss was due to fiber adhesion to air bubbles and then was removed with the froth. This postulation was challenged by Ajersch and Pelton [7-9] and most recently by Dorris and Page [18]. They found that the hydrophobicity of a fiber surface does not contribute to fiber loss, and fiber loss is due to the mechanical entrainment of fibers in the froth. In a recent study [17], it was found that both physical entrainment of fibers in an air bubble network and adhesion of hydrophobic parts of fiber surfaces on air bubble surfaces contribute to the total fiber loss. However, the physical entrainment is the major contributor. It was found that the fiber and water losses are directly related to the froth stability and froth structure. The fiber entrainment is dictated by the gravitational, buoyant, fluid dynamic drag, and surface forces. In general, a froth with high void space between air bubbles causes high fiber and water losses due mainly to the fiber and water carrying over.

Because mechanical entrainment of fiber and water in the froth is the major reason for fiber and water losses, the establishment of an effective method to control the stability, structure, and fluid dynamics of froth is critical for reducing fiber and water losses. It is also clear that effective control of froth properties can be achieved by controlling surfactant concentration and distribution in the froth.

In this study, we propose a novel approach, using one simple mechanical device, i.e., an atomizer to spray frother at the top of the flotation column as shown in Fig. 1, to control several key process variables, i.e., frother consumption, concentration and its distribution, froth structure and stability, and fluid dynamics within the froth. Therefore, frother is not directly added into the pulp suspension during stock preparation, rather it is delivered through a spray during the flotation process. Several advantages can be achieved using the frother spray approach. For example, the spray delivers frother concentrated in the top layer of the froth not in the bulk pulp suspension to create a strong frother concentration gradient in the region of the froth and pulp suspension interface. The concentration gradient is supported by the froth liquid holdup capacity and the bulk convective flow of the pulp suspension driven by the air bubbles. Therefore, the contamination of fibers by frother can be avoided, the hydrophobicity of ink particles will not be affected, the ink removal efficiency can be increased, and the frother will be better used. There are also significant engineering and economical advantages of using the frother spray concept to control flotation deinking: a spray can be easily achieved using a very simple mechanical device, i.e., an atomizer, and a feedback control mechanism can be easily retrofitted and implemented using a frother spray for industrial applications without significant modifications of existing flotation equipment.

EXPERIMENTAL

We used a laboratory batch-type deinking column for the present study. As shown in Fig. 1, the deinking column has an inner diameter of 10.2 cm and the height of the flotation cell is 86 cm. The volume of the pulp slurry for each batch run was 6 liters. A pressure spray atomizer was mounted at the top of the deinking column, approximately 2 cm above the pulp suspension surface. The orifice diameter of the atomizer is 0.46 mm. The atomizer was operated at a gage pressure of 0.5 atm with a mass flow rate of 1.42 g/s, which was calibrated with a stopwatch. The mean spray droplet Sauter mean diameter (SMD) was about 50 μm measured by a laser diffraction instrument (Malvern 2600). The froth depth from the pulp suspension surface to the top of the flotation cell ranges from 6.5 cm at the beginning of flotation to a maximum value of 28 cm at the end of flotation. We used compressed air to aerate the pulp slurry in the column through a metal plate with holes 50 μm in diameter. The pressure drop of the compressed air was fixed so that the bubble size as it exit the plate would be approximately the same for all the experiments conducted. The flotation air flow rate was 11-15 standard liter per minute (SLPM). The average bubble size was estimated to be about 2 mm from video imaging in the absence of fibers, but it may vary significantly with the addition of surfactant and fibers. During experiments, the spray was turned on to run frother spray flotation experiments and off to run conventional flotation experiments, respectively.

