Deinking evaluation using near infrared narrow band digital image analysis

ROLAND GONG, PAUL D. FLEMING, JOHN CAMERON, AND JAN PEKAROVIC

ABSTRACT: The current deinking evaluation methods include visual image analysis (manual and digital) and optical reflectance (using the Kubelka-Munk equation). The mechanism of image analysis is simple: dark ink (mostly black) is isolated from the light background (fiber) and then captured visually or by digital devices. The image analysis methods have inherent limits, such as poor correlation with paper optical properties, and have large variances from sample to sample and side to side. In this paper, an innovative approach that employs a band of near infrared light and a digital imaging device was applied to address these limitations. This approach has advantages for isolating specks from backgrounds, obtaining high quality raw data, and significantly reducing the variances among the handsheets and their sides. By using the ink elimination equation derived from image analysis, reliable ink elimination rates were obtained that were well correlated with paper optical properties. This system was also applied to newspaper deinking evaluation with positive results.

Application: Near infrared image analysis technology can be developed into an online instrument for instantly analyzing high-consistency pulp.

Deinking is a key process in recovering high quality secondary fibers. The common test methods used in deinking evaluation include image analysis and optical reflectance. Image analysis test methods include TAPPI Standard Test Methods T 437 om-12 "Dirt in paper and paperboard"; T 563 om-12 "Equivalent black area (EBA) and count of visible dirt in pulp, paper and paperboard by image analysis"; T 568 om-2 "Physical area of subvisible contraries in pulp, paper and paperboard by image analysis"; and ISO 5350-4 "Pulps—estimation of dirt and shives—part 4: instrumental inspection by reflected light using equivalent black area (EBA) method." Optical reflectance methods include TAPPI T 567 om-9 "Determination of effective residual ink concentration (ERIC) by infrared reflectance measurement" and ISO 9416 "Paper—determination of light scattering and absorption coefficients (using Kubelka-Munk theory)."

Deinking filtrate darkening (compared with tap water) is employed as one processing indicator. The main image analysis methods are used with digital imaging apparatuses (scanner or camera) to acquire residual ink information from paper samples. The ink is considered black, or equivalent to black. The residual ink is also called dirt, or ink specks. These images obtained via digital devices are further analyzed using software to obtain comparable data, such as equivalent black area (EBA), average speck area, number of specks, and speck distribution. These methods mainly concentrate on macrospecks, or speck area size ≥0.02 mm^2 (0.01 mm^2 in some practices). TAPPI T 568 om-2 detects subvisible speck, or the area size between $5.0x10^{-5}$ to $2x10^{-2}$ mm^2. However, it is hard to convince users that the test method can isolate the subvisible ink specks from the relatively rough paper surfaces, which determines the detectable limit of speck size. Even for a very smooth supercalendered paper, scanner resolutions of more than 36000 dpi would be required. Furthermore, image analysis methods only record specks exposed on the surface. When preparing handsheets using TAPPI T 272 sp-2 "Forming handsheets for reflectance testing of pulp (sheet machine procedure)," for example, a significant number of specks are trapped or partially trapped under the surface. Recycled newsprint exhibits this phenomenon more than other products because of its high bulk (or thickness). Furthermore, the deink data from image analysis methods have weak correlations with paper optical properties due to the lack of subvisible ink. Large EBA variance is found between paper samples, in spite of the similarity in appearance. The data obtained from both sides of the same handsheet are also quite different. The uneven paper surface and poor contrast between specks and fiber are the major barriers. These drawbacks have been challenged by optical reflectance methods (e.g. TAPPI T 567 om-9 and ISO 9416) [1,2].

