Evaluation of Flotation and Washing Processes in Deinking Old Newsprint and Office Waste

Antonio Davila, Gary M. Scott, John H. Klungness, and Mahendra Doshi

ABSTRACT

The sequence of washing and flotation on the effectiveness of deinking has been the subject of recent discussion. The effects of interchanging the sequence of flotation and washing on three recovered fiber furnishes were examined. The three furnishes included a low-level ash stock, a high-level ash stock, and office waste. Ink removal efficiency was obtained for each sequence with respect to ink particle size and the cleaning quotient measure of performance for overall ink removal. The washing-flotation sequence with low surfactant dosages achieved the highest overall performance for the low-level ash stock and office paper. For overall cleaning of the high-level ash stock, the washing-flotation sequence with 0.10% surfactant dosage achieved the maximum cleaning quotient. The flotation washing sequence had the highest overall weight loss, with a majority of the loss occurring in the washing operation. This was more evident with the high-level ash furnish. Weight loss is reduced when the operations are reversed. This could be the result of having the full level of surfactant present in washing, but the interaction with ash is unclear.

KEYWORDS

Deinking, Flotation, Magazine papers, Newsprint, Washing

Davila is Chemical Engineer, Scott and Klungess are Research Chemical Engineers, USDA Forest Service, Forest Products Laboratory, One Gifford Pinchot Dr., Madison, WI 53705-2398, USA.

Doshi is President, Doshi & Associates, Inc., 18 Woodbury Ct., Appleton, WI 54915, USA.

INTRODUCTION

Deinking systems commonly use both washing and flotation operations to remove ink from recovered fibers. However, the sequence of such deinking systems has been the subject of discussion (1,2). Most deinking systems typically use a flotation-wash sequence, but there is no consensus on the use of this sequence.

Furnishes containing both newsprint and magazines are traditionally deinked by flotation followed by washing to exploit the presence of fillers in the magazine stock which improve the collection of ink particles (1). Also, offset inks used in magazine papers are detached from fibers during pulping and their size range is optimal for flotation. Thus, this stage should be used first since the greatest amount of ink is in this size range. In some studies, flotation precedes washing for furnishes containing electrostatic inks (3). The repulping of paper printed with electrostatic inks results in relatively larger, flat ink flakes that may require agglomeration for effective removal by flotation and hydrocyclones.

Washing could be used prior to flotation for any furnish to remove chemicals that hinder the effectiveness of flotation. Also, if a recycle loop is used in any sequence, deinking chemicals can be prevented from migrating through the entire deinking system, thereby saving chemicals and thermal energy (4).

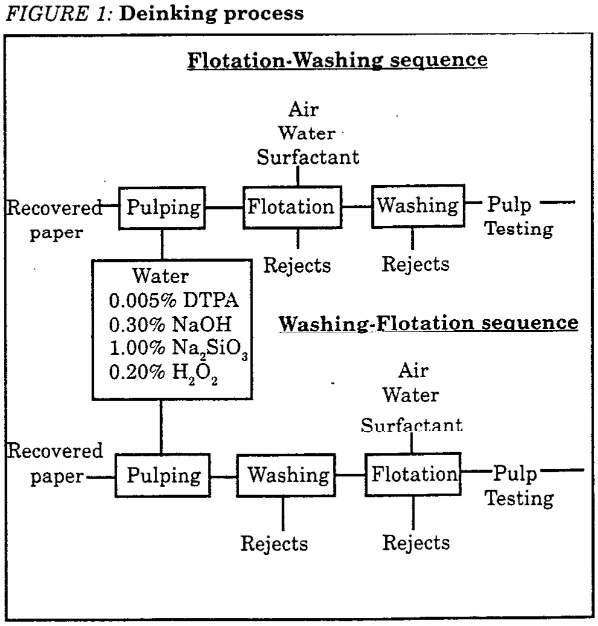
The objective of this study was to evaluate the effects of interchanging flotation and washing sequences on three recovered fiber furnishes. The performances of a flotation-washing (F-W) sequence, a washing-flotation (W-F) sequence, and a washing-flotation sequence with a half dosage of surfactant added (w-f) were evaluated in this study. Fig. 1 illustrates the deinking process that was used.

