Deinking at Papelera Peninsular and the philosophy of deinking system design

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This new system deinks a furnish of 100% waste newsprint by flotation deinking. The design is based on measuring the ink particle size distribution by image analysis.

Papelera Peninsular's mill, located in the center of Madrid, has been using deinked pulp for the production of 52-g/m^2 newsprint since 1973. In 1986, we embarked on a rebuild of the deinking system with the following objectives:

1. To produce newsprint from 100% deinked stock
2. To produce deinked stock from 100% waste newsprint by flotation only.

Phase I of this program has now been completed. The specific objectives of Phase I were to:

1. Increase the addition of deinked stock from 20% to 50% of the furnish
2. Improve the quality of the deinked stock
3. Increase the yield of the deinking system
4. Increase the production of the deinking system.

Scientific principles have led to the development of our deinking system philosophy, which we have applied to design a deinking system that meets our specific requirements. One of the novel features of our system is that it was designed to deink a furnish containing 100% waste newsprint by flotation only. This objective was achieved by an appreciation of the fundamental importance that ink particle size distribution has on the ink removal efficiencies of deinking systems.

Deinking system design philosophy

Measurement of ink particles

The process of deinking waste paper is essentially one of removing ink particles from usable fibers. Developments in deinking have been greatly hindered by the fact that there was no analytical technique to measure ink particles. Hence it was not possible to determine the ink removal efficiencies of existing systems, and the development of more efficient deinking units and systems was extremely difficult.

Consequently, we have developed automatic image analysis techniques to measure not only the amount of ink but also the nature of the ink particle size distribution (*1*). This work has proven successful, for not only has it given us the basic tool for measuring the ink but it has also given us a fundamental understanding of the deinking process. We can determine the major operating parameters that control the mechanism of ink removal, and we can then develop more efficient ink removal units by optimizing these parameters.

The automatic image analysis system we use is shown in **Fig. 1**. The system consists of a high-powered microscope, a video camera, and the image processor. The analytical procedure is illustrated in **Fig. 2**, which shows the display on the imaging screen. The real image of a field viewed through the microscope is shown in the bottom left quadrant, and the process image showing the detection of the ink particles is illustrated in the bottom right quadrant. The top of the screen shows the captured particles, and the parameters of each individual particle that can be measured are placed in memory. For meaningful statistical data, we may have to analyze up to 200 fields.

Distribution of ink particle size

Figure 3 shows a typical distribution of ink particle sizes that were obtained after pulping a newsprint furnish (50% letterpress and 50% offset) with a standard recipe of deinking chemicals. Ink particles can be considered to have a platelike shape and are generally described by their longest diameter.

The two histograms shown are based on the size classification of longest diameters of the ink particles. The top histogram shows the number of particles in each class of longest diameters. The bottom histogram shows the summation of the areas of all the particles in each class

