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On Quantification of Residual Ink Content and Deinking Efficiency in Recycling of Mixed Office Waste Paper

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ABSTRACT: Although (flotation) deinking has been a common industry practice for several decades, true residual ink content and deinking efficiency have never been quantified. Paper brightness and ERIC (Effective Residual Ink Concentration), based on measurements of the absorption coefficient of deinked pulp, have been used to determine performance of flotation deinking processes and the quality of deinked pulps. This study demonstrated a new method for quantifying true residual ink content of mixed office waste paper by determining the trace iron content in pulp samples. Two sets of laboratory studies were conducted, one using mixed pulp samples of different ink contents and the other using samples from flotation deinking experiments with different surfactant dosages. All pulp samples including flotation feeds and accepts were characterized by ERIC, brightness, and iron-content-derived ink content. The results suggest that ERIC and brightness are less suitable than iron content for evaluating the residual ink in very clean papers. In flotation studies, both ERIC and brightness predict lower deinking efficiencies than are obtained from iron-content measurements. However, brightness is suitable for evaluating the final quality of very clean deinked pulp because of its high accuracy at high brightness levels.

INTRODUCTION

Recycling of waste paper is an effective way to conserve forest resources. Waste paper and paperboard recovery was 63.4% or approximately 50 million tons in 2009 in the United States. However, only about 29 million tons were recycled to produce paper products in the U.S. The remaining 21 million tons were exported (American Forest and Paper Association, Washington, DC, 2009, http://www.paperrecycles.org/stat_pages/recovery_rate.html). Effective separation of contaminants is key to increasing recovery and utilization of waste paper in paper production in the U.S. This is especially true for mixed office wastepaper (MOW) made of bleached pulps and containing two major contaminants, inks and adhesives. About 14 million tons of MOW were recovered, or 60.8%, during 2009 in the U.S. Deinking is the critical step to produce high quality pulp from MOW.

Brightness and effective residual ink concentration (ERIC)[1,2] measurements have been commonly used to evaluate the quality of deinked pulp and deinking efficiencies in paper recycling operations. However, both methods are indirect measures of ink content through measuring the optical properties of pulp or paper. The brightness method, originated from evaluating bleached pulp,[3] suffers from problems associated with the effects of various nonink colorants present in recycled pulp.[4] The ERIC method developed by Jordan and Popson[1] is a near-infrared technique that uses reflectance to determine the specific absorption coefficient of a sample according to Kubelka−Munk theory.[5] The ratio of the measured specific absorption coefficient of the sample to that of ink, expressed in parts per million (ppm), is the ERIC of a sample. The contributions to specific absorption by lignin and other colorants in the paper sample are greatly reduced by using a near-infrared source at 950 nm wavelength. Both brightness and ERIC are sensitive to the size distribution and dispersion of absorbing ink particles in ways that are yet to be characterized. In the case of ERIC, these influences can affect the measurement results as outlined qualitatively in the TAPPI Test Method T567-om-04.[6] Furthermore, ERIC measured using the reflectance technique[1] has large uncertainties for paper samples of high opacity resulting from high basis weight, ash content, and ink concentration (high ERIC value).[2,7] Although measurements such as dirt count are often carried out to provide additional information about pulp residual ink content, direct ink content measurements are not possible using existing techniques. As a result, deinking efficiency is often determined using indirect measures of residual ink, such as relative brightness gain, or relative ERIC reductions.

This study attempts to develop an accurate and direct method for measuring deinking efficiency in MOW recycling operations. MOW consists of a significant amount of paper printed by toner that contains iron (Fe). When the iron content in ink is known, the ink content in a pulp or paper sample can be determined by measuring the iron content in the sample. For industrial applications with variable sources of wastepaper of unknown toner or iron content in ink, the present method can be used to accurately determine deinking efficiency. More specifically, the method can be used to compare the ink removal efficiencies among different processes or stages in a given industry operation. While residual ink content is an important control parameter for a recycling process, deinking efficiency is also important as it can provide a measure of the performance of deinking unit operations and provide information for proper balancing between the amount of

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Figure 1. Ash of flotation rejects from a toner printed paper sample.

ink removal and fiber yield. The objectives of the present study are (1) to evaluate the reliability and accuracy of brightness and ERIC methods for indirect residual ink and deinking efficiency measurements in laboratory studies and (2) to provide direct measurements of deinking efficiency in recycling MOW. The comparative results can provide guidelines for industrial deinking operations.