EXPERIMENTAL

The three furnishes evaluated included a low ash furnish consisting of 75% old newsprint (ONP) and 25% old magazines (OMG) (I), a high ash furnish consisting of 60% ONP and 40% OMG (II), and office papers (III), with ash concentrations of 8.3%, 12.7%, and 11.2%, respectively. All furnishes were pulped for 45 min at 46°C in a 50 L Voith[1] pulper at a consistency of 8.0%. During the pulping process, deinking chemicals were added on a percentage by weight oven-dry solids basis. Chemicals used included 0.05% diethylenetriamine pentaacetic acid (DTPA), 0.3% sodium hydroxide (NaOH), 1.0% sodium silicate (Na_2SiO_3), and 0.2% hydrogen peroxide (H_2O_2). The DTPA forms complexes with metal ions, which prevents them from decomposing H_2O_2 (5). The NaOH was added to adjust the pH to the alkaline region to hydrolyze the ink resins. The fibers also swelled as a result of the NaOH, where the fibers take on water and become more flexible (6). The Na_2SiO_3 was added as another source of alkalinity. However, Na_2SiO_3 also aids in deinking by preventing the ink from redepositing on the fiber surface (7,8). The H_2O_2 was added to retain the original furnish brightness. Solutions of DTPA and NaOH were made in concentrations of 25 g/L and 200 g/L, respectively. A 30% H_2O_2 solution was used. The pH at the end of the pulping process was approximately 10.3.

For the F-W sequence, pulp was processed through a 90 L batch Denver flotation cell with an agitator speed of 840 rpm, followed by a 200-mesh sidehill screen (45 degree angle). The consistency of the furnish was 1.0% to which 0.10% surfactant (Lionsurf 729, nonionic polyalkylene oxide) was added to the cell prior to mixing. The furnish was allowed to mix for 3 min prior to flotation. The flotation process began with the addition of air for 3 min. Each furnish was washed to complete this deinking series. In the W-F sequence, the flotation cell was used as a mixing chamber prior to washing. Surfactant (Lionsurf 729) was added at 0.10% prior to mixing. Three min of mixing followed. The pulp slurries, at 1.0% consistency, were then washed over the sidehill screen prior to flotation. In the flotation cell, the consistency was adjusted to 1.0% and an additional dosage of 0.10% surfactant concentration was added. A separate w-f sequence was carried out in the same manner, except that the amount of surfactant added at each operation was 0.05%. Thus, the total amount of surfactant added was the same as in the F-W sequence, but at one-half the amount of the W-F sequence.

FIGURE 1: **Deinking process**



Handsheet Forming and Testing

Throughout each of the deinking series, handsheet samples were collected after each operation for testing. Tests for brightness, opacity, and tensile strength were performed according to the appropriate TAPPI standard methods. Image analysis was used to measure the amount of residual ink.

Handsheets (60 g/m^2) were made according to TAPPI Test Method T205. Tensile tests were done following TAPPI Test Method T220. Brightness and printing opacity were measured with a Technidyne Corp. Technibrite Model TB-1 diffuse brightness apparatus, according to TAPPI Test Method T525. Individual and overall ink removal efficiency was calculated by material balances. The balances assumed that no agglomeration or breakup of ink particles occurred. However, this assumption may not have been valid since ensuing findings indicated negative efficiency values in some cases.

Ink Removal Efficiency

High resolution analyses were used to determine total ink area per unit area of pulp samples entering and leaving a process. The total ink value was then divided by its specimen weight. This concentration was multiplied by the total weight either entering or leaving an operation to characterize the

1 The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

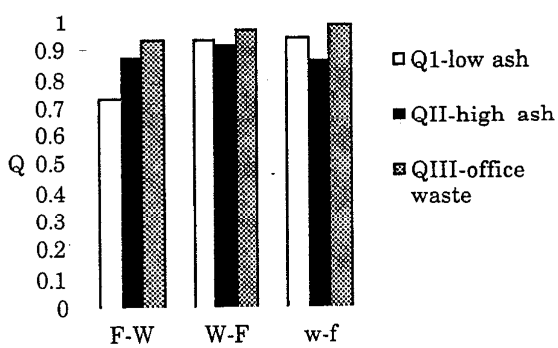
total ink. Ink removal efficiency was calculated using the total ink measured. High resolution analyses were performed using a Cambridge Instruments Quantimet 970. The analysis measures ink particles from 2.5 to 160 μm diameter; macro analysis was used to measure ink particles greater than 160 μm diameter. High resolution analysis used four cellulose nitrate filters, pore size of 0.8 and 90 μm in diameter. The samples were prepared by taking 2 g (o.d. basis) and diluting to 1000 ml. From this new solution, another 0.2 g (o.d. basis) was taken and diluted to 2000 ml. This final solution was used to prepare four pads, with 50 fields per pad being analyzed by image analysis. For macro analysis, the handsheets were prepared using TAPPI Method T205. Five handsheets were analyzed on both sides, with six fields per side.

