Application of Wet Image Analysis on Recycled Paper Ink Elimination Evaluation

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Abstract

This paper introduces a new image analysis approach to determine ink elimination using scanning high-resolution scanning image acquisition combined with innovation specimen preparation. Saturating white fiber in handsheets with water turns fiber translucent [1]; hence, the trapped ink specks become visible through the entire thickness of the handsheet. Thus, it is possible to obtain extra and accurate speck information with the same image analysis settings. Two-side scanning also becomes unnecessary with proper set-up. Furthermore, the increased scanning resolution and rewetting not only detect smaller specks, but also eliminate the negative effect from the uneven surface, such as holes and even wrinkles. The result has positive relation with handsheet optical properties. More importantly, with a concept of ink elimination rate, it provides a reliable deinking predication compared with the limitations of the ERIC method.

Introduction

The deinkability of print products, as an important knot of the paper-recycling loop, has become an issue for printers and consumers. Although digital print products count only 10% in overall recycled paper, their controversial deinking performance has already become a hot topic. Dry toner based electrophotography has been approved as having good deinkability currently; on the other hand, water based inkjet and liquid electrophotographic toner are still not good enough [2]. It is no doubt that this will impact customer behavior in selecting digital printed products. Deinking is more than removing ink; other contaminants also need to be eliminated, such as stickies [3]. The ultimate goal of deinking is to maximize contaminant removal and minimize the reject rate of fibrous material [4]. Two types of approaches are applied to evaluate ink elimination. The first approach applies image analysis, which directly counts dirt area manually or digitally, such as TAPPI T437 and T563. It basically counts total visible dirt whose size is over 0.02 mm^2. The second approach is an indirect method which applies the Kubelka-Munk equation [5] to determine Effective Residual Ink Concentration (ERIC), such as TAPPI T567 and ISO 9416. There is no apparent correlation between the two methods, because ERIC method also detects subvisible “dirt”, while current TAPPI image analyses focus on macro specks. The indirect method has been broadly discussed since the beginning[6]; its application has also increased because of the quick and convenient measurement. However, its accuracy is intensively argued [7] [8] [9], so that image analysis methods are still preferred by a number of researchers.

Table 1 illustrates a brief comparison between current image analysis methods and ERIC methods. Manual dirt count is not convenient; a digital apparatus is employed to increase the speed and accuracy, such as a scanner or digital camera. T563 is the only standard using a digital scanner to calculate the specks on deinked paper and paperboard. It indeed calculates the equivalent black area (EBA), and has a unit of parts per million (ppm). The calibration procedure of T563 is extremely important, and also complex for daily application. Further, the unevenness of dry paper surface gives significant negative impact in defining specks via image analysis. Increasing scanning resolution cannot alter the situation but generates even worst errors. Hence, the common scanning resolution is 600 dpi, whose single pixel area is 0.00179 mm^2. Since dirt shape is close to round, a minimum 4 pixels is required to define the dirt, or 0.0072 mm^2. Considering the paper surface influence, this method hardly detects the subvisible specks (< 0.02 mm^2) properly. However, these subvisible specks more significantly impact paper optical properties than their appearance.

Table 1: A comparison of between current evaluation methods

Items	Dry Image Analysis	ERIC
Representative	TAPPI T437, T563	TAPPI T567, ISO 9416
Apparatus	Scanner, manual	Colorimeter
Resolution	Standard	N/A
Detection	Direct	Indirect
Calibration	Yes	Yes
Double sides	Yes	Yes
Handsheet impact	Moderate, severe	Moderate, severe
Contaminant identity	Yes	No
Ink elimination rate	No	Yes
Test area	Large	Moderate
Overall accuracy	Poor, limited	Moderate, limited

An interesting phenomenon is that saturating white fiber in handsheet with water turns fiber translucent [1]. Thus, it is possible to obtain extra and accurate speck information with the same image analysis settings. Two-sided scanning also becomes unnecessary with proper set-up. Furthermore, the increased scanning resolution not only detects smaller specks, but also eliminates the negative effect from an uneven surface, such as holes and even wrinkles. More importantly, with a concept of ink elimination rate, it provides a reliable deinking predication compared with the limitations of the ERIC methods.