METHODOLOGY

MOW consists primarily of large amounts of copy or laser toner papers printed through noncontact imaging. Toners consist of fine iron powder and polymers which are electrostatically transferred to the surface of a photoreceptor drum assembly. The image is then transferred from the drum to paper. The transferred toner powders are fixed permanently to paper by subjecting them to pressure and heat. As a result, fused ink particles on printed paper tend to have large sizes on the order of 100 μm[8] with plate shapes.[9] Iron (Fe), which can be found in toner, is used to facilitate imaging. As a metallic element, iron can be traced in recycling processes. This can be seen from the red color of MOW flotation rejects (Figure 1). Because the iron content in a given toner or bulk ink of a given wastepaper is constant, deinking efficiency and residual ink content in pulp (with known iron content in the bulk ink) can be determined by analyzing iron in the deinked pulp. Iron analysis can be accurately executed by many modern techniques, such as Inductively Coupled Plasma Optical Emission Spectrometry (ICP).

The toner content in a pulp sample, T_p, can be expressed by the iron content in pulp, I_p, divided by the iron content, I_t, in toner (or bulk ink in wastepaper) as follows

$$T_p = \frac{I_p}{I_t} \tag{1}$$

The iron content in pulp, I_p, can be determined by measuring the iron content in the ash of the pulp, I_a, and the ash content of the pulp, A_p, as follows

$$I_p = A_p \times I_a \tag{2}$$

I_t should be a constant for a given toner or wastepaper and can be calibrated using eq 1 in laboratory studies. For example, a certain amount of toner is printed on several sheets of white paper, and the paper is weighed before and after printing under the same environmental conditions. The difference in the weights is the amount of toner on the printed paper, used to determine the toner content in pulp, T_p. The printed paper is then ashed, and the iron content in the ash is analyzed to obtain I_p.

The deinking efficiency can be calculated as follows

$$E = \frac{P \times T_p - P' \times T_{P'}}{P \times T_p} \times 100\% = \frac{I_p - yI'_p}{I_p} \times 100\% \tag{3}$$

where P and P' are the oven-dried (od) weight of pulp before and after deinking, and $y = P'/P$ is flotation pulp yield. T_p and T_p' are toner content in feed and accept pulps, respectively. I_p and I'_p are experimentally measured iron content in the feed and accept pulps obtained using eq 2. When flotation loss is ignored, the ideal deinking efficiency can be shown by eq 4 to be

$$E' = \frac{T_p - T'_p}{T_p} \times 100\% = \frac{I_p - I'_p}{I_p} \times 100\% \tag{4}$$

If the iron content in the toner (or in bulk ink in the wastepaper) or the initial ink (T_{p0}) is known, then the present method can be used to determine the (residual) ink content in pulp or paper samples by substituting eq 2 into eq 1

$$T_p = A_p \times \frac{I_a}{I_t} \tag{5}$$

or simply

$$T_p = T_{p0} \times (1 - E) \tag{6}$$

where T_{p0} is the initial toner content of the MOW.

EXPERIMENTAL SECTION

Materials. All experiments used A4 copy papers. The paper sheets were weighed, and moisture content was determined by oven drying at 105 °C. The paper sheets were then printed double-sided; each side was printed with 46 lines, and each line was uniformly printed with 52 letters from A to Z using a laser printer (LEXMARK W820, IBM, Lexington, Kentucky, USA). The papers were placed in a conditioned room (23 °C and 50% humidity) for at least 24 h before and after printing. The printed papers were weighed, and the moisture contents were determined by oven drying at 105 °C. The papers were stored in a zip-lock plastic bag for at least 24 h before use in the next step. The toner content of the printed paper was calculated using the measured moisture contents and weights of the paper before and after printing. The feedstock in flotation deinking experiments consisted of only printed paper.