The pulp was made from xerographic copied bond papers printed with a fixed pattern of X. The papers were pulped at a pH of 10 and a consistency of 8% without any chemicals added, except sodium hydroxide. The water and fiber losses were obtained by a gravimetric method. The ash content in the original pulp and removed solids (all substances other than water removed with the froth, such as fines, fibers, filler, and ink waste) were 16 and 8.2%, respectively. The pulp consistency used in the flotation process was 0.5%. Triton-100 (analyze grade, J.T. Backer Inc.) was used as frother. The required amount of Triton-100 was added directly into the pulp before flotation in "conventional flotation," but was sprayed through the atomizer from the top of the pulp suspension during flotation in "frother spray flotation." Deinked fibers were used to make handsheets using a 15-cm Büchner funnel according to TAPPI standard method (T 218 om-91). Brightness analysis of the handsheets were conducted according to TAPPI standard method (T 452 om-92) using a Shimadzu UV-VIS spectrophotometer (UV-160A).

The surfactant transfer through convection and diffusion from the froth to the pulp suspension in the flotation column was characterized in terms of the concentration change as a function of time and vertical location along the flotation column. A hypodermic syringe was used to take samples at different times from the flotation column through sampling holes drilled on the column at different locations from the froth-water suspension interface. The concentration of the surfactant (TX-100) was measured using a UV spectrophotometer (Beckman DU 640) at a wavelength of 223 nm. Deionized water was used as a reference. The surfactant transfer experiments were only conducted in the absence of fibers because the absorption of UV light by fibers can cause measurement difficulties.

RESULTS AND DISCUSSION

Froth Establishment by a Frother Spray

The froth formation under the application of a frother spray was first examined in the absence of fibers. No foam layer was established when air bubbles were injected from the bottom of the flotation column that contains only pure water. However, when a small amount of Triton-100 solution was sprayed from the top of the flotation column, a stable foam layer was established on the surface of the pure water in less than 0.5 minutes. The rate of foam formation on the top of pure water depends on the mass flow rate of the spray and frother concentration in the spray solution.

Frother Distribution between Froth and Pulp Suspension

We measured frother concentration distribution within the flotation column without the presence of fibers. The first set of experiments was conducted by taking samples from 20 and 50 cm below the froth-water interface at various times from 1 to 13 minutes during flotation with frother spray. UV analysis of all the samples found no absorption at 223 nm, indicating that the surfactant concentration was essentially zero at these two locations. The second set of experiments was conducted at the end of flotation (10 minutes) with samples taken at the distances of 1, 10, 30, and 50 cm below the froth-water interface. Similar results were obtained, i.e., no detectable frothing agent was found in the flotation cell. These results indicated there is a strong frother concentration gradient in the region of the froth and the pulp suspension interface. Because there is no frother present in the flotation column during frother spray flotation, the fiber contamination and surfactant adsorption onto the fiber and ink particle surfaces were eliminated.

Comparisons of Ink Removal

Because the methods to apply frother in the conventional flotation and spray flotation are completely different, we used the frother consumption (mg)/ovendry pulp (kg) as the basis for comparison of the performance of the two processes. The definition of "surfactant concentration" used in figure captions are different for the two flotation processes. For conventional flotation, it is the frother concentration in the bulk pulp suspension; while for spray flotation, the term "surfactant concentration" is the frother concentration in the spray solution. Fig. 2 shows the comparison of the brightness gain of handsheets made of deinked fibers using frother spray flotation and conventional flotation under the same operational conditions. The results clearly show that the frother consumption in the frother spray flotation was only about 2-3% of that required for the conventional flotation process to achieve the same brightness gain. This is not surprising because the frother was directly applied to the froth phase to stabilize the foam in the frother spray flotation, while a large amount of surfactant was dissolved in pulp suspension in the conventional flotation process and did not contribute to froth stabilization. Theoretically, the frother consumption used in the spray flotation process can be further reduced by increasing the ratio of the height to the cross-sectional area of the flotation column because the frother consumption in spray flotation is independent of the total volume of the pulp suspension and dependent on the cross-sectional area of the froth. Therefore, frother is better utilized in spray flotation.