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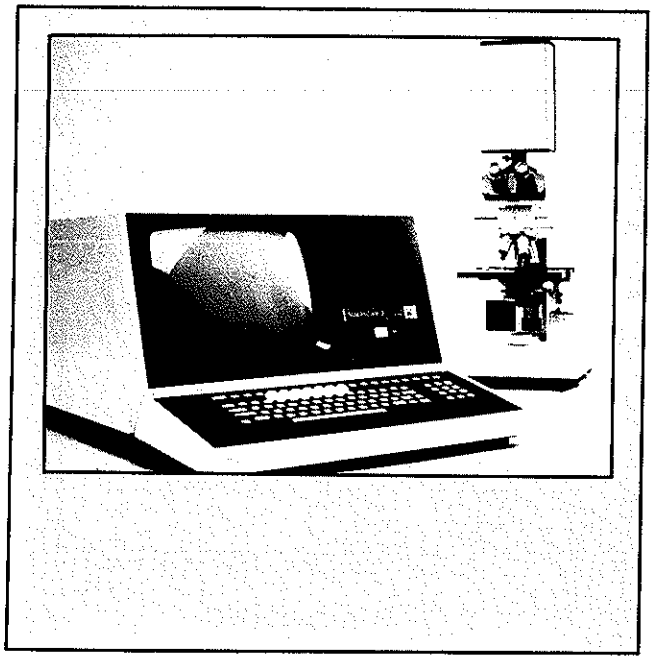
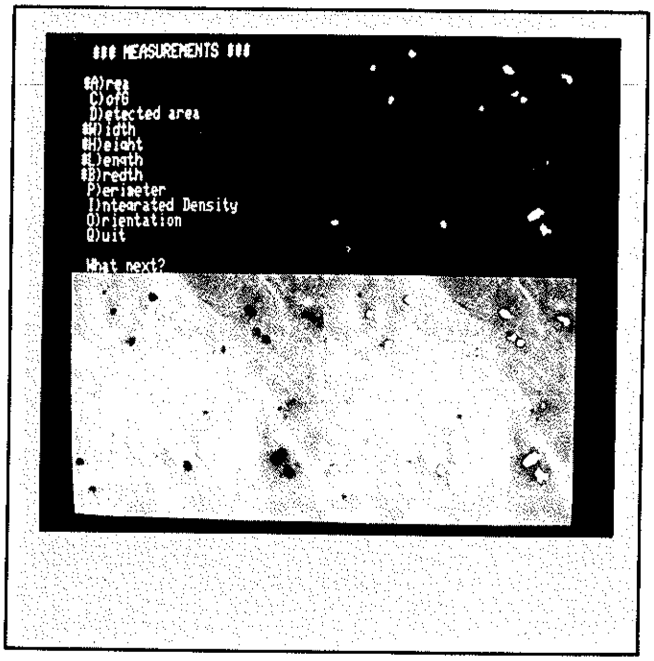
1. Image analysis system, showing the microscope and monitor



2. Identification and measurement of ink particles on the image analysis monitor



of longest diameter. Both of these histograms are important. The area histogram correlates to the amount of ink that is present, while the number histogram describes the nature of the ink.

Efficiency of ink removal vs. particle size

The bottom half of **Fig. 4** illustrates the ink removal efficiencies achieved by various deinking operations: washing, flotation, and cleaning.

Washing. One of the primary parameters that control the efficiency of ink removal by washing is particle size (*2*). As the ink particle size increases, the tendency for entrapment of ink particles in the fiber matrix also increases, making removal less efficient.

On the other hand, as the ink particle size decreases, the probability increases that the smaller particles will become entrapped on the fiber surface or within the individual fibers (*3*), again reducing efficiency. Thus, there is a parabolic relationship between the ink removal efficiency and the particle size.

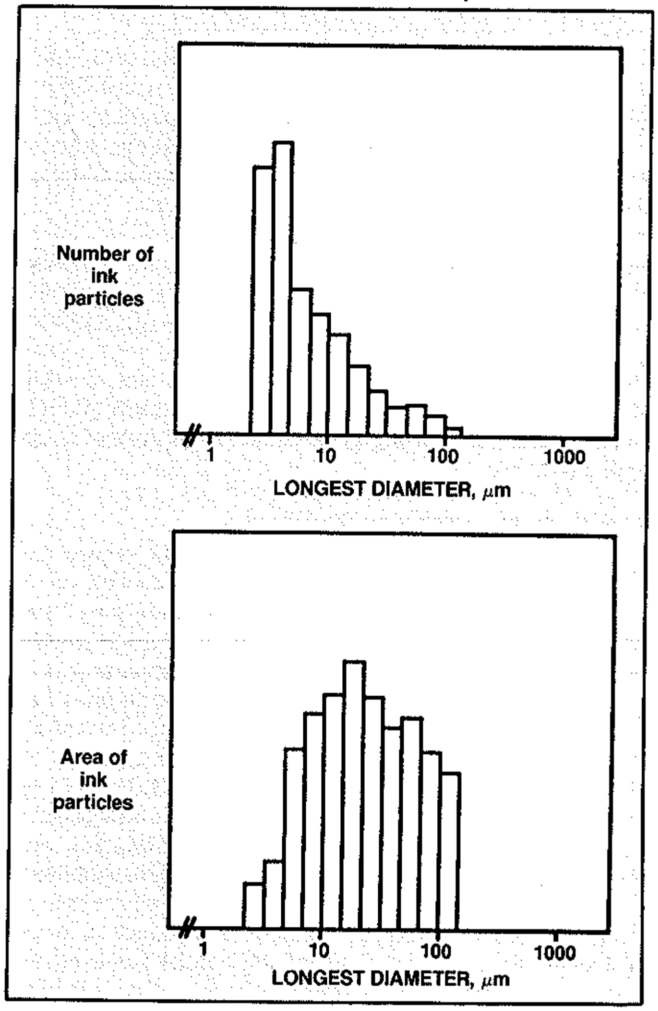
Flotation. The process of flotation deinking can be divided into three stages:

1. Collision between the ink particle and the air bubble
2. Attachment between the ink particle and the bubble
3. Flotation of the ink particle and bubble complex to the surface.

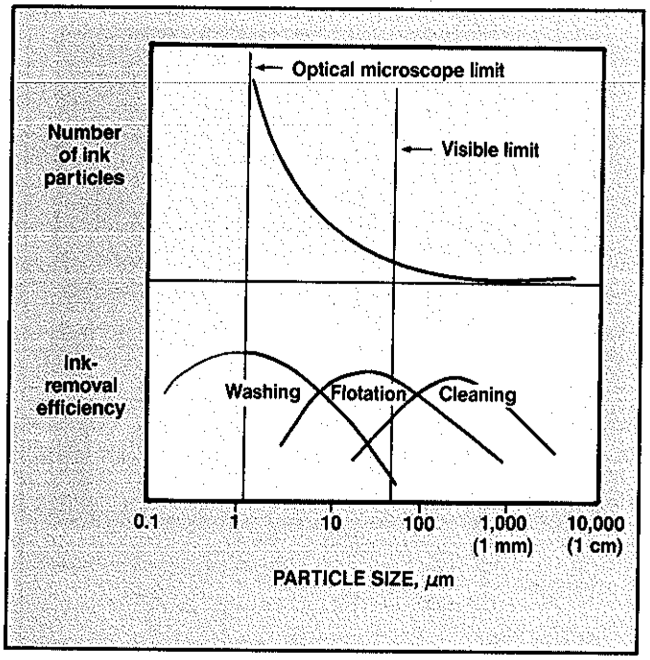
The probability that each of these stages will occur is dependent on the particle size. The probability of attachment is also dependent on the hydrophobic nature of the particle.

In fundamental studies, Larsson *et al.* (*4*) demonstrated that the flotation of ink particles is dependent on particle size. Below a certain size, the efficiency of flotation decreases because the frequency of bubble particle

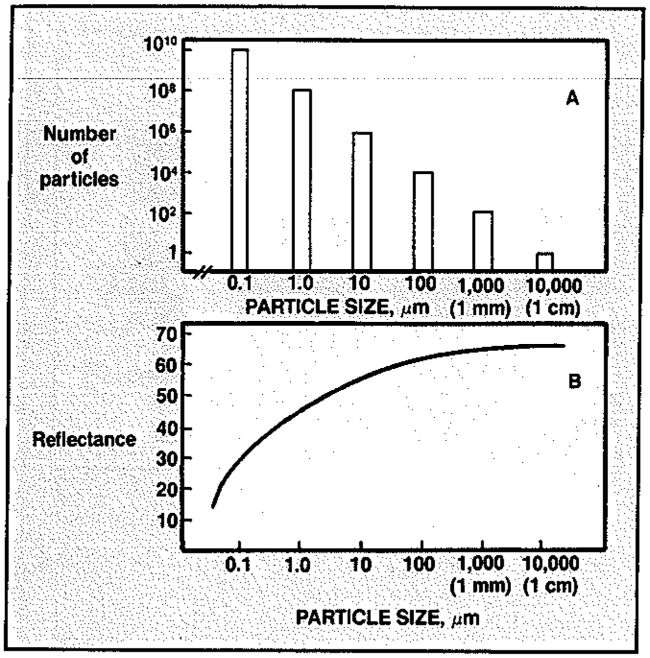
3. Size distributions of ink particles for samples of 100% waste newsprint furnish with strong dispersion chemistry