A set of pulp samples was prepared by mixing the pulp of the printed paper with the pulp of blank (unprinted) paper at mixture ratios of 0, 20%, 40%, 60%, 80%, and 100%. The toner content in these pulp samples, T_p, was simply the toner content of printed paper times the mix ratio. These samples were used to calibrate iron content, I_t, in the toner using eq 5

Nonionic surfactant used for flotation, BRD 2349, was donated by Buckman Laboratories International, Inc. (Memphis, Tennessee, USA).

Table 1. Iron Contents in the Six Pulp Mixtures Measured by ICP in Triplicate

printed pulp content in mixture (%)	0	20	40	60	80	100
toner content in mixture (%)	0	0.564	1.127	1.691	2.254	2.818
test I	0.0066	0.1517	0.3239	0.4457	0.6414	0.7704
test II	0.0051	0.1571	0.3168	0.4448	0.6374	0.8232
test III	0.0058	0.1503	0.3211	0.5161	0.6093	0.7874
average iron content	0.0058	0.1530	0.3206	0.4689	0.6294	0.7937
standard deviation (STD)	0.0008	0.0035	0.0036	0.0409	0.01750	0.0270
relative standard deviation (RSTD) (%)	12.9	2.3	1.1	8.7	2.8	3.4

Pulping and Flotation. A total of 160 g od weight of printed paper was used in each flotation experiment. The printed sheets were pulped at 65 ± 2 °C and 15% consistency using a laboratory pulper (Formax 450H, Adirondack Machine Corporation, Queensbury, NY). Pulping duration was 25 min. Flotation deinking of the resultant pulp was carried out using a laboratory scale flotation cell (Denver D12, Svedala Industrials, Inc., now Metso Corporation, Helsinki, Finland). Surfactant (BRD 2349) application dosage ranged from 0.0025 to 0.10 wt % of od pulp. All flotation experiments were conducted at 43 ± 2 °C and 1% consistency for 5 min using 100 g od pulp. The moisture content of the flotation feedstock and accept pulp samples were measured to determine flotation pulp yield.

Handsheet Making and Measurement Methods. Handsheets were made using TAPPI Test Method T205[6] from flotation feeds and accept pulps for ERIC and brightness measurements. The basis weight of the handsheets was 170 g/m^2 as suggested by the literature[7] to avoid ink loss during the sheet forming process. Handsheet pressing and drying followed TAPPI Test Method T272.[6] The brightness values of handsheets were measured using a commercial brightness tester (Technibrite TB-1, Technidyne Corporation, New Albany, Indiana, USA) using TAPPI Test Method T525.[6] For the study using mixed pulp samples, ERIC values of the handsheets were measured using a commercial instrument (ERIC 950, Technidyne Corporation, New Albany, Indiana, USA). For the flotation study, ERIC values were measured using a reflectance-transmission technique developed by Vahey et al., at the US Forest Service, Forest Products Laboratory (FPL) on an in-house bench system.[2] Deinking efficiency can be indirectly determined using the relative gain in measured brightness or by reduction in ERIC of the handsheets made of accepted pulp over those of the handsheets made of feed pulp.

The iron contents in the ash were measured by the Analytical Chemistry and Microscopy Laboratory (USDA Forest Service, Forest Products Laboratory). The collected solids were air-dried. Very small amounts (~1 mg) were digested in a microwave oven (MDS-2000, CEM Corp., Matthews, North Carolina, USA) with 5 mL of HNO_3 and 5 mL of 30% H_2O_2. ICP-AES (Ultima model, Horiba Jobin-Yvon, Edison, New Jersey, USA) was then used for Fe determinations. All measurements were in duplicate unless indicated. The averages were reported, and the standard deviations were used as error bars.