For conventional flotation, the deinking efficiency increased with the increase of frother concentration up to 5 g/kg dry pulp, then decreased rapidly as the frother concentration was further increased as shown in Fig. 2. There was an optimum frother concentration at which ink removal was maximized. The optimum surfactant concentration in conventional flotation deinking was also observed in previous studies [10,11,16,17]. Combining the present results with those of previous studies, we believe that the increase in deinking efficiency at low surfactant concentration is due to the increase in the froth stability, and the decrease in deinking efficiency at high surfactant concentration is because of the decrease in the hydrophobicity of ink particle surfaces caused by the adsorption of surfactant. It is difficult to find the optimum surfactant concentration and then operate the flotation facility at the optimum condition constantly in industrial flotation applications because there are many variables, such as fiber source, that change constantly. Furthermore, once the surfactant is applied into the pulp suspension during stock preparation, it cannot be taken out.

In contrast to the conventional flotation process, the data show that ink removal increased with the increase of frother application in the frother spray flotation. This is because frother is concentrated in the froth, not in the pulp suspension, in the frother spray flotation approach; therefore, the adsorption of frother onto toner particle surfaces is significantly reduced. As a result, the hydrophobicity of the ink particle surfaces will not be reduced and ink removal will not decrease. The results demonstrate that proper control of delivery of surfactant, such as using a frother spray, can maximize the positive effects of the surfactant on flotation deinking and minimized the negatives. With spray delivery, the application of frother can be constantly adjusted during flotation. Therefore it is very suitable for feedback process control in industrial applications.

Comparisons of Fiber and Water Losses

Fig. 3 plots the correlation of fiber loss as a function of brightness gain. The results show that the fiber loss was reduced by 50% when frother was sprayed from the top of the flotation column compared to that obtained using conventional technology at the maximum ink removal condition. This indicated the success of the proposed technology in reducing fiber loss without reducing the deinking efficiency. Physical observations indicate that the structure of the froth obtained by spray flotation is different from that obtained by conventional flotation, which must contribute to the reduction in fiber loss in spray flotation. Spray washing plays a significant role in improving mineral selectivity in mineral flotation [19-22]. However, it is not clear how spray washing contributes to the fiber loss reduction in spray flotation. A quantitative study of the relationship between fiber loss and froth structure and fluid dynamics within the froth with spray washing is needed in the future.

Fig. 4 plots the correlation of water loss with brightness gain. The results show that the water loss was reduced by 75% when surfactant was sprayed using the proposed approach compared to that with the conventional flotation process at the maximum ink removal conditions. This indicated the success of the proposed technology in reducing water loss without reducing deinking efficiency. Although the water loss caused by flow entrainment in the flotation deinking process has not been considered a serious problem, we believe that reducing water usage in paper recycling will attract more and more attention as environmental consideration increases.

Comparison of Ink Removal Rates

Fig. 5 shows the rate of ink removal in the frother spray flotation and the conventional flotation processes. The two "spray" plots (a) and (b) are obtained using the data from the same sets of experiments (a) and (b) shown in Figs. 2-4, respectively; while the two "conventional" plots (c) and (d) were obtained by conducting two sets of experiments using two different frother concentrations of 2 and 20 mg/L in the pulp suspension, respectively. The duration time of flotation was varied in each set of experiments. It should be noted that the frother concentration of 20 mg/L used to obtain plot (d) corresponds to the optimum frother concentration that gives the highest brightness gain in conventional flotation as shown by plot (c) in Figs 2-4. The results shown in Fig. 5 indicate that ink removal increases with flotation duration time for all of the four experiments conducted initially. However, for the conventional flotation conducted at a frother concentration of 2 mg/L, ink removal efficiency reached a constant value after 80-second flotation. A constant ink removal is present solely because there was not enough frother in the system after 80 seconds so that the foam was not stable. The results indicate that the ink removal rate using the frother spray processes was not significantly reduced (comparing plot (b) with (d)) than that of the conventional process even though the frother consumption was reduced by more than 99%. Furthermore, the results show that a 10-minute flotation duration was sufficient to achieve the desired brightness using the frother spray technology.