Another alternative indicator of deinking efficiency is the cleaning quotient. In a mill situation, this index can cut laboratory workload and simplify process reporting (9). The cleaning quotient is calculated by the following formula:

$$Q = (Er - Rw)/[Er(1 - Rw)]$$

where Q is the cleaning quotient; Er is the ink removal efficiency, which is defined as the amount of ink in the reject stream divided by the amount of ink in the feed stream; Rw is the total weight loss. The cleaning quotient (Q) takes into account the effect of weight loss on the ink removal efficiency, and helps define the performance of a process in recovering fiber while removing contaminants. The ink removal efficiency (Er) defines the performance of the overall ink removal from a process and does not take into account the effect of weight loss. Higher values of Q signify efficient process sequences. For all three sequences, QI defines the value of the low-level ash furnish, QII defines the high-level ash furnish, and QIII defines the office waste furnish (Fig. 2).

FIGURE 2: **Cleaning quotients for each furnish after each sequence.**



RESULTS

Effect of Sequence

The F-W sequence was observed to have the highest total weight loss (Rw) when compared with the other sequences. This was regardless of the furnish utilized. The majority of the loss occurred during the washing process. During the sequence trial, the surfactant level in the washing operation was not readjusted to the original level that was present in the flotation cell.

By placing washing prior to flotation (W-F or w-f sequence), the weight loss is reduced. The reasons for the high weight loss in the F-W sequence as compared to W-F or w-f sequence are not clear. More research is essential to understand the role of surfactant and its interaction with fibers, fines, fillers, and inks.

Effect of Ink Particle Size

Micro ink particles were generally removed in the washing operations of the W-F and w-f sequences. The exception was seen in office waste furnish. In F-W, flotation was observed to remove a higher concentration of micro particles than the washing operations in the other sequences for this furnish. Micro ink particles may have been entrapped in fiber crevices and therefore not effectively removed. Another thought is the agglomeration of micro ink particles into the mid-size range. This was evident by the increase of concentration of this size range after washing (Table 3).

Mid-range ink particles were noticed in some cases to increase in concentration after being subjected to an operation in a sequence. The F-W sequence for low-ash furnish (Table 1) shows an increase of about 36% in concentration after flotation and another 78% increase after washing. This could be the result from agglomeration of micro ink particles or the disintegration of macro ink particles into this size range.

Macro ink particles were generally removed more efficiently in the F-W sequence. They were in the size range that are more susceptible for removal in flotation. This is seen as the concentration decreased more significantly in this operation for the F-W than the other sequences for all furnishes studied. In W-F and w-f sequences, washing removed

Table 1. Performance of Ink Concentrations for Low-Level Ash Furnish.

	Pulping process	Flotation process	Washing process	Overall ink removal efficiency, *Er*(%)
F-W Sequence				
Micro concentration (ppm)	22.4	17.1	11.9	64.6
Mid-range concentration (ppm)	3.6	4.9	8.7	-60.9
Macro concentration (ppm)	24	8.2	6.6	81.7
Total ink concentration (ppm)	50	30.2	27.2	63.8
Final				
Weight loss, *Rw* (%)	—	5	28.4	31.98
Cleaning quotient, *Q*	—	0.878	-0.062	0.733
W-F Sequence				
Micro concentration (ppm)	22.4	11.9	13.5	52.5
Mid-range concentration (ppm)	3.6	2.9	3.1	27.9
Macro concentration (ppm)	24	5.4	9.3	79.9
Total ink concentration (ppm)	50	20.2	25.9	63.9
Final				
Weight loss, *Rw* (%)	—	3.3	7.2	10.3
Cleaning quotient, *Q*	—	0.865	0.778	0.935
w-f Sequence				
Micro concentration (ppm)	22.4	10.5	14.8	57.8
Mid-range concentration (ppm)	3.6	1.6	4	59.9
Macro concentration (ppm)	24	6.08	10	74.5
Total ink concentration (ppm)	50	18.9	28.8	65.9
Final				
Weight loss, *Rw* (%)	—	1.3	8.6	9.8
Cleaning quotient, *Q*	—	0.943	0.767	0.944

