

Deinking of inkjet digital nonimpact printing

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ABSTRACT: Pigmented nonimpact (inkjet) printing is a concern in conventional flotation deinking, due to the problems associated with the hydrophilic, submicron-size pigment particles of the ink. Preliminary experiments were conducted to evaluate the efficiency of a conventional flotation deinking process in detaching those inkjet particles from the fiber surfaces and network. A Denver D-12 laboratory flotation cell was used to test 100% old newsprint paper (ONP) with the ISO brightness target set to 58, which makes a paper recyclable. The inkjet-printed ONP was floated to 47 ISO brightness by the INGEDE Method 11. It was enhanced to 50 ISO brightness using flotation, with the addition of nonionic surfactant for better repulping. In addition, a patented electric field technology was used for further improving the floated ISO brightness to 52.5—yet still short of the 58 target for recycling. This improvement was reached with small air bubble sizes, which are more likely to collide and interact with ink particles, causing additional ink to be brought up to the surface of the water pool. The increasing problem of deinkability from digital nonimpact inkjet printing means that additional technical efforts are needed to overcome the crossroad between environmental concerns and technological progress. Papermills, inkjet suppliers, printer manufacturers, and academic and industrial deinkers should take collective action to meet the challenges to future success.

Application: Recycling mills can improve brightness and expand the mill's capability to handle a percentage of 100% inkjet-printed paper by adding nonionic surfactant in pulping processes and using electric field treatment in flotation.

Inkjet digital nonimpact (inkjet) printing has expanded beyond personal and office computer printing to newsprint, display graphics, digital photography, textile printing, and packaging printing. Advantages of inkjet printing include its speed, improved detail, overprint reduction, and elimination of storage costs. While the volume of digital inkjet printing is increasing at a fast pace, many problems will occur in the foreseeable future because deinking involves submicron-sized pigmented inkjet particles. Even small amounts of inkjet papers in paper machine broke can introduce a serious deinking challenge in a papermill. INGEDE [1] has claimed that inkjet prints are not recyclable for old newsprint (ONP) and copying paper, as it results in a dark shade for the recycled paper. As inkjet printing expands from households and offices to high-volume direct mail and newsprint, the graphic paper recycling system will be inadequate.

The traditional newsprint deinking process deals with oil-based hydrophobic ink. The large particle size of the ink and its water repelling properties aids separation from the pulp in a flotation system, where air bubbles attract ink particles. The bubbles are floated to the top of a flotation chamber for skimming.

Pigmented nonimpact printing inks have generated concerns about the ability to deink papers by the conventional air bubble flotation deinking procedure. The submicron-size hydrophilic pigment particles are smaller than those best suited for flotation removal. The motivation behind the use of water-based pigmented inks is the reduced emission of volatile organic carbon compounds associated with many conventional solvent-

based types of ink. The printing quality of water-based inks is crisp, and the print has a lower rub off and see-through [2,3].

A waste paper furnish that contains pigmented inkjet-printed ONP is difficult to deink with a conventional flotation process. The poor floatability can be ascribed to the water-based acrylic resin, which is an alkaline medium that prevents ink agglomeration by electrostatic and steric repulsion mechanisms [4,5]. These small hydrophilic inks are ideal for deinking by washing [6]; however, washing consumes a large amount of water, and an elaborate water decontamination process is needed to clean the wastewater. Also, the yield loss associated with washing is economically unacceptable. A single-wash deinking stage can have up to 35% yield loss [7]. Galland and Vernac used a two-stage flotation process for deinking of wastepaper that contains flexographic-printed material and offset-printed paper [8,9]. In their work, deinking inkjet pigment with even smaller hydrophilic particles was an even greater challenge.

In the current work, preliminary experiments were conducted to evaluate the efficiency of the conventional flotation deinking process in detaching those inkjet pigment particles from the fiber surface and network. Physiochemical and hydrodynamic forces do not provide enough lifting surface area and force in the flotation process for inkjet-printed particles to be deinked. Experiments involve the addition of a nonionic surfactant, plus the patented electric field technology in the flotation process [13]. This process could be applied with existing technologies to improve the deinkability of recycled paper. This work also demonstrated the importance of bubble size in flotation deinking.