Methodology and DOE

Toner printed office paper waste (Hammermill IP, 20lbs, brightness 92%, ash content 18%) was applied as general office waste. The deinking procedure applies INGEDE method 11p for comparison purpose. The flotation was completed via a Voith laboratory floatation cell at a fixed rate. Each sample was floated 20 minutes to obtain target deinking results.

Four factors paper condition, basis weight, resolution and minimum ink specks area were observed for their influence during this approach, see Table 2. All handsheets were made with a handsheet machine followed by T272 (for optical properties). 10 handsheets were prepared for each basis weight, representing deinked pulp (DP), undeinked pulp (UP) and unprinted pulp (*unpr*), respectively. A total of 90 handsheets were prepared.

Table 2: Experimental design

Factor	Scale
Paper condition	Dry, wet
Basis weight	45, 52, 63 ± 1.5 gsm, OD
Scanning resolution	600 and 1200 dpi
Min. specks area	0.01, 0.02, and 0.04 mm^2

The brightness of these samples was measured via a Technidyne BrightiMeter Micro S-5 (T458, C/2° light source, 457nm). Luminosity (Y, 557nm), CIE a* and b* were also taken with this instrument based on T524 (45/0). Besides, an X-rite Eyeone was applied to measure Y, a*, b* values at D65/2° conditions. All optical properties were measured on the smooth (plate) side. To obtain the filtrate darkening values, a pad was prepared with a Buchner funnel according to T218. Whatman G41 filter paper (intermediate pore) and cellulose nitrate membrane filters (pore size, 0.45 μm) were applied. Filtrate darkening was measured the membrane filters using luminosity (Y) with the X-rite Eyeone at D65/2°. Handsheet thickness and opacity are also measured following corresponding TAPPI standards.

An Epson Perfection V750 Pro scanner and Verity IA Light and Dark Dirt v3.4 software (IGT) were applied to measure the visible dirt area. The area of interest (AOI) for image analysis was a 10cm diameter circle in sheet center. The analyzed area was kept consistent between 600 and 1200 dpi. Only ink specks were calculated and converted to EBA (ppm). Both sides of dry handsheets were measured and their speck values were summed. Rewet samples were taken on the non-smooth side, due to more dirt accumulated there. The obtained values on each handsheet were then averaged.

Results and analyses

Optical properties

The selection of handsheet basis weight considered fiber translucent performance and the ERIC test (opacity <95% at 950nm). The basis weight difference has no impact on most major handsheet optical properties, such as Luminosity (see Figure 1), CIE L*a*b*, brightness; including both DP, UP and *unpr* sheets (those values are not listed here). Further, all of DP and *unpr* handsheets optical properties were almost identical, which indicate a perfect deinking process. ΔY of filtrate darkening is much better than target value (ΔY = 6 [10]) which also confirms this good deinking result. The only influence was on paper opacity, which is already predicted, see Figure 2. However, all of those sheets were satisfactory for ERIC test requirements (opacity <95% at 950nm). This offers the flexibility to optimize handsheet basis weight for evaluation by image analysis.

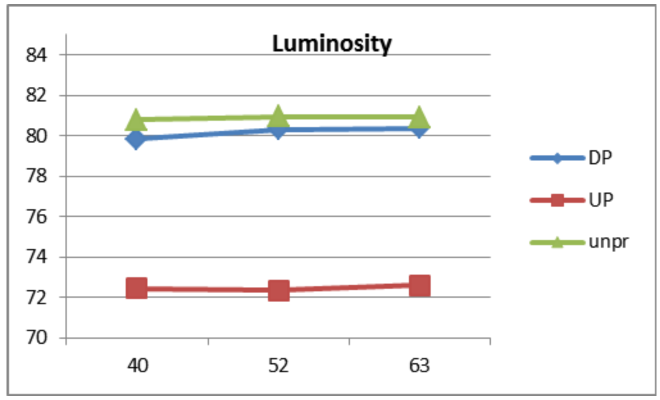

Figure 1: Paper basis weight has no influence on handsheets paper luminosity.