4. Size distribution of ink particles in the pulper (top) and ink removal efficiencies as a function of particle size for the major deinking operations (bottom)



5. The effect of ink particle disintegration on (A) the number of particles generated and (B) the brightness of deinked pulp



collisions decreases. The smaller ink particles do not have enough energy of impact to disrupt the streaming water layer between the particles and the air bubbles.

Other research (*5*), especially in mineral flotation, has shown that when the particles exceed a certain size limit, particle removal efficiency decreases. The particles can be too large for total capture by a single bubble. Large particles also reduce the buoyancy of the particle bubble complex, reducing its rate of rise to the surface.

Centrifugal cleaning. The efficiency of particle removal by centrifugal cleaning is controlled primarily by specific gravity and secondarily by particle size and shape. Large particles, with diameters of 100-1000 μm, tend to be rejected more.

Screening. Ink particles have a platelike shape, with a thickness of 2-10 μm. They will align themselves with the fibers and pass through the screen, so ink removal by screening is poor.

Deinking system design vs. particle size

Our design scheme is summarized in **Fig. 4**, where we have combined two histograms of ink particle size distributions. The top histogram shows the number of ink particles vs. particle size obtained when a 100% waste newsprint was pulped with a strong dispersion chemistry. The second histogram is the efficiency of ink removal for the various deinking operations. The fundamental principle is that we can define the requirements of the ink removal modules in the system in relation to the nature of the ink particle size distribution obtained in the pulper.

Specifically for the case of 100% waste newsprint, the figure shows that most of the ink particles can be removed by washing. Thus, the simple design philosophy is that a strong dispersion chemistry is used to produce a large number of small ink particles which can be removed by washing. In effect, we attempt to move the ink size distribution in the pulper into the "washing removal zone," or to produce a negatively skewed distribution.

However, a fine ink dispersion has a negative effect on brightness, as illustrated in **Fig. 5**. In the top histogram, we have calculated the number of ink particles that could be produced if we take one particle (1 cm in diameter) and disintegrate it into a number of particles of known particle size. Simple calculation shows that one large ink particle can be disintegrated into 10 billion smaller particles (0.1 μm in diameter).

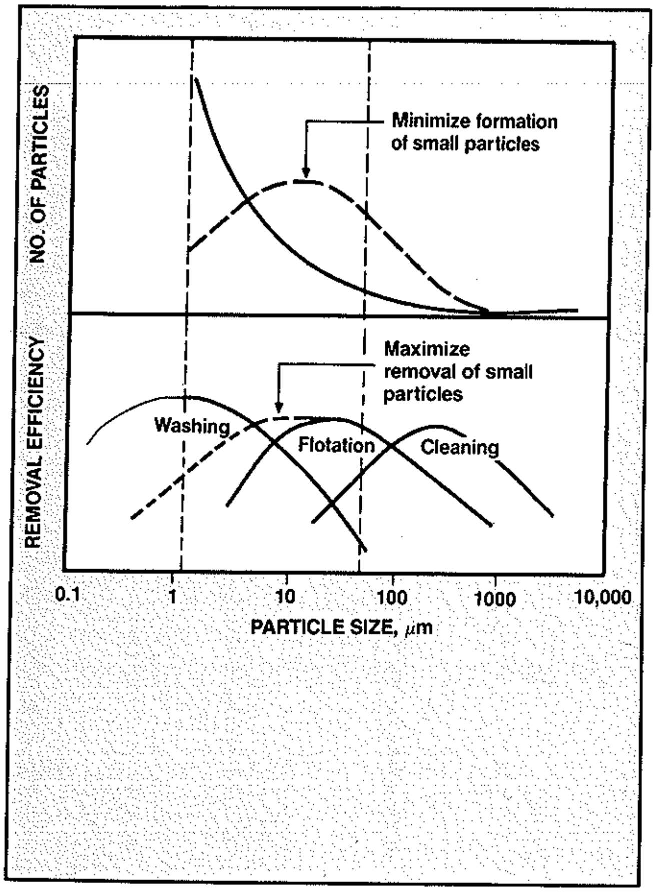
The effect of particle size on brightness was determined in a classic experiment carried out by Compton and Hart (*3*), who worked in the detergent industry. They measured the reflectance of a series of two-component mixtures containing 99% cotton fibers and 1% carbon black pigment of well-defined particle size. Their results are plotted in Fig. 5B, which shows that the smaller particle sizes have a dramatic effect on brightness.