RESULTS AND DISCUSSIONS

Calibration of Iron Content in Toner. The iron content in the toner (ink) was calibrated using the 6 mixtures of printed and unprinted pulps. The contents of printed pulp in the mixtures were varied from 0 to 100% with an increment of 20% as described in the previous section. The ash contents of the pulp mixtures and iron contents in the ashes were analyzed in triplicate. The iron content in the pulp mixtures as determined according to eq 2 are listed in Table 1. The toner content in a pulp mixture was determined by multiplying the toner content in the printed paper by the weight percentage of printed paper in the mixture. The repeatability of the measurements was good as can be seen from the measured standard deviations. The measured averages of iron content in the toner were linearly proportional to the actual toner contents of the mixtures, i.e., $y = 0.282x$ with $r^2 = 0.9997$. The slope of the relation between T_p and I_t, 28.2%, is the iron content in the toner.

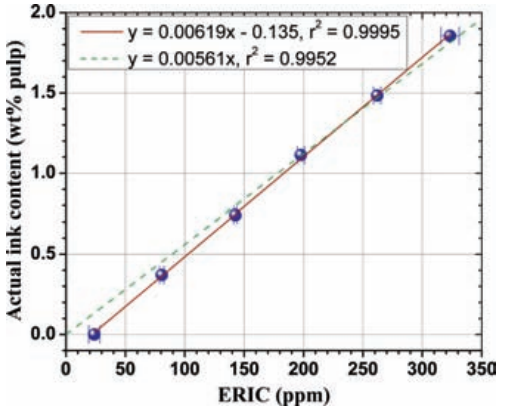

Figure 2. Correlation between ERIC values and actual ink contents for six pulp mixtures of printed and unprinted papers of mixture ratios of 0, 20, 40, 60, 80, and 100%.

Measurements of Ink Contents of Handsheets Made of Printed and Unprinted Paper Mixtures of Known Ink Content. Handsheets made of 6 printed and unprinted pulp mixtures (from a second batch of printing different from the samples in Table 1) were used to evaluate the accuracy in using ERIC and brightness for characterizing ink content in paper. The actual ink contents of these 6 sets of handsheets are determined based on the amount toner printed and the weight percentage of the printed paper in the mixture. It was found that the measured ERIC values linearly correlate to actual ink contents very well (Figure 2). To illustrate using ERIC as a measure of ink content, actual ink content determined by weight was plotted on the y axis and ERIC on the x axis of Figure 2. The standard error of the regression line is only 0.015% ink. However, the correlation has an intercept of −0.135% because the measured ERIC value of the unprinted paper was 23.8 ppm instead of the value 0 ppm expected. A toner content of 0.135% is a significant number. It represents a sample containing a mix of 7.3% printed papers and 92.7% unprinted papers, based on a toner content of 1.855% in the printed papers. This error becomes very obvious when we force a zero intercept

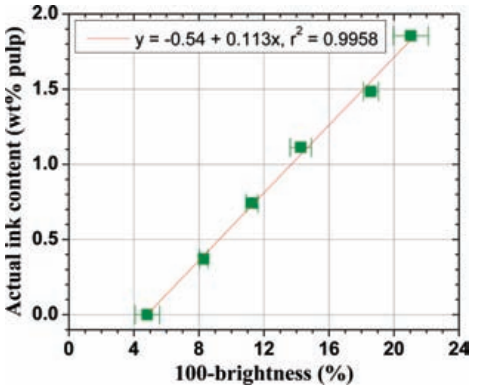

Figure 3. Correlation between brightness values and actual ink contents for six pulp mixtures of printed and unprinted papers of mixture ratios of 0, 20, 40, 60, 80, and 100%.

(ink content) for the unprinted paper in fitting the data (the dashed line in Figure 2). The most likely explanation for this error is that the unprinted basesheet used in the experiments had no iron but contained residual ink, lignin, or dyes absorbing at 950 nm. In this case, the 23.8 ppm ERIC offset was present in all mixes, and the high regression coefficient (r^2 =0.9995) was preserved.