INKJET PRINTING

A new electric technology for deinking

Electric field technology is essentially an electrolytic cell consisting of two electrodes and an electrolyte solution. The electrodes are connected to an external power source that drives nonspontaneous chemical reactions. In an electrochemical cell, the reduction and oxidation processes responsible for the overall reaction are separated in space: oxidation takes place in one electrode compartment and reduction takes place in the other compartment. If the electrodes are in the same compartment, oxidation and reduction take place at each electrode.

As the reaction proceeds, the electrons released in the oxidation at one electrode travel through the external circuit and reenter the cell through the other electrode; there, they bring about reduction. The electrode at which oxidation occurs is called the anode; the electrode at which reduction occurs is called the cathode. In an electrolytic cell, the anode is still the location of oxidation but now electrons must be withdrawn from the species in that compartment because oxidation does not occur spontaneously, and at the cathode there must be a supply of electrons to drive the reduction. Therefore, in an electrolytic cell the anode must be made relatively positive to the cathode. Although the cathode is still the site of reduction, it is now the negative electrode whereas the anode, the site of oxidation, is the positive electrode [10].

Electrolysis of water is the decomposition of water (H_2O) into oxygen (O_2) and hydrogen gas (H_2) as an electric current is passed through the water. An electrical power source is connected to two electrodes, typically made from some inert metal such as stainless steel, that are placed in the water. With adequate potential from the power source, hydrogen will be produced at the cathode and oxygen at the anode. The generated amount of hydrogen is twice the amount of oxygen, and both are proportional to the total electrical charge as shown in the following reactions:

At cathode $2\text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g}) + 2\text{OH}^-(\text{aq})$ standard potential at 298k is -0.83V

At anode $2\text{H}_2\text{O}(\text{l}) \rightarrow \text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^-$ standard potential at 298k is +1.23

Combining these two reactions yields the overall decomposition of water into oxygen and hydrogen in the expression below:



Decomposition of pure water into hydrogen and oxygen at standard temperature and pressure is not favorable in thermodynamic terms, as half of the reaction's standard potential are negative values. Thus, energy supplied by an external electrical power source is needed. Care must be taken in choosing electrolyte, as an anion from the electrolyte is in competition with the hydroxide ions to give up an electrode. An electrolyte anion with less standard electrode potential than hydroxide

will be oxidized instead of the hydroxide and no oxygen gas will be produced. At the cathode, a cation with a greater standard electrode potential than a hydrogen ion will be reduced instead and no hydrogen gas will be produced.

Flotation at 1% consistency or less and the addition of surfactant with electric field gave the best deinking efficiency. Bubble stability affects deinking efficiency. The bubbles generated by electrolysis of water were about 30 μm in diameter [11], which promoted better bubble stability and had lower bubble coalescing.

EXPERIMENTAL

Raw materials

The following were used as raw materials:

- Inkjet printed on newsprint
- Inkjet printed on copy paper
- Floatsan (a nonionic surfactant, Product 209 [BASF, Snellville, GA, USA], reactivity 0, no unusual hazard, health/flammability 1 —may be irritating)



1. Mixer and Denver D12 laboratory flotation machine.



2. Electric field–applied flotation cell and the anode generate fine bubbles.

- ONP (*Atlanta Journal-Constitution*)
- 100% flexographic-printed ONP (*Macon Telegraph*)

Techniques

An HP DeskJet 6940 with ink cartridges 95 and 96 (LD Products; Long Beach, CA, USA) was used to print onto precut blank newsprint, as well as onto copy paper. A Denver D12 Laboratory Flotation Machine (Sepor; Wilmington, CA) with 1000-g stainless steel tanks was used in the experiments. The motor-driven machine includes a ½-hp totally enclosed, fan-cooled, variable-speed motor with mounted tachometer.

The International Association of the Deinking Industry (INGEDE) Method 11 (“Assessment of print product recyclability—deinkingability test”) was used for the deinking experiments. The following pulp consistencies were used:



3. Counterclockwise, from top: pulped, floated, and reject pads of old newsprint (ONP).

12% (using a KitchenAid mixer), 5% (soaking pulped slurry), and 4% (hydropulper for dispersion).

Filter pads were made from feed (pulp samples after pulping), accept (pulp slurry after flotation), and rejects. Samples are analyzed for effective residual ink concentration (ERIC) and ISO brightness by a Technidyne Color Touch 2 (Technidyne; New Albany, NY, USA). **Figures 1–4** show the equipment used in the experiments.