Even if it were possible to remove a high percentage of the ink particles in the washing system, the remaining ink would be in a finely dispersed form and would have a disproportionate effect on the brightness of the pulp. In fact, our wash deinking system operating with 100% waste newsprint typically removes only 50-70% of the measurable ink.

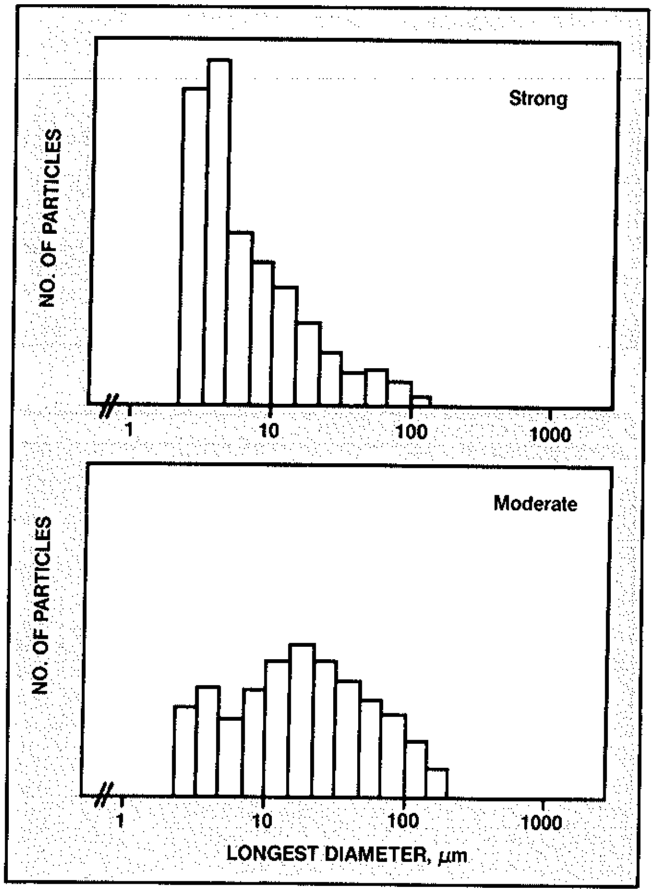
The specific system design

One of our major constraints in designing the deinking system was that the raw material was 100% waste newsprint. Conventional industrial experience indicates that deinking of 100% newsprint waste is difficult with flotation. In fact, in the United States, deinking of 100% newsprint is carried out by washing only, while in Europe a significant portion of magazine waste (20-50%) is incorporated into a newsprint furnish.

6. The major objectives are (A) to modify distribution to minimize formation of small ink particles and (B) to optimize flotation to maximize the removal of small ink particles.