Even in the absence of this mechanism, the potential error in ERIC in clean sheets is significant. Vahey et al. conducted a detailed error analysis of three ERIC methods and found that the coefficient of variation in ERIC at an ERIC value of 50 ppm is about 50% and increases exponentially as ERIC further decreases.[2] Most MOW deinking operations are interested in a final ink content corresponding to an ERIC value around 50 ppm or lower. This suggests that ERIC is not suitable for evaluating the quality of very clean paper products. It may only be suitable for evaluating the performance of a particular flotation deinking stage, since this relies on the high degree of linearity shown in Figure 2 and is independent of the offset. This point will be further elaborated when presenting the flotation deinking data later in the text.

Iron content measurement of residual ink using ICP also has a sensitivity issue in low-ink containing papers. Although typical sensitivity of ICP measurements is less than 1 ppm, the ICP measurements resulted in a nonzero iron content of 0.0058% (58 ppm) for the unprinted paper based on the average of triplicate measurements (Table 1). Because the unprinted paper contained a certain percentage of recycled fibers, this nonzero value of iron content can be contributed from the residual ink of the recycled fibers. It can also be partly from sources other than toner such as iron contaminates in the paper. Using the same analysis as for ERIC, linear regression between the iron content and actual ink using the data in Table 1 resulted in a standard error of 0.02% ink concentration, comparable to that for ERIC. However, the intercept was only −0.0036%, compared to −0.135% for ERIC. In absolute value terms, this is equivalent to ink content corresponding to a mix of 0.13% printed papers and 99.87% unprinted papers. In other words, the iron-content method suffers a systematic error at low ink levels that is only about 3% of the systematic error in ERIC.

The handsheets in Figure 2 were also measured for brightness as a common alternative to ERIC. Ink contents were found to correlate well to brightness values of the sheets (Figure 3). The standard error was 0.045% compared to 0.015% for ERIC and 0.020% for iron content. It is small enough that brightness testing can be reliably used to evaluate the stage-to-stage performance of deinking.

The horizontal axis of Figure 3 was (100 − Brightness) to reflect the inverse relation between brightness and ink content. Because fibers always have natural color from components such as residual lignin, it is not possible to have 100% brightness for unprinted white paper with zero ink content. For the present study, the brightness of the unprinted paper used was 95.2 (very high) that translated to an intercept of −0.54% ink content in linear regression (Figure 3). In absolute value terms, this corresponds to a mix containing 29.1% printed papers and 70.1% unprinted papers. Therefore, paper brightness cannot be a quantitative measure for residual ink of the final product although it is the standard for evaluating recycled MOW quality by the pulp and paper industry. This point can be further illustrated by comparing two hypothetical deinked MOW pulp samples: consider a first deinked pulp from a feedstock that was extensively bleached to a brightness of 95 before printing. A second deinked pulp was from a less-bleached paper source with brightness of 90 before printing. It is very possible that the brightness of the first deinked pulp is higher than the second deinked pulp even when the actual residual ink of the second pulp is much lower than that of the first pulp sample. This occurs when the 5% difference in brightness of the two feedstock papers corresponds to an ink content of 0.54%, as in the correlation of Figure 3. In other words, the brightness of the second pulp sample after deinking will not reach that of the first pulp after deinking unless its residual ink content is at least 0.54% below that of the first pulp sample. When brightness is the only important measure from a customer's point of view, rather than actual ink removal, or when we evaluate deinked pulp samples from the same wastepaper but under different processing conditions, then brightness can be a good measure because of its simplicity and accuracy. It should be noted that within-laboratory repeatability and interlaboratory reproducibility in brightness measurements were reported to be 0.2% and 1.2%, respectively, based on a study organized by TAPPI (the Technical Association of the Pulp and Paper Industry) and participated in by 15 laboratories using TAPPI Test Method T525.[6] In this sense brightness as the standard in evaluating final deinking quality of MOW used in the pulp and paper industry has some validity.