RESULTS AND DISCUSSION

ONP was used to establish the control samples. A KitchenAid mixer (Fig. 1) was used to pulp samples at 12% consistency for 20 min according to INGEDE Method 11. A Denver D12 laboratory flotation machine (Fig. 2) was used to float the hydrophobic inks to the top. **Figure 5** shows the dirt content

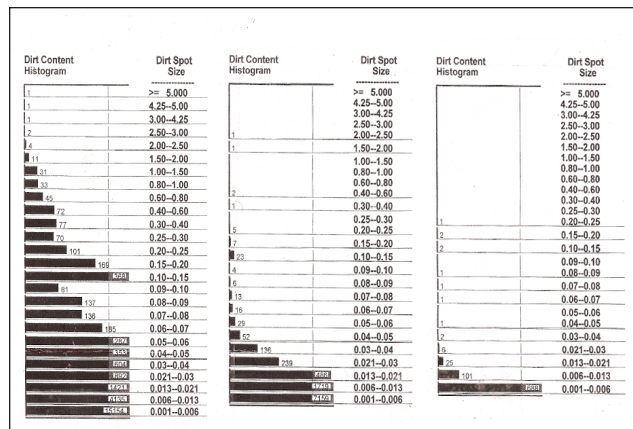


4. Counterclockwise, from top: pulped, floated, and reject pads of flexographic-printed (top photo) and inkjet-printed (bottom photo) newsprint.

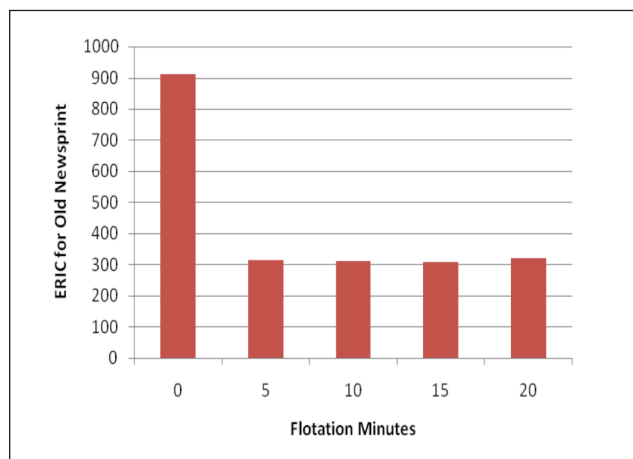
histogram for ONP during the progress of air flotation at 0, 2, and 4 min, indicating that ink particles of more than 10 μm in size were removed effectively. The ERIC of ONP at 0, 5, 10, 15, and 20 min is shown in **Fig. 6**. The data show that 5 min were adequate to complete the ERIC reduction to about 300. The ISO brightness data are shown in **Fig. 7**. After 5 min, the ISO brightness was improved from 48 to 58. The calculated inkless ISO brightness was about 70. This ONP was considered to be deinkable on the basis of these experimental results.

Four different methods of pulping and flotation (Nos. 1–4) were used to deink inkjet printing.

- (1) Inkjet-printed ONP was deinked according to INGEDE Method 11 (no nonionic surfactant).



5. Dirt content histogram for ONP during air flotation. Apogee Spec Scan 2000 software (Trending Pacific; Sawston, UK) was used to determine the particle size measured in microns over a square meter.



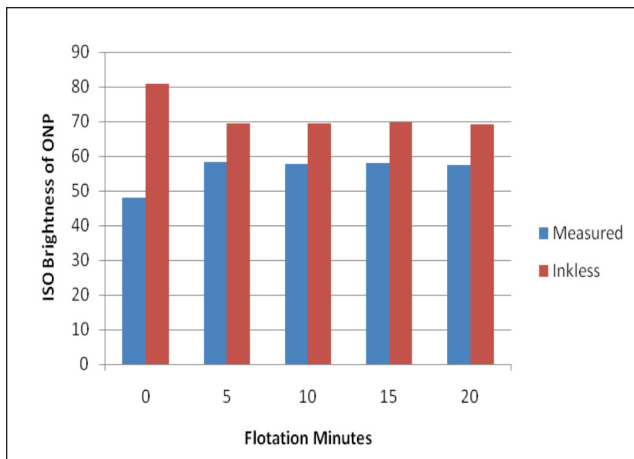
6. ERIC of ONP for flotation at 0, 5, 10, 15, and 20 min.