To eliminate the influence from the lignin chromophore and paper tints (e.g., blue, green), TAPPI T 567 om-9 uses near infrared light (NIR, 950 nm) to determine the effective residual ink concentration (ERIC) [3]. In preparation for this study, other wavelengths were examined with a JAZ spectrometer (Ocean Optics; Dunedin, FL, USA), and the insensitivity to lignin was found to be valid at wavelengths as low as 800 nm [4]. In addition, the NIR light between 830 and 850 nm exhibits strong absorption on pure black and three-color (cyan, magenta, yellow) black (or gray) inks [4], which means the contrast between ink specks and fiber is increased. Specifically, NIR light has extended depth visibility, which can detect those trapped ink specks, or even the ones on the other side of the sheet. The image sensor of a digital camera is sensitive to light between 830 and 850 nm, which can detect the ink specks. In this experiment, a commercial digital single lens reflex (DSLR) camera was retrofitted to receive NIR light. Laser printed office paper and offset printed newspaper were studied, using the deinking methods described in INGEDE method 11 "Assessment of print product recyclability—deinkability test (July 2012)" (deinking score not applied). The current evaluation methods (TAPPI T 563 om-12 and T 567 om-9) and paper optical properties were used as references. An ink elimination rate determined by image analysis [2] also was studied in comparison with the corresponding rate from ERIC.

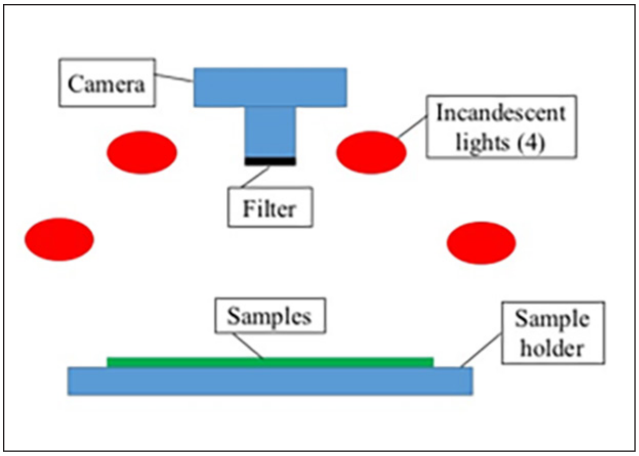
METHODOLOGY

Sample preparation

Two types of paper were studied. One was monochrome laser printed office paper (Hammermill, International Paper; Memphis, TN, USA) and the other was offset printed virgin newsprint (Boise, Packaging Corporation of America; Lake Forest, IL, USA). These samples were deinked following INGEDE method 11 in the Western Michigan University Pulping Laboratory. Three types of handsheets were made: deinked (DP), undeinked (UP), and unprinted (unpr). The basis weight of handsheets has an impact on the deinking evaluation determined by scanned image; however, the purpose of multiple basis weights in this experiment was to discover the NIR visibility. Hence, three basis weight handsheets were prepared for each type of handsheet at 45, 50, and 60 g/m² for office paper and 40, 45, 50 g/m² for newsprint. The sample names were defined by pulp type and basis weight. For example, DP45 refers to a handsheet made of deinked pulp with 45 g/m² basis weight. Ten sheets were made for each type of sheet and each basis weight, for a total of 180 handsheets. All handsheets were trimmed using a punch to eliminate uneven sheet edges.

Image acquisition

A Canon T3i DSLR (Canon; Tokyo, Japan) was used to capture the images. The camera had the hot filter (or IR block filter) removed in front of its image sensor (CMOS type, 3456 × 5184 pixels, pixel pitch 4.3 μm) to produce a full spectrum camera. An 840 (±10) nm bandpass filter from Edmund Optics (Barrington, NJ, USA) was mounted on a Canon 40 mm macro prime lens (equivalent to 64 mm on a 35 mm camera). Four incandescent lights (color temperature 2700K, 150 W each) were projected on samples to obtain even and sufficient intensity. A tripod was used to hold the camera. All paper samples were photographed from both sides at the same light condition, aperture, and shutter speed. The samples were placed on a white plastic board. The setup is illustrated in **Fig. 1**.



1. Schematic of infrared image acquisition.

The image files were originally taken in RAW format that had not been compressed, with an effective resolution of approximately 770 dpi. The image files were further converted to TIFF format using Adobe Photoshop CS6 (Adobe Systems; San Jose, CA, USA). An Epson Perfection V750 Pro scanner (Seiko Epson Corp.; Nagano, Japan) was used to scan both sides of each handsheet at 600 and 1200 dpi. All images were taken in color mode without any adjustments to brightness, contrast, or saturation.