Table 2. Performance of Ink Concentrations for High-Level Ash Furnish.				
	Pulping process	Flotation process	Washing process	Overall ink removal efficiency, *Er*(%)
F-W Sequence				
Micro concentration (ppm)	64.1	30.4	13.1	89.3
Mid-range concentration (ppm)	16.7	9.8	3.7	88.4
Macro concentration (ppm)	12.2	8.7	8.2	64.8
Total ink concentration (ppm)	93	48.9	25	85.9
Final				
Weight loss, *Rw* (%)	—	12.2	35.5	43.4
Cleaning quotient, *Q*	—	0.855	-0.651	0.874
W-F Sequence				
Micro concentration (ppm)	64.1	17.9	19.4	77.6
Mid-range concentration (ppm)	16.7	4.5	4.3	78.4
Macro concentration (ppm)	12.2	7.1	13	53.4
Total ink concentration (ppm)	93	29.5	36.7	74.6
Final				
Weight loss, *Rw* (%)	—	5.6	14.4	19.2
Cleaning quotient, *Q*	—	0.858	0.71	0.919
w-f Sequence				
Micro concentration (ppm)	64.1	23.3	46.7	72.8
Mid-range concentration (ppm)	16.7	5.4	14.3	75.8
Macro concentration (ppm)	12.2	6.8	9.5	58.3
Total ink concentration (ppm)	93	35.5	70.5	71.4
Final				
Weight loss, Rw (%)	—	3.9	21.2	24.3
Cleaning quotient, Q	—	0.926	0.887	0.871

Table 3: Performance of Ink Concentrations for Office Waste.

	Pulping process	Flotation process	Washing process	Overall ink removal efficiency, *Er*(%)
F-W Sequence				
Micro concentration (ppm)	17.5	5.6	2.7	89.3
Mid-range concentration (ppm)	25.5	8.5	7.1	80.8
Macro concentration (ppm)	375.4	82	68.8	87.3
Total ink concentration (ppm)	418.4	96.1	78.6	87
Final				
Weight loss, *Rw* (%)	—	2.9	28	30.1
Cleaning quotient, *Q*	—	0.999	0.894	0.936
W-F Sequence				
Micro concentration (ppm)	17.5	4	10.3	79.5
Mid-range concentration (ppm)	25.5	4.4	34.3	84.5
Macro concentration (ppm)	375.4	86.8	313.8	79.3
Total ink concentration (ppm)	418.4	95.2	358.4	79.6
Final				
Weight loss, *Rw* (%)	—	1.3	9	10.2
Cleaning quotient, *Q*	—	0.999	1.071	0.971
w-f Sequence				
Micro concentration (ppm)	17.5	2.7	9.4	85
Mid-range concentration (ppm)	25.5	6.7	31	74.4
Macro concentration (ppm)	375.4	63.4	338.9	83.5
Total ink concentration (ppm)	418.4	72.8	379.3	83
Final				
Weight loss, Rw (%)	—	1.4	1.1	2.5
Cleaning quotient, Q	—	0.995	1.008	0.995

most of the deinking chemicals needed to remove macro ink particles in flotation. The decrease in macro ink particle concentration in flotation following washing was probably the difference between the macro ink particles being removed, but replaced by the agglomeration of micro and mid-size ink particles into macro ink particles as a result of the readjustment of the surfactant level in the flotation cell.

Effect of Ash

Cleaning Quotient

In all furnishes, the largest total amount of ash removed was in F-W, but the lowest cleaning quotient value for all three furnishes also occurred in F-W sequence. The large removal of ash correlated with large weight loss. As observed with weight loss, the majority of the ash was removed in the washing operation. The interaction between ash and surfactant is not clear. One explanation is that the surfactant is removed in flotation, resulting in greater natural negative charges for both the fillers and fibers. This would tend to repel or disperse ash, making it easier to permeate through the screen.

Brightness

The addition of OMG for ash content in the high ash furnish decreased the brightness by 5.2% in the feed stock (Table 4) and increased micro ink concentrations by 186% as compared to the same parameters in the low-ash furnish. One reason for the lower initial brightness could be from the presence of higher concentrations of different inks in the OMG stock, as noted by Letscher et al. (10). F-W increased the brightness in the high ash stock by 11.7% from the feed, and in the low-ash stock, the increase was 1.3% from the feed. The increase in brightness with the other sequences gave similar results as the F-W sequence for both the feeds, but the resulting brightness for each sequence, for both stocks, is not significantly different from each other in value.