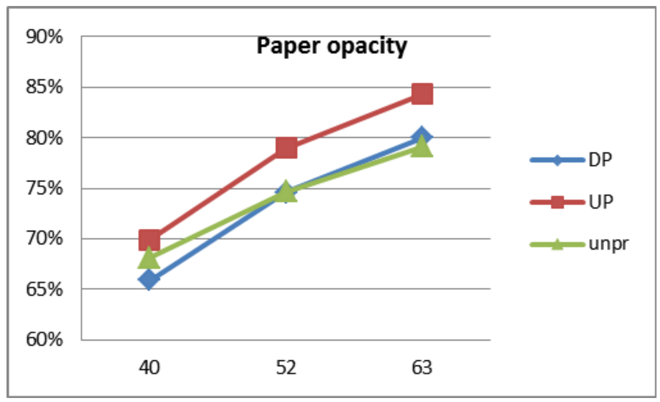

Figure 2: Paper basis weight influences handsheets paper opacity.

Image analysis factors for handsheet ink evaluation

From Minitab analysis, paper condition, basis weight, resolution and minimum ink specks area, all four factors significantly influence sheet EBA performance. In Figure 3, paper condition (dry or wet) and minimum ink specks area are the major factors among the four. The ppm values obtained in wet conditions are less than those in dry conditions. Since the wet handsheets are translucent with high contrast, missing dirt is less possible. Dirt count for dry sheet conditions is over estimated. The extra values are believed to be coming from noise of uneven paper surface and repeatable dirt counting from both sides. This phenomenon prevents increase the analysis accuracy via increasing scanning resolution under dry condition. Figure 4 illustrates how wet condition increase ink specks contrast on the same handsheet with the same scanning resolution. The ink specks on wet sheets are clear, and the total volume is higher than dry sheet even by naked eyes.

The minimum ink speck area impact on ppm values is easily understood. Small dirt area obtains higher ppm values than large one; which is positively related to paper optical properties.

High scanning resolution gets smaller speck areas than a low one. For example, a speck has 2.4965 mm^2 areas by 600 dpi; while it becomes 2.4759 mm^2 when using 1200 dpi. Although high scanning resolution reduces analysis speed and scanning speed (the influence is not significant in modern instruments); it increases the final value accuracy. This phenomenon is also found on undeinked handsheets, see Figure 5.

Handsheet basis weight has influence on EBA values too; however, it isn't consistent between DP and UP handsheets. Comparing these three basis weights, the ppm values of 52 GSM are less variable, whether in DP or UP.

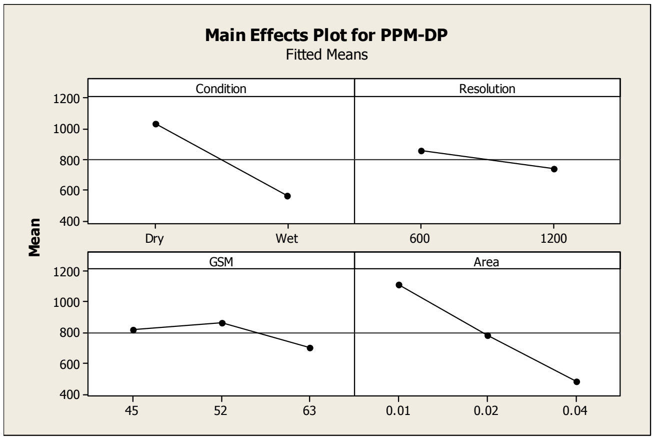

Figure 3: Major factors for deinked (DP) handsheets EBA.

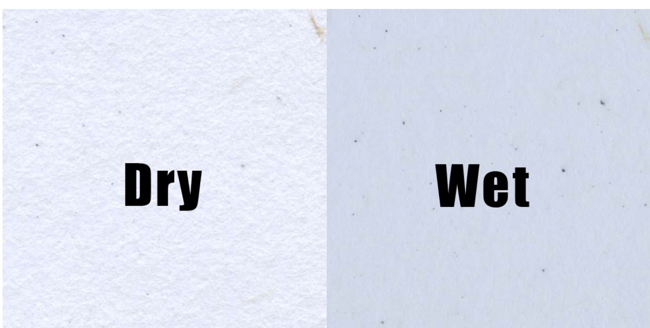

Figure 4: Comparison on same handsheet in dry and wet condition, 600 dpi.