Quantification of Residual Ink Content and Deinking Efficiency in Flotation Deinking. Pulp samples were evaluated before and after flotation deinking using nonionic surfactant BRD 2349 at 6 different dosages. They were evaluated by the iron-content method, while ERIC and brightness values were measured on handsheets made from pulp samples. Samples of flotation feed and accept (deinked) pulps were ashed, and the iron contents in the ashes were analyzed by ICP. The feed pulp sample for each flotation experiment was separately printed; therefore, the ink content measured by the iron-content method of each feed pulp sample and the ERIC and brightness of the handsheets made from the feed pulp were all different (Table 2). The measured pulp ash content, A'_p, ash iron content, I'_a, and pulp yield, y', along with the calculated residual ink (toner) content in pulp, T'_p, are listed in Table 2. The results clearly show that the residual ink content in accept pulps decreases as surfactant dosage increases (Figure 4). This is because the increase in surfactant dosage increased the froth stability and therefore ink removal.

Similar results were also observed from the ERIC values of the sheets made of accepted pulp samples (Figure 5). However, the ERIC values of the handsheets did not decrease below a constant value of approximately 30 for samples obtained from flotation using surfactant dosages greater than 0.05 wt % od pulp. Neither iron-content nor brightness measurements duplicated this plateau

Table 2. Ink Contents of Six Flotation Feed and Accept Pulp Samples Characterized by ERIC, Brightness, and Iron-Content Methods, along with Flotation Yields[d]

BRD 2349 dosage (wt% pulp)	ERIC (ppm)	brightness (%)	A_p / A'_p [a] (%)	I_a / I'_a [b] (%)	T_p / T'_p [c] (wt% pulp)	flotation yield y (%)
0.0025	368/82	72.2/84.6	8.944/9.059	10.443/0.735	3.312/0.236	94.9
0.005	370/66	70.8/85.0	9.043/10.814	9.455/0.522	3.302/0.200	95.5
0.025	444/58	71.0/87.7	14.405/12.393	5.519/0.405	2.819/0.178	96.0
0.05	400/31	72.5/89.1	12.486/11.240	5.529/0.241	2.448/0.096	94.3
0.075	393/27	71.6/89.6	12.847/11.294	6.306/0.177	2.873/0.071	92.8
0.1	386/31	73.0/90.1	13.200/10.613	5.664/0.151	2.651/0.057	91.6

[a] Ash content in pulp. [b] Iron content in ash. [c] Toner content in pulp. [d] The data before the slashes are for the flotation feed pulp samples while the data after the slashes are for the flotation accept pulp samples.

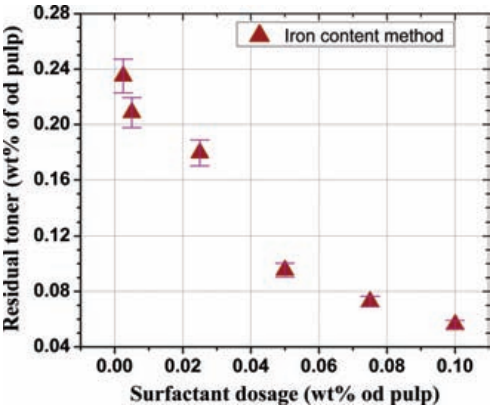

Figure 4. The present iron content method measured true residual toner contents of six flotation accept pulp samples obtained using different surfactant dosages.