Tensile Strength

The addition of OMG for ash content in the high ash stock compared with the low ash furnish increased tensile strength in the feed stock by 8.9%. But the resulting value after F-W was similar for both stocks. The resulting values for W-F and w-f, for both stocks, were mixed. The strength was greater in W-F for the low ash and greater in w-f for high ash. Therefore, the benefits of adding OMG to ONP is again, as shown for brightness, mixed. These results are shown in Table 4.

FIGURE 3: **Gain per loss in yield for low-level ash furnish.**

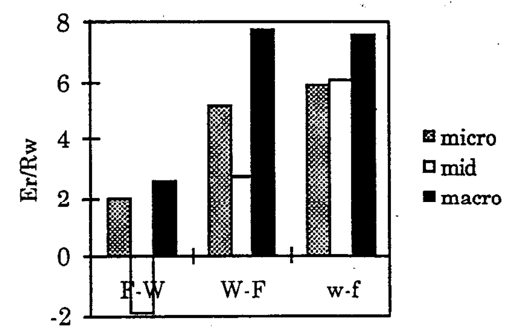


FIGURE 4: **Gain per loss in yield for high-level ash furnish.**

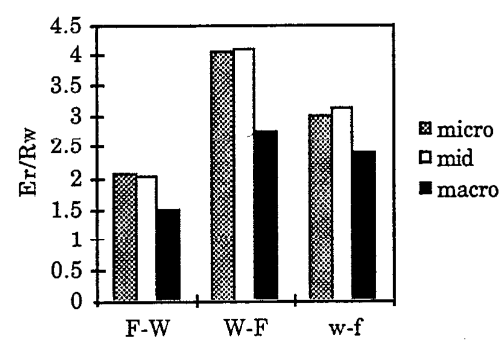
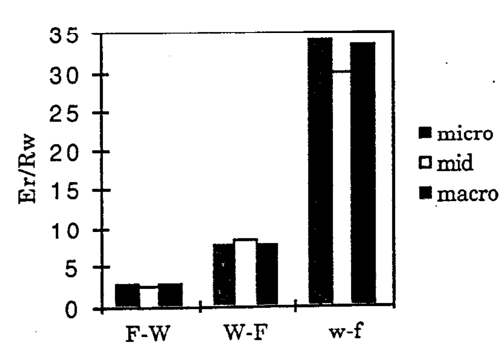


FIGURE 5: **Gain per loss in yield for office waste furnish.**



Overall Performance

In the F-W sequence for the low-level ash furnish, ink removal efficiency (*Er*) was negative at the mid-range ink particle size. This was probably due to the disintegration of larger particles, or the agglomeration of smaller particles into this size range. The *Er* values were positive for this sequence when greater ash furnishes were used. It is possible that the high-level ash content contributed ink particles into the micro-size range to form higher ink concentrations, as noted by Letscher and Sutman (10).

The w-f sequence had the highest cleaning quotient (*Q*) for the low ash content (QI) and office waste furnishes (QIII). The W-F sequence had the highest *Q* with the high ash furnish (QII). Results are shown in Fig. 2. These conclusions are reflected in Figs. 3-5 when measuring gain per loss (*Er/Rw*) in each furnish for each of the sequences. This measurement was used as an alternative to cleaning quotient in evaluating the deinking sequences because it measures quality versus yield.

DISCUSSION

Ink Removal Analysis

Micro Range

Low-Level Ash The F-W sequence produced the maximum *Er* (ink removal efficiency) in the micro particle range. The ink particles in this size range were evenly removed in both operations for this sequence, with both operations removing about 5.3 ppm of micro ink. But the removal of the micro inks correlates to the weight loss during the washing step for this sequence. To evaluate a sequence, a measure in quality for the removal of inks is used. For micro inks, the gain per loss (*Er/Rw*) increases from F-W to the W-F, w-f sequences utilized (Fig. 3). The order of the sequences in the axis had no particular significance. But it is used to demonstrate that the change in operations is seen to have the greatest effect in increasing the *Er/Rw* ratio. This may be due to several factors. One factor may be that the individual washing operations in both the W-F and w-f sequences removed a greater amount of micro ink particles than did the flotation operation. This was expected because micro ink particles are more susceptible to removal by this process than flotation. Because the deinking chemical concentrations were assumed to be lower after this operation, the effect of flotation in removing micro ink particles was expected to be minimal. The other factor could be that in the flotation cell, the surfactant levels were readjusted to levels that occurred in the washing processes in W-F, w-f. This readjustment may have stabilized the slurry, decreasing fiber and ink interactions, which resulted in less weight loss.