7. Size distributions of ink particles (top) in a mill using strong dispersion chemistry and (bottom) in our mill, where dispersion is moderate



However, by analyzing the effect of the size distribution of ink particles, we were able to take a more radical approach. The major limitations of the washing system are that the yield is poorer, the water requirements are higher than a flotation system, and the residual finely dispersed ink has a negative effect on pulp brightness. Consequently, we decided to re-evaluate whether 100% waste newsprint could be successfully deinked by flotation.

The major problems in deinking of this raw material by flotation can be discerned in Fig. 4. These are (a) that 100% waste news can produce a large number of small ink particles and (b) the efficiency of ink removal of small ink particles by flotation is poor.

Hence, to make flotation deinking of 100% waste newsprint successful, our objectives were clear. We must (a) minimize the formation of small ink particles and (b) maximize the efficiency of flotation of small ink particles. These objectives are illustrated in **Fig. 6.** In effect, we are attempting to move the ink particle distribution into the "flotation removal zone," while increasing the spectrum of the flotation removal zone.

Minimizing the formation of small ink particles

To minimize the formation of small ink particles, we have modified the pulper chemistry, added clay, and optimized the chemical collector.

Modification of the pulper chemistry. We have modified the pulper chemistry from a conventional strong dispersion to a more moderate dispersion. In our system, we have ensured that after the ink is detached from the fiber, it is not dispersed to any great extent. Hence, the chemicals have only a mild dispersion effect, and the concentrations are kept to a minimum.

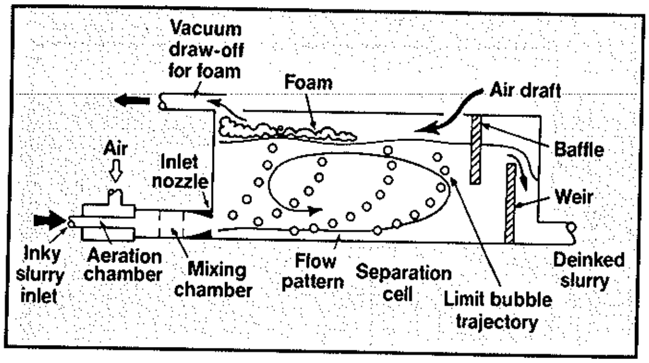
Addition of clay. In the pulper, we have also added a small amount of clay. Our mill, like many European newsprint mills, produces filled newsprint. About 7% clay is added to the stock before the paper machine. We conducted a series of trials to test whether the clay would improve flotation efficiency. These trials showed that although a good deinking efficiency was obtained with 100% newsprint, a significant improvement in ink removal occurred after clay was added to the pulper. Trial work showed that 2% clay was sufficient.

The role that ash plays in flotation deinking is not fully understood. However, a plausible hypothesis is that the fine ink particles are absorbed onto the surface of the inorganic material. This material can be floated more efficiently because the particle size is larger and the particle complex is more hydrophobic.

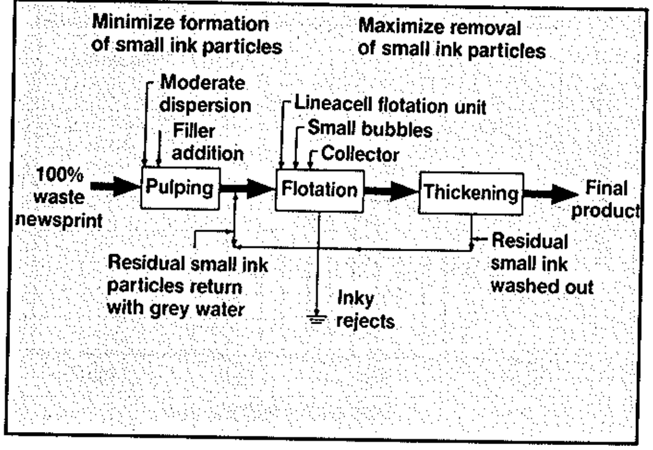
Optimization of the chemical collector. A collector is added before the flotation cells to maximize the flotation efficiency. These collectors were also evaluated for their ability to agglomerate fine ink particles.