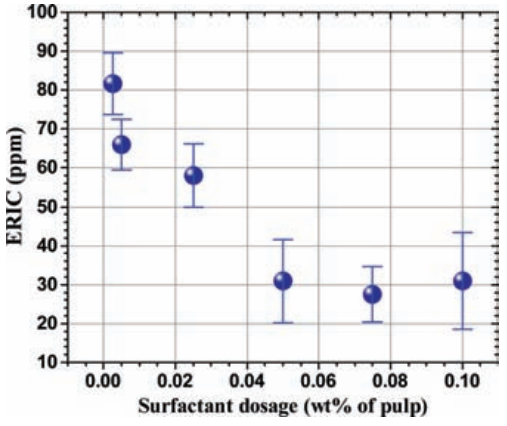

Figure 5. The ERIC values of the same flotation accept pulp samples shown in Figure 4 obtained using different surfactant dosages.

at higher surfactant dosages (Figures 4 and 6). This can be indirectly verified from the steady increases in brightness values of the handsheets made of flotation accepted pulp samples (Figure 6). The brightness increased from 89 to 90 with a maximal standard deviation of only 0.4 when surfactant dosage increased from 0.05 to 0.1 wt % od pulp. Iron content was found to decrease as brightness increased. These observations support the earlier finding that ERIC is not sensitive at very low ink contents and, therefore, not suitable for determining the quality of very clean deinked pulps.

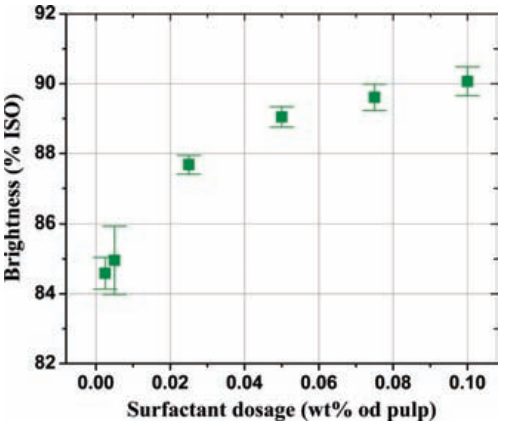

Figure 6. The brightness values of the same flotation accept pulp samples shown in Figure 4 obtained using different surfactant dosages.

It should be pointed out that ERIC is only a relative measure of residual ink content. The ERIC values in Figure 2 are based on a default ink absorption coefficient of 10^4 m^2/kg. An ERIC of 350 ppm is found at approximately 2% actual ink content (measured by gravimetric methods shown in Figure 2), which corresponds to 20,000 ppm. Most of this disparity, a factor of 57, is due to the size distribution of ink particles in the experiment. Jordan and O'Neill have pointed out the absorbing power of ink is greatest when specks in the tens or hundreds of μm in size are avoided in preference to much finer particulates.[10] The reason is that only the ink at the surface of large specks (>10 μm) is available to absorb light, while the entire speck contributes to the gravimetric ink weight. Large specks are invariably present during recycling, and flotation deinking preferentially removes them.[11] This suggests that optical methods like ERIC and brightness will remain poor ways to characterize residual ink content in an absolute sense, at least in practical recycling operations. The iron-content method, being chemical rather than optical, is not subject to this limitation. Unfortunately, there is no quantitative data on the effect of ink particle size on ERIC measurements. This factor can affect the results obtained from the present study (Figure 5), especially when comparing the ERIC values of the undeinked and deinked pulp samples after preferential removal of toner particles in a size range of 10−100 μm.[10,11]

The deinking efficiencies of the six flotation experiments were calculated using eq 3 based on the measured toner contents in the flotation feed and accepted pulp samples. For comparison purposes, we also calculated deinking efficiencies using the relative reductions

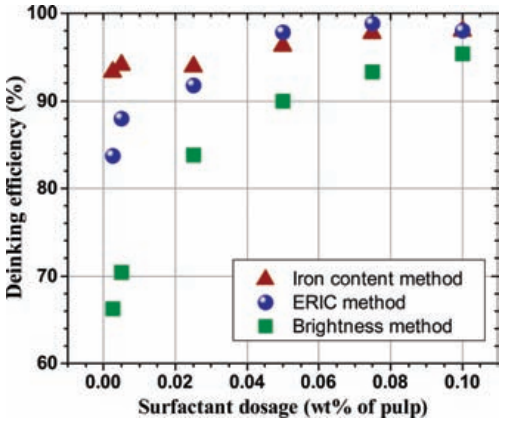

Figure 7. Comparisons of deinking efficiencies determined by the present iron method, handsheet ERIC and brightness values for a set of flotation deinking experiments using different surfactant dosages.