- (2) Inkjet-printed ONP was deinked according to INGEDE Method 11 (nonionic surfactant added).
- (3) An electric field apparatus was used for experiment in No. 2.
- (4) An electric field apparatus was used for experiment in No. 3, with longer pulping.

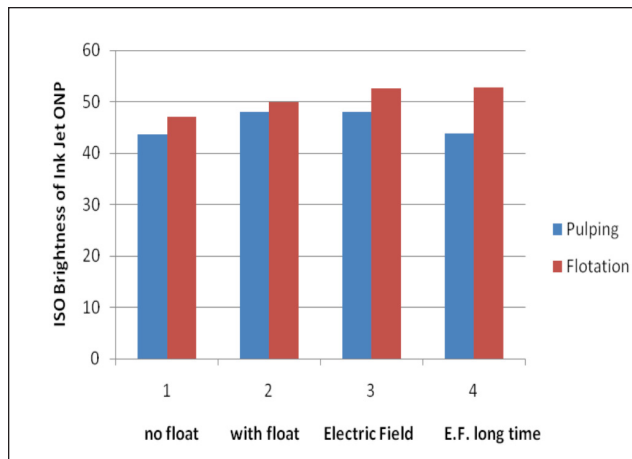
ERIC data at the end of pulping showed improvement from No. 1 to No. 3, while more dirt was generated with longer pulping time in method No. 4 (**Fig. 8**). However, the ERIC at the end of flotation was improved from No. 1 to No. 3. Electric field flotation brought final ERIC No. 4 closer to No. 3.

The ISO brightness at the end of pulping showed improvement from experimental condition No. 1 to No. 3, with slightly lower brightness for No. 4 due to the longer pulping time (**Fig. 9**). However, the brightness improved from No. 1 to No. 4 with electric field flotation.

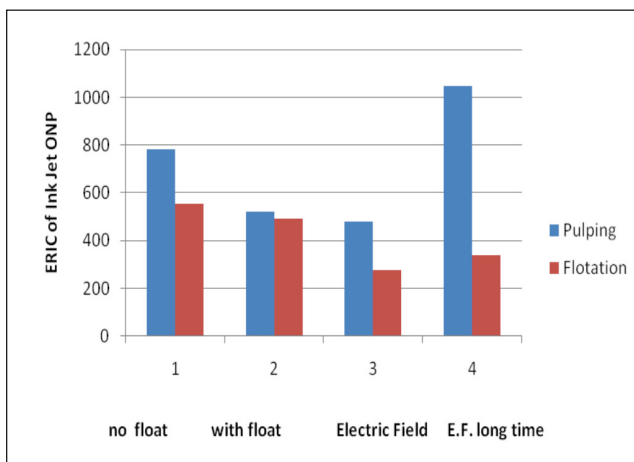
Reject pads were collected for all four experimental methods. **Figure 10** shows that ERIC worsened from experiment No. 1 to No. 2 and, while it improved slightly in No. 3, it be-



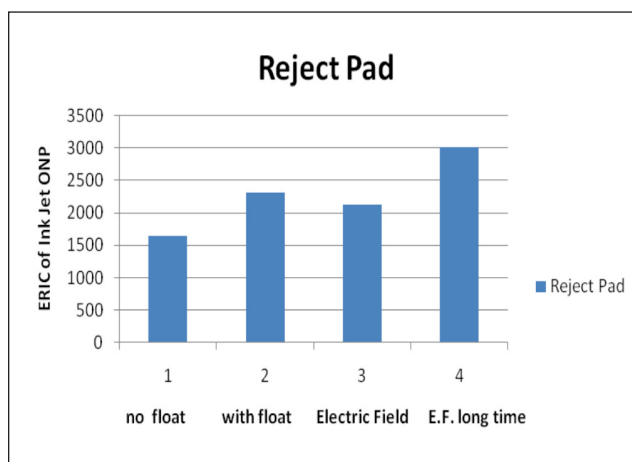
7. ISO and calculated inkless brightness of ONP, 20-min flotation.