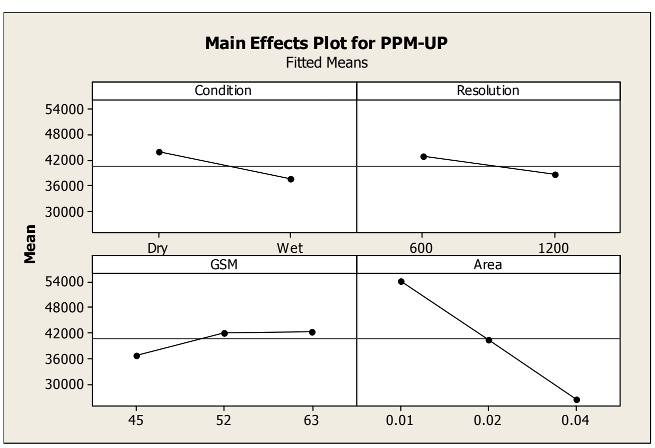

Figure 5: Major factors for undeinked (UP) handsheets EBA.

Unprinted sheets were prepared for IE via ERIC measurement, which can reduce the error coming from fiber; see Equation (1). However, they are not favored for deinking evaluation via image analysis. The main problem comes from the image analysis software whose threshold uses the most frequent gray value (by mode) in a sheet. Those gray values are above threshold and are considered as ink specks, the rest are fiber. The thresholds from unprinted sheets are meaningless to other DP and UP sheets; hence, they cannot be applied to refine calculation results. For example, parts of EBA values obtained from 600 dpi unprinted sheets are larger than those from 1200 dpi, which is in contrast to the above analysis.

$$IE = \frac{ERIC_{UP} - ERIC_{DP}}{ERIC_{UP} - ERIC_{unpr}} \times 100 \quad (1)$$

How dry and wet condition impact EBA

The correlation coefficients of dry and wet sheets are 0.938 for DP sheets and 0.964 for UP sheets. This means that the two conditions are providing consistent information. To further discover the influence from paper conditions, the wet sheets EBA values are normalized with the corresponding dry sheets, see Figure 6. The bold arrow line divides the plot into two main sections, representing 600 and 1200 dpi scanning resolution. The thin lines further divide each section into three parts, referring to three handsheet basis weight settings (45, 52 and 63 GSM, left to right). Within each part, three dots represent three minimum speck area settings (0.01, 0.02, 0.04 mm^2, left to right).

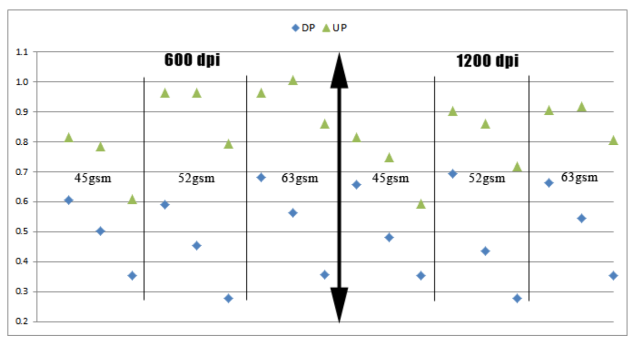

Figure 6: Wet sheets EBA values are normalized with dry sheets EBA.

Comparing DP handsheet normalized values, the EBA values of wet sheets are much smaller than their dry counterparts. The difference on 0.04 mm^2 minimum speck area is most significant; whose values are as low as 0.3. It indicates large minimum speck area suffer lower accuracy than small minimum speck area. At minimum speck area of 0.01 mm^2, the normalized values increase above 0.6. Decreasing minimum speck area (the low threshold should be convincible under current technology) helps image analysis accuracy, even on dry handsheets.