Figure 7 compares the ink particle size distribution at our mill and that obtained in a typical washing mill using 100% waste newsprint with a strong dispersion chemistry.

8. Diagram of the Lineacell flotation unit



9. Flow chart of the system design



I. List of factors optimized

System input	
Raw material	Waste paper
	Printing inks
Chemical additives	Filler
	Surfactant
	Silicate
	Silicate replacement
	Sequestrant
	Hydrogen peroxide
	Collector
Energy	Heat
	Electrical power
Water	
Final product	(quality and quantity)
System rejects	Ink
	Ash
	Fiber
	Water

Not only have we reduced the number of ink particles below 10 μm by 65%, but there has also been a significant increase in the number of particles in the size range best suited for flotation.

Maximum flotation efficiency

To maximize the efficiency of flotation of small particles, we have (a) installed a highly efficient flotation cell, (b) maximized the production of small bubbles, and (c) designed the system to maximize removal of small particles.

A highly efficient flotation cell. The technical heart of the deinking system is the Beloit Lineacell Flotation unit (**Fig. 8**), which has three major zones: the aeration, mixing, and separation zones. In the aeration zone, air can be added in the correct amount and nature independently of the flow.

A dedicated mixing zone is incorporated to maximize both the intensity and frequency of collisions between ink particles and bubbles. This is the most important part of the flotation cell because it is here that the attachment of ink particles and bubbles occurs.

The design of the mixing zone was based on both practical studies (*7*) and theoretical studies (*8*) which concluded that "the more strongly a particle and bubble collide, the more likely their attachment." Hence, the mixing zone increases the energy of impact of small particles on bubbles, which is the rate-controlling parameter.

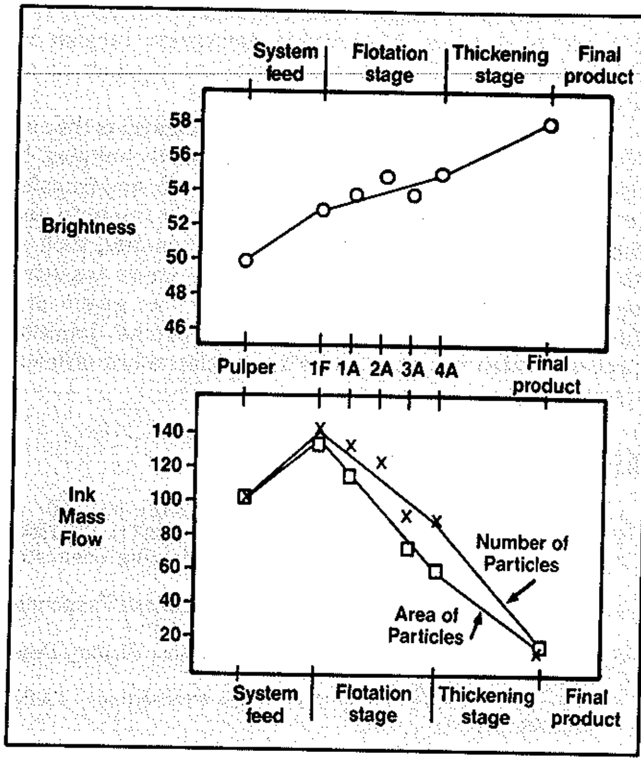
The separation zone is designed so that (a) the ink bubble complex can be brought to the surface as quickly as possible and then (b) the inky foam can be removed from the surface of the stock with minimum fiber loss.

By "a highly efficient flotation cell," we mean one that minimizes the fiber losses and maximizes the ink removal. In the Lineacell, the inky foam is removed from the surface of the stock by a vacuum system designed to remove only the inky foam. Hence, the fiber losses are much less than those of a conventional flotation cell, which requires a pulp overflow to remove the foam. In fact, in our installation we only have four stages of primary flotation and no secondary stages, whereas the comparable industry standard would normally be 6-9 primary flotation stages and 2-3 secondary stages.