CONCLUSIONS AND IMPLICATIONS

In summary, the present study using a frother spray for process control in flotation deinking using frother spray demonstrates several advantages over the conventional flotation deinking process:

1. Spray frother at the top of the flotation column can effectively establish a stable froth for good ink removal.
2. Frother application through a spray at the top of the column can effectively prevent the fiber from contamination by the frother and eliminate the modification of deinking chemistry through surfactant adsorption, thus resulting in increased ink removal and reduced surfactant consumption and fiber and water losses.
3. Control of frother delivery through mechanical devices, such as a spray, is an excellent approach to control froth stability and to improve the performance of the flotation deinking process significantly. Our laboratory studies demonstrated that without sacrificing deinking efficiency, the proposed approach can reduce fiber loss by 50%, water loss by 75%, and surfactant consumption by 95%.
4. Control of surfactant delivery is a potentially effective method of improving the effectiveness of dispersant, collector, and frother in flotation deinking.

5. Control of surfactant delivery has potential advantages in the process control of flotation deinking, and, in particular, can be used to stabilize flotation operations when pulp sources are changing.

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List of Figures:

Fig. 1

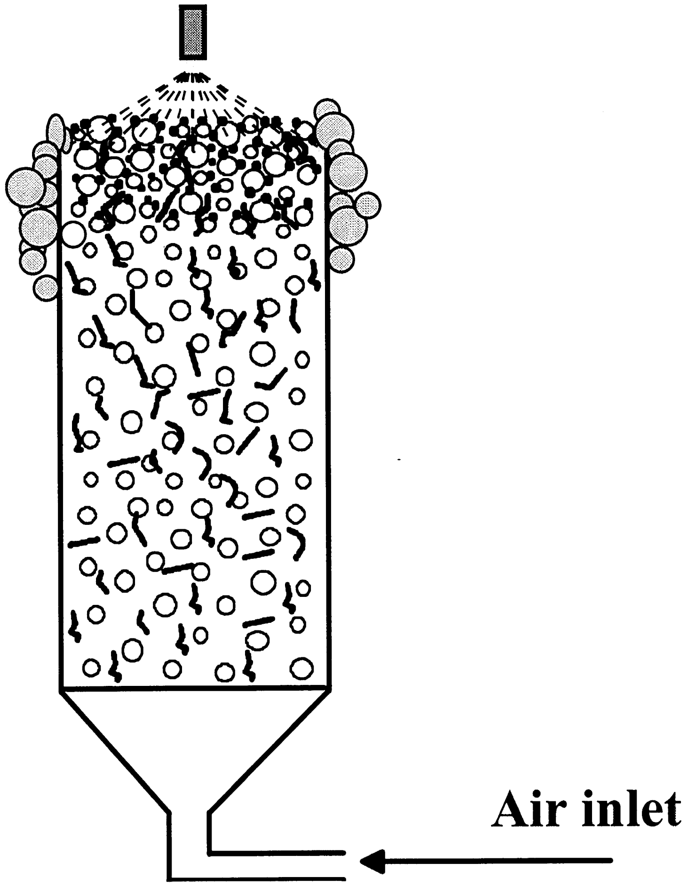
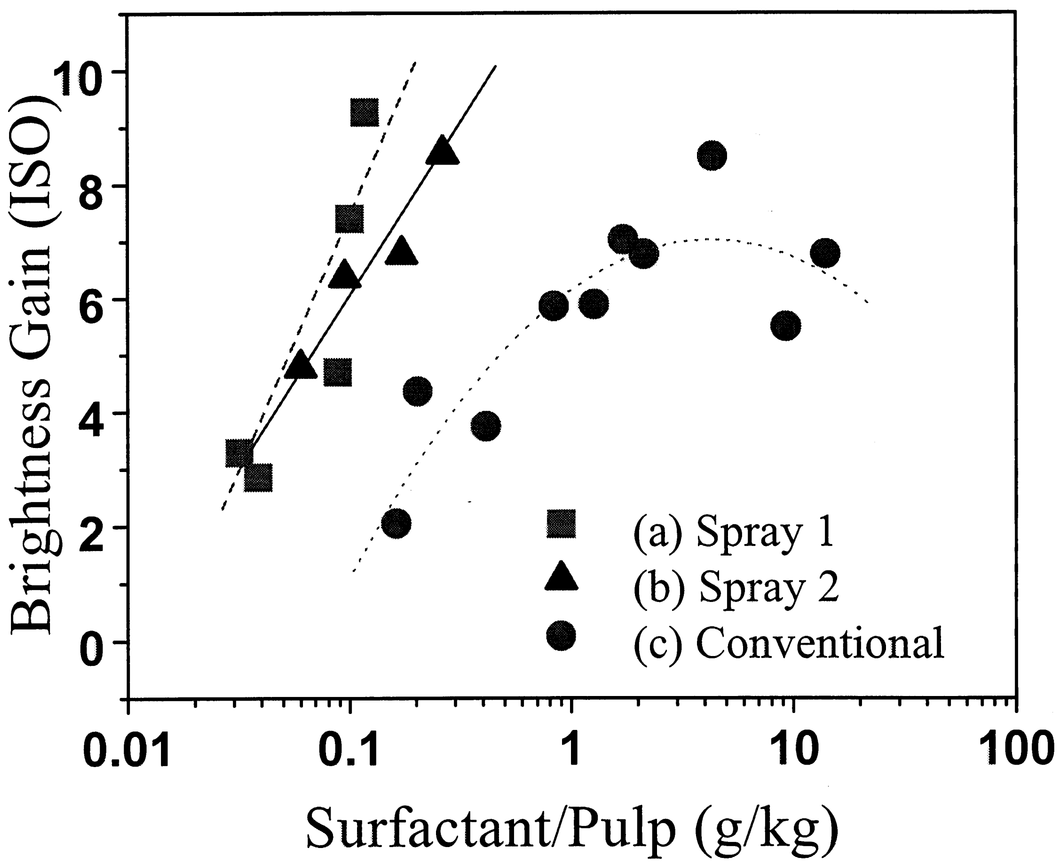