The normalized values of UP sheets have no apparent relations to the same of DP sheets. First, the normalized values for UP sheets are generally higher than for DP ones; or the EBA difference between dry and wet sheet are lowers. A minimum speck area of 0.04 mm^2 still has lower values than the other two settings, which indicates low accuracy. However, the speck area setting of 0.02 and 0.01 mm^2, their EBA values are almost identical at 600 dpi resolution. This is against the previous conclusion that wet EBA value is lower than the dry one. It becomes normal when using 1200 dpi resolution. Hence, using 1200 dpi scanning resolution has advantages for wet sheet analysis. However, UP sheet has much more ink specks than DP sheet, part of the specks could be covered by those above them, which cause EBA miscalculation on dry UP sheets. How this problem impacts final readings is unknown. In this experiment, this problem is considered as a minor factor and neglected.

Ink elimination rate via image analysis

Recycled mills intend to use EBA, or ppm, to monitor the deinking process. However, how much ink is totally removed is not clear even though the test is robust. The IE rate is given in Equation 1 which applies the ERIC evaluation method. Similarly, another IE rate via image analysis is given in Equation (2).

$$IE = \frac{EBA_{UP} - EBA_{DP}}{EBA_{UP}} \times 100 \quad (2)$$

Carry corresponding into Equation 2; the IE rates are illustrated in Figure 7 (plot is divided as same as Figure 6). Generally, the IE rates from wet sheets are slightly higher than the dry ones, about 1% for the same setting. In wet sheet analysis, the influence of minimum speck area setting is clear. The small analysis area slightly decreases the IE rate, however, it is convincible. Sheet basis weight also slightly impact the IE rate, high basis weight having high values. The scanning resolution has no apparent impact on this item. In dry sheet analysis, it is hard to draw similar conclusions as wet sheets because of the EBA error, or low consistency. IE rate from dry sheet is not reliable.

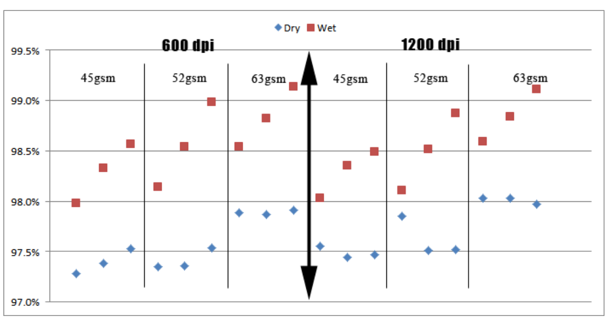

Figure 7: Ink elimination rate via image analysis

Considering the previous conclusion, the IE rate obtained from wet sheets with 52 GSM, using 1200 dpi scanning resolution and 0.01 mm^2 minimum speck area, is the most accurate value; or 98.1%. This IE rate is well matching with the optical properties. The EBA value from the ERIC method and image analysis methods do not compare, but the IE rate difference from both methods is available. The average IE of ERIC on 52 GSM sheets is 90% (dry sheet), which is less than IE of image analysis (98.1%). Considering the handsheet optical properties, the IE via image analysis is apparently close to the appearance. Meanwhile, the ERIC values from this experiment are once again meaningless [8]. For example, the average EBA values from 52GSM *unpr* handsheets is over 50000 ppm; which is far larger than its appearance. Hence, the ERIC method is not reliable in this experiment.

Conclusions

This paper introduced a new deinking evaluation via wet image analysis. The related factors are discussed too. Rewetting paper samples turn fiber into translucent which increase ink speck contrast. This improvement helps to identify residual ink from fiber, and has an advantage to increase accuracy. Increasing scanning resolution (1200 dpi) and using smaller minimum speck area (0.01 mm^2) can increase analysis accuracy too. Handsheet basis weight also influences sample EBA values, 52 GSM handsheets are found having least influence.

Ink elimination rate via image analysis is introduced and discussed. This item offers a useful value to monitor the deinking process from the beginning. The IE rate obtained from wet image analysis is found well correlated with sample optical properties. This experiment once again found the weakness of ERIC methods.

This new image analysis method should be further studied. It overcomes the shortage of current industrial standards (based on dry sheets); such as eliminating the influence from sheet textures. It also removes the complex calibration “and” testing procedure. Its factors are not discussed well due to the paper limitations, such as the details of how paper basis weight impacts results. In next steps, the EBA values combining with paper weight is interesting.

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