9. ISO brightness of inkjet-printed ONP for pulping and flotation.



8. ERIC of inkjet-printed ONP after pulping and various flotation methods.



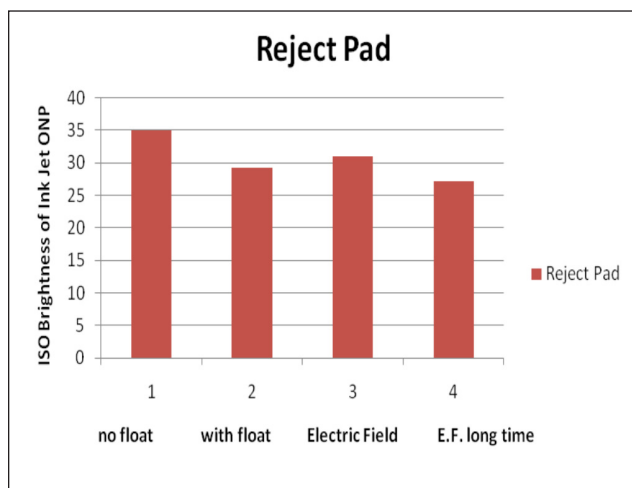
10. ERIC of inkjet-printed ONP for various pulping and flotation methods.

came worse in experiment No. 4. For the reject pads data, the worse the ERIC, the better the flotation results.

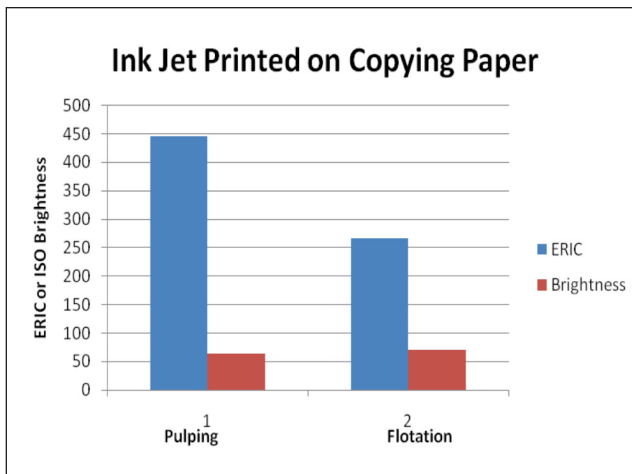
As shown in **Fig. 11**, the ISO brightness was gradually lower from No. 1 to No. 4. For the reject pads, the lower the ISO brightness, the better the flotation results.

Deinking experiments were also performed on inkjet-printed blank copying paper with ISO brightness of about 92. The ISO brightness after pulping was 63 (**Fig. 12**) and after flotation was 71%, which was significantly short of our target of 92%. The ERIC dropped from 446 to 267, which is not considered deinkable. For the copy paper, the inkjet-printed fiber surface exhibited better quality. However, after pulping, the entanglement of ink with flexible cellulosic (less lignin present) fibers did not show any advantage for deinking over newsprint.

Figures 13 and 14 show that both ERIC and ISO brightness values of flexographic prints were much worse than the values of inkjet-printed ONP. The experimental data showed that the inkjet-printed ONP, copy paper, and flexographic-printed ONP were not considered deinkable. Even though



11. ISO brightness of inkjet-printed ONP for various pulping and flotation methods.



12. ERIC and ISO brightness for inkjet-printed copy paper.

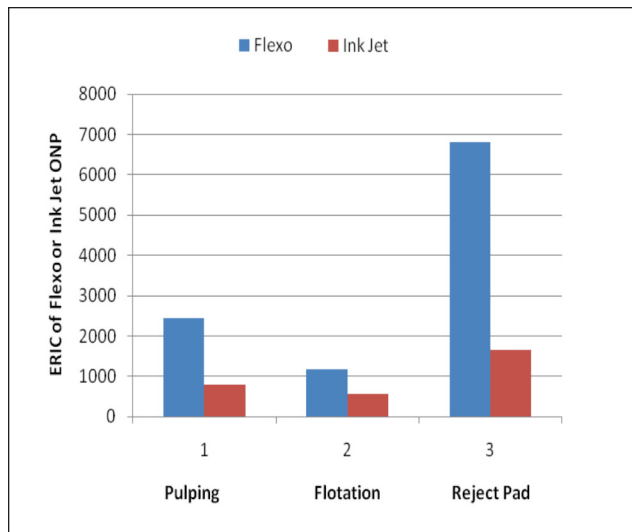
both the flexographic ink and inkjet particles are hydrophilic, their sizes are different by an order of magnitude. Flexographic ink particles are in the micrometer scale, whereas inkjet ink particles are in the submicron scale, and consequently provided more surface area to be deinked. More flocculation of inkjet particles is needed to improve their air-bubble flotation. More laboratory breakthroughs are needed to overcome the challenges of deinking pigmented inkjet particles.