Fig. 2



Brightness Gain (ISO)
10
8
6
4
2
0
0.01
0.1
1
10
100
Surfactant/Pulp (g/kg)
(a) Spray 1
(b) Spray 2
(c) Conventional

Fig. 3

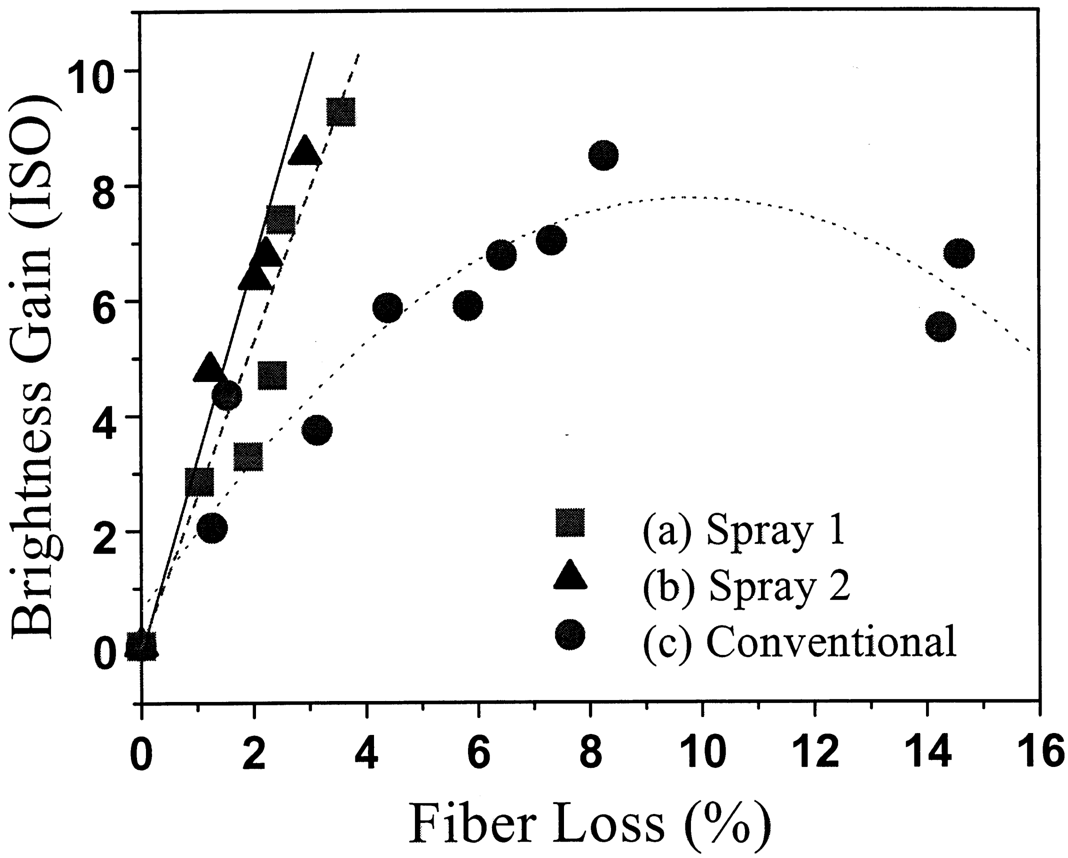
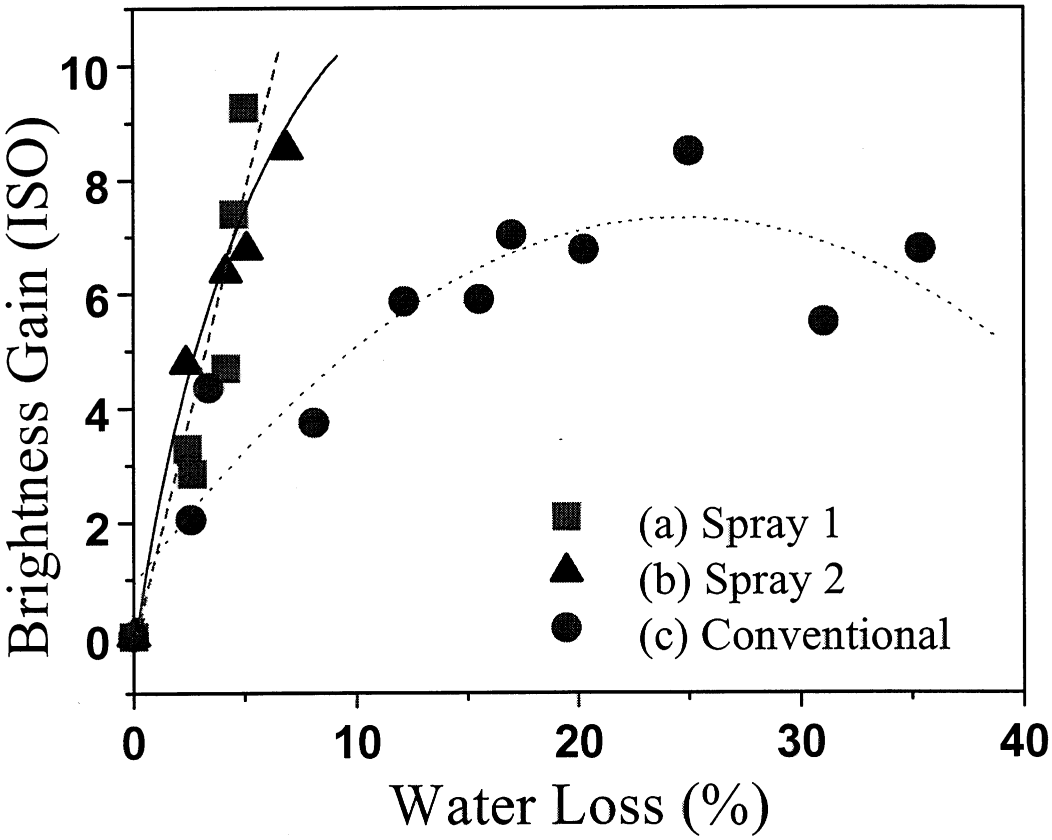
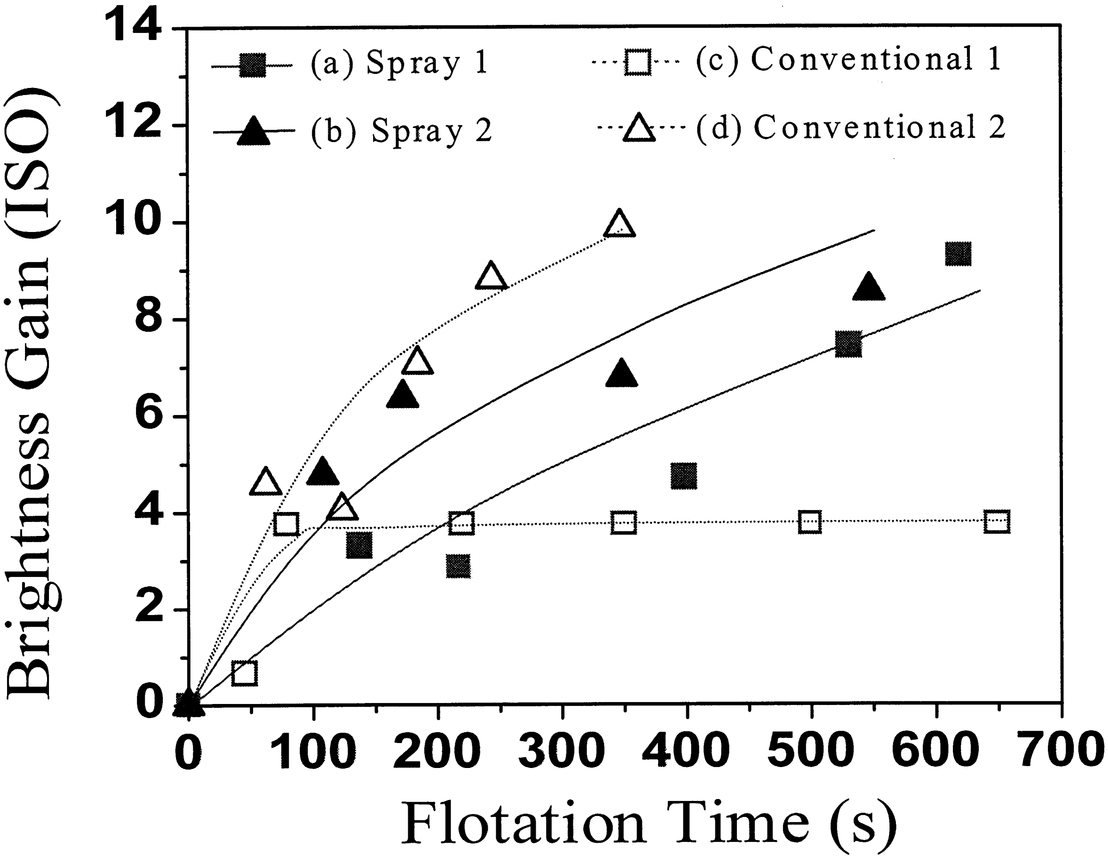

Brightness Gain (ISO)
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
Fiber Loss (%)
(a) Spray 1
(b) Spray 2
(c) Conventional

Fig. 4



10
8
6
4
2
0
Brightness Gain (ISO)
0
10
20
30
40
Water Loss (%)
(a) Spray 1
(b) Spray 2
(c) Conventional

Fig. 5



Brightness Gain (ISO)
Flotation Time (s)
(a) Spray 1
(b) Spray 2
(c) Conventional 1
(d) Conventional 2
0
2
4
6
8
10
12
14
0
100
200
300
400
500
600
700