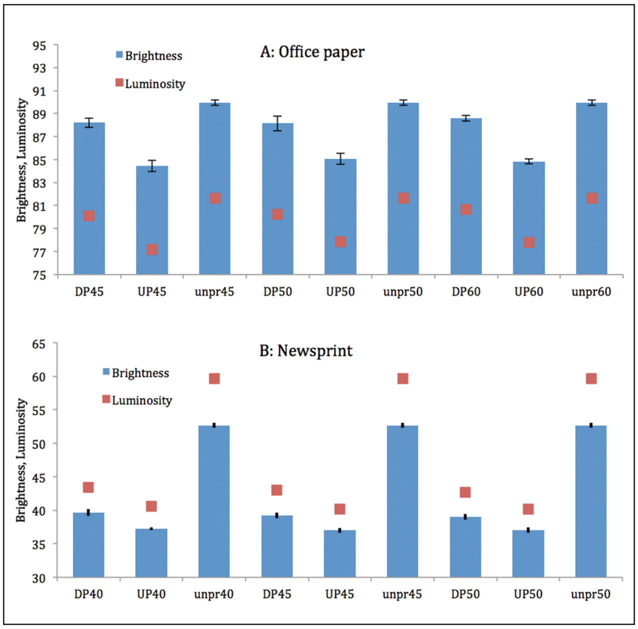
Measurements

The paper brightness of the samples was measured using a Brightmeter Micro S-5 (Technidyne; New Albany, IN, USA) (T458, C/2° light source, 457 nm). Luminosity (Y, 557 nm) and CIE L*a*b* values were obtained at the same time. The thickness, caliper, and opacity of handsheets were measured with Technidyne instruments following the TAPPI test methods. Verity IA Light and Dark Dirt v3.4 software (Ascend Technology; Milwaukee, WI, USA) was applied to analyze image files coming from scanner and camera. The area of interest of each sheet is an 11 cm diameter circle, at the sheet center. The software processing parameters, such as minimum speck area, were defined by considering the capability and accuracy for three groups of image files acquired from the scanner (600 dpi and 1200 dpi) and camera (NIR). The parameters remained the same within each group, whether DP or UP handsheets. For unpr handsheets, EBA was not calculated because it did not influence the DP and UP analyses [5].

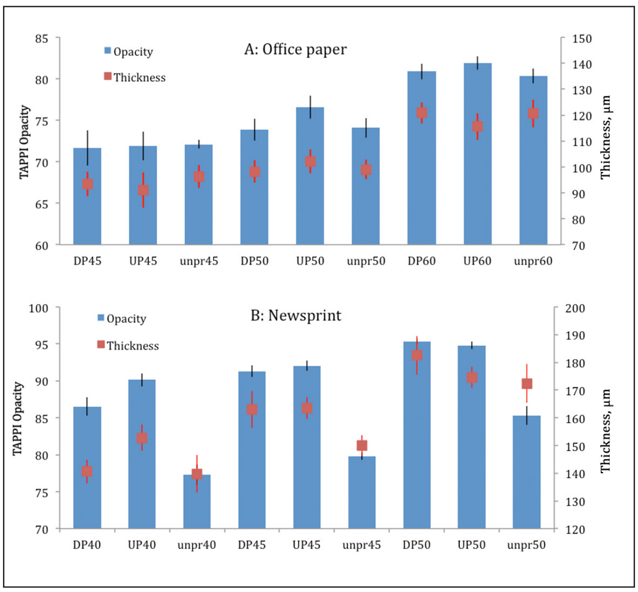
RESULTS AND DISCUSSION

Optical properties

The paper brightness, luminosity, and CIE L*a*b* (not illustrated) of the DP and UP handsheets are similar to one another, as shown in **Fig. 2**. For office paper, the optical properties of DP sheets were close to those of unpr ones, which indicated a successful deinking. The brightness gaps between DP and UP sheets were relatively small (around 4%). Thus, the