Er/Rw was maximum in the w-f sequence for mid-range inks in the low ash furnish. There was no indication of agglomeration or disintegration occurring in this sequence. The lower surfactant level was more effective in improving pulp quality. This could have resulted from the lower concentration of micelles generated from competing with each other to solubilize inks in the micelle interior. This in turn results in the mechanism similar to detergency in removing ink particles from cellulose fibers.

As indicated in Fig. 3, the sequences provide a higher *Er/Rw* for macro inks in this furnish. Macro inks were higher in concentration after pulping (Table 1), so its removal takes precedent over micro and mid-range particles. The large differences in *Er/Rw* between F-W and W-F sequences for both micro and macro inks could be due to the removal of micro inks by washing followed by the removal of agglomerated micro and mid-range ink particles by flotation with the readjustment of surfactant level. Fig. 3 is similar in performance characteristics as shown in Fig. 2 for overall performance of *Q* (QI for low-ash). *Er/Rw* is the greatest for w-f, and if micros and macros gains per losses were averaged out, this would be reflected in the overall performance of QI for w-f.

High-Level Ash The overall *Er* of the high-level ash stock was greatest with the F-W sequence for ink particles in the micro range. The high-level ash content of 12.7% was the maximum in the flotation unit for this sequence and aided in deinking by stabilizing the foam (10), as indicated by the large decrease of ink concentration that was achieved. The washing operation in this sequence achieved a high concentration of micro ink removal (389%). As shown in Fig. 4, *Er/Rw* is relatively low for this sequence, which was reflected by the large weight loss. The *Er/Rw* value increases for the W-F and w-f, relative to F-W sequence. It is suspected that ink removal by flotation in the W-F, w-f sequences was limited because surfactant was displaced from the furnish during washing. Furthermore, the 6.8% ash present in the flotation step of the W-F, w-f sequences may not have been sufficient to aid flotation.

The *Er/Rw* value decreased from W-F to w-f because the *Rw* was greater after the washing process for the w-f sequence. Although the cause is not clear, the lower surfactant level applied in w-f may not have been adequate to minimize fiber-fiber interactions in washing, thus making it more difficult to conserve fiber than in the W-F sequence. Also, the increased loading of ash may interfere with the interactions between surfactant and ink particles. The mechanism here is not clear. It could be that the micelles generated have more affinity for ash than ink particles, and because of the lower surfactant level used, this was probably the only action taking place.

In Fig. 4, *Er/Rw* is greater for micro particles than for macro particles. The *Er/Rw* values for the micro and macro ink particles in w-f were closer than the *Er/Rw* values for the micro and macro ink particles in W-F. As previously stated, the lower level of surfactant may have interacted more with ash, thus allowing some agglomeration of micro and mid-range ink particles into macro ink particles from the washing process. This mechanism may have enabled these size ranges to float out more readily. However, as Fig. 2 illustrates, W-F provided higher overall performance in removing all inks from the high-level ash furnish, which is reflected in the *Er/Rw* in Fig. 4.

Office Waste The F-W sequence was the most effective in terms of *Er* in removing micro ink particles from office waste. The W-F sequence was not as effective, probably because the high surfactant level aided in agglomeration and particles become too large to be removed by washing alone. Flotation in the W-F sequence removed most of these particles efficiently because of the size range of the agglomerated inks. This was, however, not the case with the w-f sequence. It appears that the lower surfactant level did not play a definitive role in particle agglomeration. Instead, the level of surfactant added may have changed the surface charges of the ink particles and fibers causing repulsion. Therefore, inks were more amenable to removal, and fiber was not lost from the processes.

The majority of the ink particles for this furnish were in the macro size category. As seen in Fig. 5, w-f had the highest value of *Er/Rw* for both micro and macro ink particles. This had to do with the effect of the surfactant level added in both processes. The difference in *Er/Rw* between W-F and w-f may be that in the latter process, the lower surfactant level did not interact with the ash present, as well as the chemical composition of the ash in this furnish. The micelles generated were effective in ink solubilization and surface charge changes to float out macro inks. Again, this is reflected in the overall performance of QIII for all inks in office waste.

In Fig. 2, w-f shows the highest performance in cleaning quotient resulting from the balance of yield and ink removal.