in ERIC values and gains in the brightness (B) of handsheets made of flotation accepted pulp samples, i.e.

$$E_{ERIC}(\%) = \frac{ERIC_{feed} - yERIC_{accept}}{ERIC_{feed} - ERIC_{unprinted}} \quad (7)$$

$$E_{Brightness}(\%) = \frac{B_{accept} - B_{feed}}{B_{unprinted} - B_{feed}} \times 100\% \quad (8)$$

where y is pulp yield from flotation (Table 2), B stands for brightness, and $B_{unprinted}$ and $ERIC_{unprinted}$ (should be zero theoretically) are the brightness and ERIC of the unprinted papers used in the present study and were 90.9 and 21.0 as measured before printing. Equation 8 is the deinkability factor (DEM) proposed by Papiertechnische Stiftung (PTS) of Germany.[12] The results show that deinking efficiency determined from the iron content increased linearly from 93 to 98% as surfactant dosage was increased from 0.0025 to 0.1% ($y = 93.4 + 50.4x$, $r^2 = 0.915$, Figure 7). Since the iron-content is a chemical-based measurement, the linearity reflects ink weight removal without regard to size. The deinking efficiencies determined from ERIC (eq 7) and brightness (eq 8) also increase with surfactant dosage but not linearly. Both ERIC and brightness deinking efficiencies at low surfactant dosages are much lower than those determined from the iron-content method. Because both ERIC and brightness are essentially optical measurements that are affected by the size distribution as well as total weight of absorbing materials, preferential removal of toner particles of size range 10−100 μm through flotation leaves behind many small toner particles around 1 μm or less. The weight of these small toner particles is very low, which keeps ERIC values higher and brightness values lower to a degree not reflected by their total weight. This happens because the linear relation between actual ink content and ERIC shown in Figure 2, obtained from samples with the same toner morphology, is no longer valid for flotation feedstock and deinked pulp samples that have different toner particle-size distributions.

The resulting underpredictions of flotation efficiency by the ERIC and brightness methods can lead to excessive cost and energy waste by increasing surfactant dosage, aeration, or duration. At a surfactant dosage of 0.0025%, the true flotation deinking efficiency determined from iron content measurements was 94%, but it was only 84% based on ERIC measurements and 66% based on brightness measurements. The latter tests would require surfactant dosages of 0.025% and 0.05%, respectively, to achieve efficiencies greater than 90%. These dosages represent an increase by factors of 10 and 20, respectively, of the amount actually required.

CONCLUSIONS

This study demonstrated a method for the measurements of true residual ink content and deinking efficiency of mixed office waste paper (MOW) based on the measurements of a trace element in ink, i.e., iron (Fe) in toner. The iron content in a pulp sample can be accurately measured by ICP even at very low ink levels, and as a result, the present method can accurately determine the residual ink content of final deinked MOW pulp. Although residual ink can be measured by ERIC using the industry standard method, ERIC has low accuracy at very low ink content and is particularly susceptible to errors which make it unsuitable for final deinked MOW pulp quality evaluation. Brightness, though not a measure for ink content, can be used for final deinked MOW pulp-quality evaluation thanks to its high accuracy at high brightness levels. Both ERIC and brightness are not suitable for determining deinking efficiency. Both of these methods underpredict deinking efficiency which can lead to excessive flotation in industrial practice. Although the iron content method cannot be used to determine residual ink content in practical applications due to the unknown iron content in the pulp, it can be used to accurately determine true deinking efficiency of mixed office waste paper in industrial practice when a sophisticated ICP system is available. Future studies need to address the issue of the effect of Fe chelating in mill process streams on deinking efficiency measurements using the present method.

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