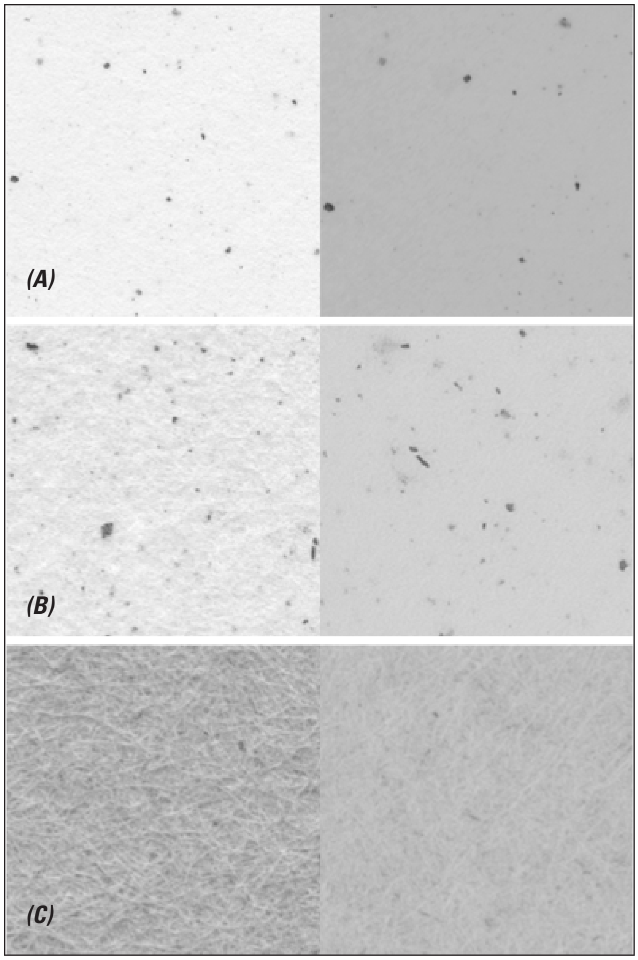
2. Paper brightness and luminosity for the different papers and basis weights (DP = deinked pulp handsheet; UP = undeinked pulp handsheet; unpr = unprinted handsheet).



3. Paper opacity and thickness for the different pulps and basis weights (DP = deinked pulp handsheet; UP = undeinked pulp handsheet; unpr = unprinted handsheet).

overall ink coverage on UP is low. In contrast, the newsprint optical properties on DP and UP were slightly different. Values were significantly below those of unpr sheets, indicating that the deinking of newsprint failed because of too little contrast between DP and UP sheets.

Within the office paper samples, the paper opacity of DP and unpr sheets was almost identical for all three basis weights (**Fig. 3**). The contribution from ink was seen only on the opacity of UP50 sheets, but was still limited. This



4. 100% cropped images acquired from scanner (left, 600 dpi, 8.4x) and near infrared (NIR) camera (right, 10.7x). (A) 45 g/m² office paper deinked F-side (close to plate); (B) 50 g/m² office paper undeinked pulp B (UP B) side (close to blotter); and (C) 40 g/m² newsprint deinked B (DP B) side.

finding confirms the successful deinking and low ink coverage on UP sheets. For newsprint, ink contributed significantly to paper opacity when compared with DP, UP, and unpr handsheets. The opacities of DP and UP sheets are almost identical when thickness is considered. Extensive residual ink remained in DP sheets.

Near infrared imaging mechanism, visibility, and advantages

The current deinking evaluation methods via imaging analysis are constrained because of low contrast between fiber and ink specks, paper surface unevenness, and ink trapping. According to Jordan and Popson [3], the dark ink specks are sensitive to NIR light and become dark spots on the imaging sensor. The fibers, including other light-colored inks, reflect all NIR light and form an even light background (e.g., a pure white and even tile reflecting all visible light). Hence, NIR eliminates the uneven paper surface influences because of nonhomogenous fiber formation. It gains high contrast between the dark ink and fiber so that visibility on ink specks is extended, and it increases analysis capability. However, in this experiment the NIR light reflected from the samples could not reach the image sensor directly. Commercial digital cameras have RGB microfilters embedded on the image sensor to describe the visible light, and it is unclear how these filters respond to NIR light. After comparing the individual channels, the images from the blue microfilter acted as close as expected (i.e., sharp ink specks and even background). However, the EBA value from blue channel is slightly lower (approximately 5%) than the one from all three (RGB) channels. The images of office paper samples had clear dark ink specks out of the uniform light background (**Fig. 4**).

The NIR images of newsprint were not as well defined as office paper. The fiber texture is still visible, although much less than that from the visible light. The 840 nm light might not eliminate the lignin chromophore influence from the mechanical pulp. The blue microfilter performance might be another reason.