Mid and Macro Range

Low-Level Ash - For ink particles characterized in the macro range, the F-W sequence had the highest *Er* for the low-level ash stock (Table 1). Flotation removed most of the ink particles to reduce the concentration with minimal weight loss (5.0%), thus resulting in an overall 81.7% *Er*. The subsequent washing step reduced the ink concentration to 6.6 ppm from 8.2 ppm. The *Rw*, (28.4%) was substantial in the washing process of this sequence. In this study, the F-W sequence was not effective in removing ink particles of the mid-size range, as indicated by the negative *Er* value. One reason could be the disintegration of larger ink particles to smaller sizes or the agglomeration of smaller particles to form mid-size range particles.

The W-F and w-f sequences resulted in a lower *Er* than the F-W sequence for the macro ink particle range. One reason could be that the washing operation removes deinking chemicals needed to remove the ink particles of this size. However, it was observed that the w-f sequence removed ink particles in the mid-range category more efficiently than the other two sequences. It could be that the surfactant level added in the washing process of the w-f did not produce competing micelles and was able to solubilize some inks. However, an increase in the mid-range ink concentration during washing, probably by agglomeration of micro inks, was noted. As indicated in Table 1, this size range increased in concentration from 3.6 ppm during pulping to 4.0 ppm during washing. This size range was removed during the flotation process, as indicated by the large decrease in ink concentration to 1.6 ppm.

High Level Ash - Ink particles in the mid and macro range of the high-level ash furnish were best removed in the F-W sequence in terms of *Er*. The mid-range ink particle concentrations steadily decreased after each operation. The macro ink particles decreased significantly after flotation, but remained virtually stable after washing. The removal of the mid-range and macro ink particles after flotation was likely due to the ink particle size that was amenable to flotation and the presence of ash that served as a foam stabilizer. The effect of the weight loss is seen in the overall performance of the F-W sequence. A factor contributing to the weight loss was that the fibers in this furnish were probably shorter than the others and more difficult

Table 4. Physical and Optical Properties.

	Ash %	Tensile (kN/m)	Brightness %	Opacity %
Low-Level Ash	8.3	2.24	47.9	99.2
Flotation	7.9	2.68	47.8	99.6
Washing	3.7	2.49	48.5	99.0
Washing	4.8	2.40	48.7	99.0
Flotation	4.5	2.71	49.7	99.1
washing	5.1	2.32	48.6	99.2
flotation	4.5	2.39	50.2	98.6
High-Level Ash	12.7	2.44	45.4	99.6
Flotation	10.4	2.67	50.4	99.3
Washing	4.9	2.48	50.7	98.8
Washing	6.8	2.31	49.1	99.5
Flotation	6.6	2.54	51.0	98.5
washing	6.7	2.42	49.1	99.8
flotation	6.6	2.63	50.3	98.6
Office Waste	11.2	3.19	76.9	86.7
Flotation	10.2	3.39	80.4	83.0
Washing	5.1	2.87	79.8	82.4
Washing	5.8	2.90	78.2	86.1
Flotation	5.2	3.09	80.8	83.5
washing	5.7	2.96	78.8	84.7
flotation	5.5	3.14	80.4	82.5

to retain on the sidehill washer. As noted in Fig. 2 for the high-level ash furnish, the performance (QII) for the F-W sequence was not as high as the W-F, which had a lower weight loss. The F-W performance is similar to w-f, which may have been affected by the lack of interaction among ink particles, due to the lower amount of surfactant used for this process.

The W-F sequence achieved a smaller overall *Er* of 78.4 ppm for mid-range, and 53.4 ppm for the macro range ink particles compared to F-W with an overall *Rw* of 19.2%. During washing, the concentration of mid-range ink decreased significantly and remained constant after flotation. This could be that the level of surfactant added to the flotation cell influenced the agglomeration of micro ink particles into mid-range ink particles that were not large enough to remove. For macro ink particles, ink concentration increased slightly during washing. This may have occurred due to the agglomeration of smaller ink particles into larger particles. By switching the unit operations, and by placing washing prior to flotation, the increase in yield, or the reduction in weight loss, could be from the result of readjustment of the surfactant level in the flotation cell to 0.10%. The readjustment allowed for the remaining micro and/or mid-range ink particles to agglomerate to macro size and be removed by flotation. The W-F sequence gave an overall QII value of 0.915 (Table 1, Fig. 2), which is greater in performance than that of F-W and w-f. This was from the combination of a relatively low overall *Rw* (19.2%) and a moderately high total *Er* that contributed to the value of Q.