We do not have numbers for the yield loss, although greater yield loss would be expected due to the nature of the process. Smaller air bubbles could carry away a certain amount of the smaller fibers and fines.

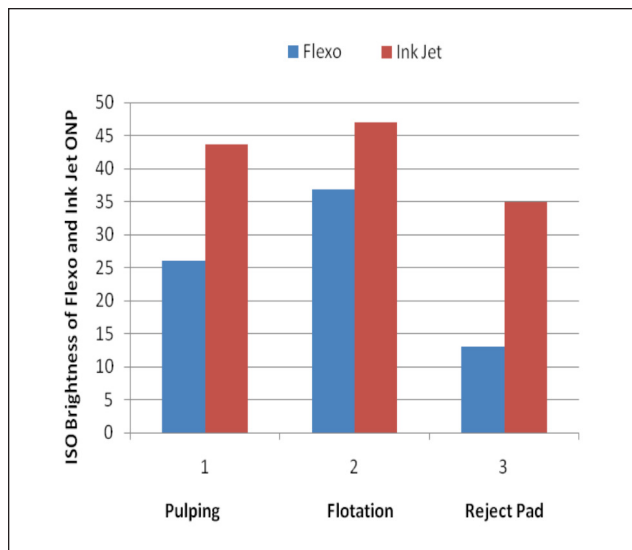
CONCLUSIONS

Preliminary experiments were conducted on samples of inkjet nonimpact digital printing papers to evaluate the efficiency of a conventional flotation deinking process in detaching pigmented inkjet submicron-size particles from the fiber surface and network. A Denver D-12 laboratory flotation cell was used per INGEDE Method 11 to test 100% ONP. ISO brightness of 58 was obtained, an improvement considered to be recyclable. However, the conventional flotation process only cleaned the inkjet-printed ONP to 47 ISO brightness. The addition of nonionic surfactant for better pulping improved the ISO brightness to 50 using the same flotation procedure. Electric field technology [12] was then applied for further improvement to obtain ISO brightness of 52.5 with conventional flotation—still 5.5 points short of the targeted ISO 58 goal for recycling [13]. The reasons for this final improvement are that more surface area is available per unit volume and the hydrolyzed hydrogen or oxygen gas molecules are more likely to collide and collect the ink particles [13] for rising to the top of the flotation chamber for skimming. The 52.5 ISO brightness is the best that can be achieved with currently available flotation technologies.

The work was performed with 100% ONP printed with pigmented inkjet without some percentage of magazines (OMG), because of the nature of control ONP we acquired.



13. ERIC of flexographic- and inkjet-printed ONP for feed, accept, and reject pads.



14. ISO brightness of flexographic- and inkjet-printed ONP.

Even though the absolute value of deinking performance will be different from an ONP/OMG mixture, we believe that the relative improvement in deinking performance will still have a similar trend.

As the problem of deinkability for digital inkjet non-impact printing grows, additional technical efforts will be needed to overcome the crossroad between the demand from environmental concerns and the limitation of technology performance. New, breakthrough technical development will be indispensable for the future well-being of the printing and paper manufacturing industries.

Collective action among paper mills, inkjet suppliers, printer manufacturers, and academic and industrial deinkers will be essential to face and overcome the important challenges to achieving our future success. This paper has defined the

goal—improved ISO brightness by about six points with newer breakthrough technology for inkjet removal. **TJ**

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ABOUT THE AUTHORS

As digital inkjet printing gains in popularity, deinking difficulties and unrecyclability will cause landfill problems, among other concerns. At present, deinking of pigmented inkjet inks is not successful. Therefore, our new technology could help.

A difficulty in this work was that the hydrophilic pigment inkjet particles could not be removed by traditional flotation.

We have developed electric field technology that can assist the flotation process.

The electric field technology can generate microbubbles for flotation, and it did improve the brightness of floated deinked inkjet stock.

Mills can now be aware that adding nonionic surfactant in pulping and using electric field treatment in flotation can improve the brightness of 100% inkjet-printed paper deinking by five or more points, increasing the tolerance for a percentage of inkjet-printed paper in the recycled paper mill. Additional emerging technology will be needed to further deink inkjet-printed paper.



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