The NIR imaging method via a camera has an advantage in analysis speed. For example, the camera can take a picture in less than 1/30 s; the scanner needs about 3–5 s for a 600 dpi image and 10–20 s for a 1200 dpi image.

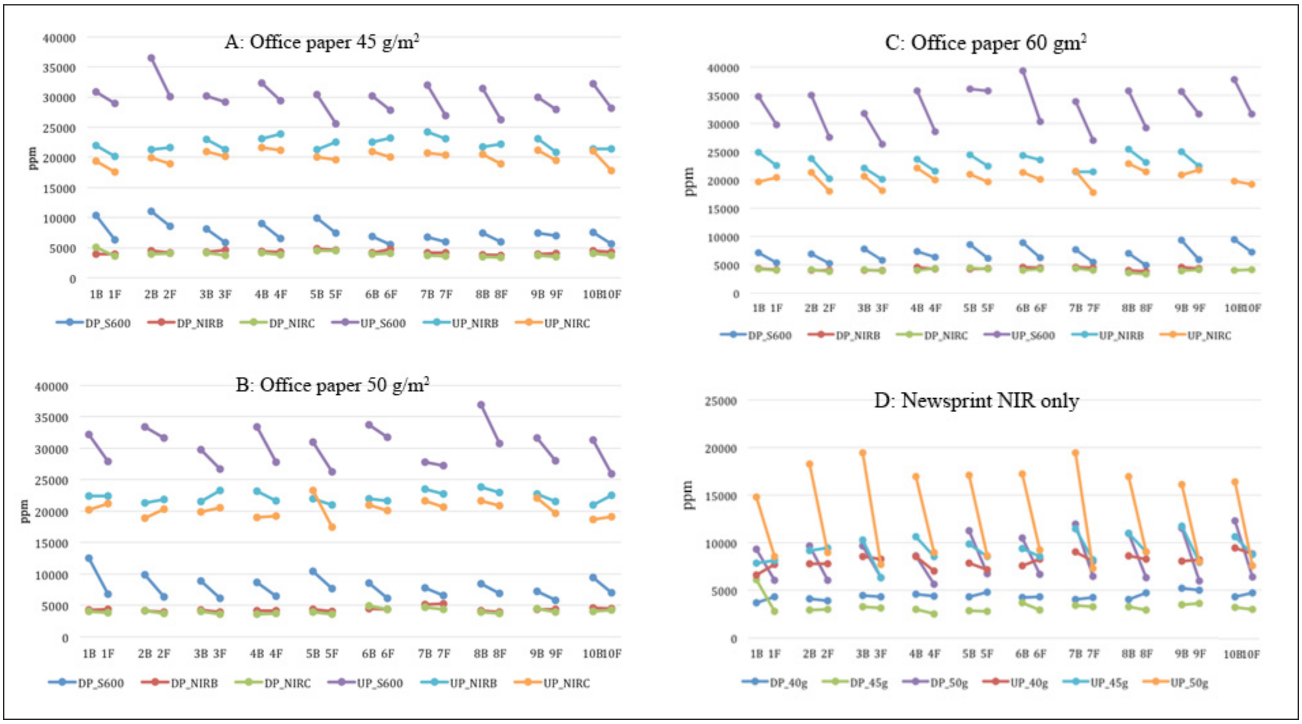
Equivalent black area analysis comparison

Both sides of handsheets were analyzed and the results are presented in **Table I**. The front side (F, smooth side) of a handsheet in this experiment refers to the side attaching with the plate. The opposite side is called the back side (B, rough side), closer to the screen. From the optical properties, both sides of the same handsheet had identical brightness. The DP and UP sheets of office paper had small gaps (4%). However, the ink specks obtained from scanned images were apparently different on both sides, whether on DP or UP. Generally, the F-sides had low EBA values compared with those from B-sides. In other words, the rough side has higher EBA value than the smooth side (**Fig. 5**). Therefore, the two-sidedness of the handsheets has an impact on EBA results. Summing EBA values from both sides could not eliminate these large variances (not illustrated). The EBA values from images scanned at 1200 dpi were larger than those from images scanned at 600 dpi. These high EBA values were composed of much noise because of paper unevenness. Thus, high resolution images do not increase the contrast between ink specks and fibers and are not reliable for high quality analysis.