The w-f sequence provided similar results to the W-F sequence in removing mid-range ink particles, but the w-f sequence increased efficiency (*Er*) in removing macro ink particles. This was due to a greater overall *Rw* of 24.3% and reflected in the lower QII value. This may have occurred because in the w-f, the furnish contained shorter fibers that were more difficult to retain than in the W-F. A result of the lower level of surfactant used probably failed to minimize the interactions among fibers in the washing process, where a higher weight loss was noted. The *Er* for macro ink particles was slightly greater in the w-f compared to W-F sequence, but *Q* was higher in the W-F sequence, which indicates that *Rw* had a greater effect than ink removal efficiency (*Er*) on defining the performance of the w-f sequence.

Office Waste - The F-W sequence was the most effective in removing macro ink particles from office waste when compared with the other two sequences in terms of *Er*. This may have occurred because the macro ink particles were more difficult to remove in the washing operation of the W-F and w-f sequences. The macro ink particles occurred in the size range where flotation is most effective. This was not seen when removing mid-range ink particles. The W-F sequence performed somewhat better than the other two sequences when considering this size range, as indicated by the *Er* result. However, the performance level in the W-F sequence was less than the w-f sequence (Fig. 2). The performance of the W-F sequence was lower mainly because the overall *Rw* was greater, which had a stronger effect on Q. As indicated in Table 3, the w-f sequence had the lowest *Rw* and a rather large total *Er*, which lead to the highest performance in treating office waste furnish (Fig. 2).

Optical and Physical Properties

Brightness increased slightly after each deinking operation for each of the furnishes studied (Table 4). The brightness value of a stock is impacted primarily by ink particles less than 10 µm in diameter. The slight brightness increase indicated that the ink particles of this size were removed to some extent (11).

Opacity was relatively constant throughout each process for the low-level ash furnish. This indicated that the number of fines or bonds were constant throughout each process. The opacity decreased after each operation for the high-level ash furnish because of the loss of ash. Opacity also decreased after each operation for office waste. The opacity was less in office waste than in the other furnishes, which suggests the increase in long fiber content.

Tensile strength increased after the flotation operation and decreased following the washing operation in the F-W sequence for all three furnishes (Table 4). During flotation, the loss of fines was probably greater than the loss of fiber, resulting in an increase in tensile strength.

Tensile strength increased after the washing and flotation operations of the W-F and w-f sequences for the low-level ash furnish. There may have been more fines removed than long fiber in washing process, which would result in a strength increase. The strength increased even more after the flotation.

For the high-level ash and office waste furnishes, the washing and flotation operations in both the W-F and w-f sequences provided similar characteristics. Tensile strength decreased after washing and increased after flotation. The reasons for this occurrence are not clear, but the influence of the fines fraction in the strength of this furnish may have been a factor.

CONCLUSIONS

Deinking sequences are dependent on the type of furnish used for recycling. It also depends on the size of ink particles that the recycler desires to remove. In this study, the F-W sequence was the least desirable mainly due to high weight loss. But this may not be a crucial factor, because in industrial applications, the rejects in one stage are often recycled to another stage for fiber recovery. The W-F and w-f sequences were the most efficient in terms of *Q* at removing ink particles considering all furnishes studied. These results were also reflected in terms of gains per losses (*Er*/*Rw*) in demonstrating their efficiency. These sequences maintained a low weight loss and high levels of cleaning quotient, tensile strength, brightness, and opacity.

The effect of washing preceding flotation was seen to reduce the overall weight loss in W-F and w-f sequences. This may have resulted from the readjustment of the surfactant level in both operations to stabilize fiber interactions, and from increased agglomeration by smaller ink particles to larger sizes that are better removed by flotation.

Ash was seen to correlate with high weight losses in washing of the F-W for both low- and high-level ash furnishes. An insufficient surfactant level in the washing step may have caused this to occur. The interaction between surfactant and ash is not clear, but the lack of the readjustment probably results in the natural negative charge of the fillers and fibers to repel or disperse and assist with their removal in washing.

By increasing the ash loading in the high ash furnish, the brightness decreased by 8.9% compared to the low ash furnish. The resulting value after F-W is similar for both stocks, thus the value of adding ash as a deinking aid needs further consideration.

Future studies in this area will include the effect of low surfactant levels in washing operations following flotation and the interactions between ash and surfactant in relation to weight loss. Another area to investigate is the increase in yield when the two operations are reversed.

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