Maximum production of small bubbles. Laboratory studies (*9*) have shown that for optimum flotation of small particles, there is an optimum air bubble size, approximately five times the diameter of the particle to be floated. Thus, a large number of relatively small bubbles should be produced for the flotation of small ink particles.

We have maximized the production of small bubbles both mechanically and chemically. Mechanically, we have modified the design of the aeration and mixing zones. Chemically, we have added at the pulper a small amount of surfactant, which reduces the bubble size considerably (*10*).

10. Brightness (top) and ink removal (bottom) of mill samples at various stages in the deinking process. 1F = 1st stage feed, 1A = 1st stage accept, 2A = 2nd stage accept, 3A = 3rd stage accept, 4A = 4th stage accept



II. Results of optimization trials, old system vs. new system

	Old	New
Ink removal		
By number of particles, %	60	87
By area of particles, %	65	88
Brightness of final product, %	54-56	58-60
Losses, %	16	8[a]
Flotation temperature, °C	45	35[b]
Reduction in chemicals, %		
Collector		50
Surfactant		80
Sequestrant		100
Silicate		(replaced)
Overall		65

[a]3% fiber, 3% ash, 2% contaminants.
[b]Change of chemicals.

Maximum removal of small particles. Figure 9 is a flow chart of our system design. It is based on a number of elements:

1. All the ink that is rejected from the system is rejected by the flotation module.
2. A moderate dispersion of ink is produced in a medium-consistency pulper (12–14%).
3. Ash is added in the pulper to agglomerate the ink.
4. Chemicals are used so that the ink particles can be separated from the pulp by flotation and washing operations.
5. After pulping, contaminants are removed by a Beloit S-Screen.
6. After screening, ink is separated from the pulp by a four-stage Lineacell flotation module.
7. After flotation, any residual ink is separated by a thickening operation, whereby the underflow, or grey water, is returned to the main line without clarification.
8. The grey water, which contains the smaller ink particles, is returned to the main line before the flotation stage, providing another opportunity for the residual small ink particles to be removed.

In the thickening operation, we want to minimize the formation of a tight pulp mat and hence minimize the entrapment of ink particles. These particles have another opportunity to be made more hydrophobic by the chemicals and another opportunity to form agglomerates with the ash. Hence, by returning the grey water to the main line, the probability of removal by flotation is increased.

System optimization and performance

During startup, we optimized the system using factorial optimization techniques (*11, 12*). **Table I** lists the major operational parameters that we evaluated.

During the series of chemical optimization trials, the collector and other chemicals were monitored throughout the system using analytical techniques (*13*) based on gas-liquid chromatography and mass spectroscopy.

After the optimization trials, we compared the performance of the new deinking system with that of the old system. The operational results are summarized in **Table II**. The major improvements have been:

1. The losses have been reduced from 16% to 8%. This 8% is made up of 3% ash, 3% fiber (predominately fiber fines), and 2% contaminants (mainly ink).
2. The temperature of flotation was reduced from 45°C to 35°C.
3. The chemical costs have been reduced by 65%.

Besides these operational savings, the system also produces a product of excellent quality. Ink removal and brightness profiles throughout the system are given in **Fig. 10**. The final product has a brightness of 58–60%, and the system ink removal efficiency of 88% is one of the best we have measured in all the commercial deinking systems we have evaluated (*1*).

Conclusions

With the adoption of an appropriate system philosophy and the selection of the right equipment and chemicals, it is possible to deink a 100% waste newsprint furnish by flotation alone and produce an excellent product at an attractive cost.

The reason these studies have been successful is that we were able to use automatic image analysis techniques. In using image analysis, we were able to compile and transfer technical information not only from within the pulp and paper industry but also from other technologies, such as mineral flotation and chemical detergent washing technology. Analysis of this knowledge has given us a fundamental technical understanding of the deinking process, which has enabled us to develop more efficient deinking units and systems.

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