In contrast, the ink specks from NIR imaging were uniform on individual sides or combined, and on each sheet. Appar-

	Deinked Paper 600 dpi (Scanner) >0.0107 mm²		Deinked Paper 1200 dpi (Scanner) >0.0040 mm²		Deinked Paper Near Infrared (Camera) >0.0044 mm²	
	Average	STD ±%	Average	STD ±%	Average	STD ±%
45 g/m² B Side	8445	18.1	13056	23.1	4256	7.2
45 g/m² F Side	6466	14.7	8917	20.8	4261	7.1
50 g/m² B Side	9201	16.3	13999	23.8	4401	6.8
50 g/m² F Side	6593	7.9	10128	13.9	4289	9.2
60 g/m² B Side	8046	12.2	12527	10.5	4362	5.7
60 g/m² F Side	5891	11.4	7897	11.1	4237	5.1
	Undeinked Paper 600 dpi (Scanner) >0.0107 mm²		Undeinked Paper 1200 (Scanner) >0.0040 mm²		Undeinked Paper Near Infrared (Camera) >0.0044 mm²	
	Average	STD ±%	Average	STD ±%	Average	STD ±%
45 g/m² B Side	31612	6.1	36466	19.4	22352	4.3
45 g/m² F Side	28018	5.1	35118	9.6	22034	5.3
50 g/m² B Side	32135	7.7	36848	8.4	22342	4.3
50 g/m² F Side	28412	7.8	34539	8.4	22159	3.2
60 g/m² B Side	35583	5.8	43657	4.5	23902	5.6
60 g/m² F Side	29802	9.3	34600	3.2	21966	5.5

I. The average equivalent black area values and their standard evaluations. The counted minimum ink speck area is varied by imaging method (scanner or camera).



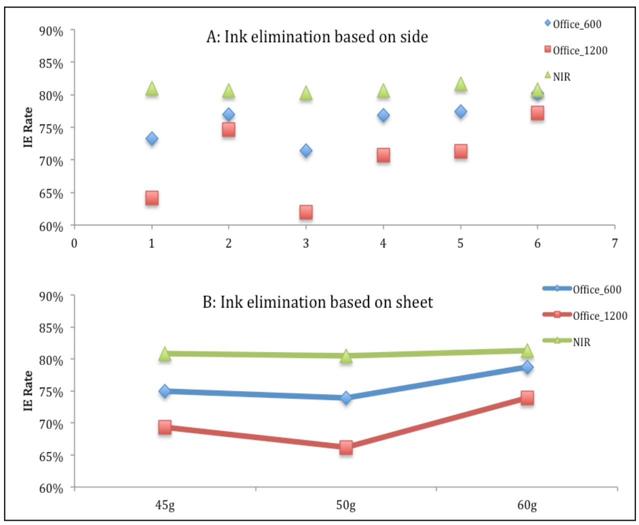
5. Equivalent black area (EBA) deinking evaluation. The images were acquired from scanner at 600 dpi and 1200 dpi, and NIR camera on the same sample, with their EBA calculated by each side (DP = deinked pulp handsheet; UP = undeinked pulp handsheet; unpr = unprinted handsheet).

ently, the data from NIR image analysis had good correlation with the uniform paper appearances. NIR provided the possibility for one side measurement, which is of interest to us for further pursuit. Meanwhile, the office paper data from NIR image analysis remains consistent regardless of the different basis weights. In addition, image analysis has sufficient visibility up at 60 g/m². NIR images had relatively lower EBA values than those from the scanner. Both noise and signal reduction can cause this, although the details are not clear. The determination of minimum ink specks area is determined by imaging resolution and noise. Technically, smaller specks can be detected in images of 1200 dpi, compared to those of 770 dpi (NIR). However, the unevenness of paper surface produces a huge amount of noise (easily found on the monitor) that limits the minimum ink speck area.

The NIR imaging method indicates that it could isolate ink from fibers in newspaper in Fig. 4. In Fig. 5, NIR images presented good data consistency, especially on 40 and 45 g/m² handsheets. The EBA values were lower than those estimated by optical scanning, because optical data indicated poor deinking. It was believed that the current NIR camera setup was not able to handle this type of sheet. However, we believe that the NIR method could be used to evaluate newsprint samples in the future, after overcoming current limitations such as image sensor and bandpass filter.

Ink elimination calculation via image analysis

We previously developed an ink elimination (IE) equation on the basis of image analysis in Eq. (1) [4]:



6. Ink elimination value via image analysis for office paper.

$$IE\% = \frac{EBA_{UP} - EBA_{DP}}{EBA_{UP}} \times 100\% \qquad (1)$$

where EBA_{UP} and EBA_{DP} are the equivalent black area values, in ppm. Ink elimination is easily understood and is convenient in deinking practices compared with EBA. Unlike IE determined from the ERIC method, IE determined from the image analysis method does not need unprinted samples, which are difficult to obtain in practice.

Ten EBA values of office paper from the same type and same basis weight were averaged and then carried into Eq. (1). The IE values were calculated in two ways — on single side and on sheet (both sides) — to discover the side influence (**Fig. 6**). The data from NIR obtained constant IE values for both scenarios. The large IE variance of the images from the scanner is consistent with the previous EBA analysis. The IE values from NIR also were higher than those from the scanner. Considering the conclusion from optical properties (successful deinking obtained), the IE values should be high. Thus, these IE results from NIR were accurate. The IE of newsprint is not discussed here because of its poor EBA results.

CONCLUSION

A new deinking evaluation method using NIR image analysis was developed to overcome the problems of current methods based on image analysis. Laser printed office paper and newsprint paper were used in these deinking trials. When compared with current evaluation methods, NIR image analysis has advantages in data acquisition, results consistency, and reliability because of its extended visibility. This new method also has advantages in operation convenience, analysis speed, and future applications. Although the evaluation for newsprint was not successful because of the deinking failure, it gave a positive response for future improvements. Regardless of the many instrument setup limitations, such as the influences from microfilters of image sensor and camera automatic gamma correction, we believe NIR image analysis could be developed into a competitive evaluation standard. **TJ**

LITERATURE CITED

1. Dorris, G.M., Ben, Y., and Richard, M., *Prog. Pap. Recycl.* 20(1): 3(2011).
2. Gong, R., Fleming, P.D., and Rosenberger, R., "Application of wet image analysis on recycled paper ink elimination evaluation," *NIP28: Int. Conf. Digital Printing Technol. Digital Fabrication*, Society for Imaging and Technology, Springfield, VA, USA, 2012, p. 543.
3. Jordan, B.D. and Popson, S.J., *J. Pulp Pap. Sci.* 20(6): J161(1994).
4. Roland Gong, "New approaches on deinking evaluations," Ph.D. dissertation, Western Michigan University, Kalamazoo, MI, USA, 2013.
5. Gong, R., Fleming, P.D., Cameron, J.H., et al., "Application of modified INGEDE method in US deinking industry," *Proc. Annu. Tech. Meet., Tech. Assoc. Graphic Arts*, Technical Association of the Graphic Arts, Warrendale, PA, USA, 2012.

ABOUT THE AUTHORS

We chose this topic because the current image analysis method has room for improvement in terms of accuracy, repeatability, and user experience. Our work on near infrared image analysis offers a new application to deinking evaluation, which has extended visibility to detect visible and subvisible ink specks.

The most challenging questions we faced were how to minimize the influence from paper unevenness to increase contrast between specks and fiber. Infrared digital imaging technology only sees dark ink specks, however, and fiber and lignin become a uniform smooth background on the image sensor.

We found infrared digital imaging technology to be very useful for deinking evaluation. The evaluation results were well matched with the optical properties of the samples and showed potential for evaluating newspaper.

Mill can use this method to get an accurate analysis for optimizing their deinking process and improved quality control. Our next step is to set up a commercial prototype, optimize the key elements, and improve the user experience.

Gong

Fleming

Cameron

Pekarovic

Gong is assistant professor, Department of Paper Science and Engineering, University of Wisconsin – Stevens Point, Stevens Point, WI, USA. Fleming is a professor and Cameron is professor emeritus, Department of Chemical and Paper Engineering, Western Michigan University, Kalamazoo, MI, USA. Pekarovic is president, Ekocel LLC, Kalamazoo, MI, USA. Email Gong at roland.gong@uwsp.edu.