Journal of Imaging Science and Technology® 56(6): 060503-1–060503-5, 2012.

Deinking of Digital Prints: Effect of Near-Neutral Deinking Chemistry on Deinkability

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Abstract. *This article demonstrates the effect of near-neutral deinking chemicals on the outcome of a deinking process. More specifically, we demonstrate that good deinkability of digital prints, i.e. liquid-electrophotographic (LEP), dry-electrophotographic and inkjet (IJ) prints, at the laboratory scale, can be achieved with effective near-neutral deinking chemistry that is based on readily available commercial chemicals. The deinking results meet or exceed the target levels, such as ink speck contamination (i.e. dirt area), ink elimination, filtrate darkening, color shade and luminosity, as defined by the European Recycling Paper Council's deinking scorecard. It is noteworthy that the proposed chemistry has a prominent effect on reducing the dirt area of LEP print media and suppressing the filtrate darkening of dye-based IJ print media. Experimental results using the proposed deinking chemistry compare favorably to those obtained with alkaline deinking chemistry.*
[DOI: 10.2352/J.ImagingSci.Technol.12.56.6.060503]

INTRODUCTION

Recycling of print products is important toward fulfilling both environmental sustainability and economical returns. In Europe, approximately 90% of newspapers are printed on recycled paper while 72% of print media are recycled (data for 2009).[1] In North America, these numbers are somewhat lower, but the trend is increasing rapidly. An important factor that affects the overall yield of paper recycling is the efficiency of the deinking process. As digital printing technologies continue to gain market share, sustainable deinking of digital print media can positively impact the effectiveness and yields of paper recycling. Digital prints based on different digital printing technologies do not generally yield the same deinking outcome, as this is influenced by a number of factors associated with the deinking processes.[2–4] The recovered pulp must be free of visually detectable residual inks if it is to be used for re-making high-grade office, graphics and writing papers. Hence, it is highly desirable to implement a deinking process that is effective for a wide range of wastepaper mixes, including both analog and digital print media.

In this article, we show that deinking chemistry can be optimized to obtain good deinkability for various digital print media, including liquid-electrophotographic (LEP), dry-electrophotographic (DEP) and inkjet (IJ) prints. Our results indicate that with an appropriate choice of deinking methodology, all three of the above-mentioned prints can be deinked to either meet or surpass the deinking thresholds and criteria, with reference to international deinking grading standards, such as the European Recycling Paper Council's (ERPC) deinking scorecard.[5] The proposed approach is applicable to various offset print media[6] and is expected to be scalable to be adopted in recycling paper mills.

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Received Jan. 29, 2010; accepted for publication Jan. 9, 2013; published online Mar. 2, 2013.
1062-3701/12/56(6)/060503/05/$20.00

EXPERIMENT

Figure 1 shows the major steps of the deinking process adopted in our work. Briefly, for aging of the print products, two hundred grams of each test media was stored in a thermostat-controlled oven at 60°C for three days to simulate three to six months of natural aging. All test media were cut on a paper-cutting machine to approximately 4 cm × 4 cm in size. During the pulping stage, a Hobart pulper was used. The test media was mixed with the deinking chemicals and de-ionized water that was treated with calcium chloride dihydrate to achieve a water hardness of 128 mg Ca^{2+}/L. During storage, the stock was diluted with treated water to a pulp consistency of 5% and stored for 60 min in a water bath maintained at 45°C. Prior to the flotation stage, the stock was further diluted with 45°C warm water to a consistency of approximately 0.8% in a Voith Delta 25 flotation cell. The flotation was allowed to proceed for 20 min with extra warm water added during the process to ensure foam removal and overflow. The rotor speed was set at 1470 rpm, with an airflow of 6–7 L/min. During the flotation stage, the overflow was collected and measured according to ISO 4119, including the consistency of the overflow by drying on a filter paper, to determine the flotation yield. From the deinked and undeinked pulps, respective handsheets were made to determine the dirt area. Corresponding filter and membrane pads were made to determine the various optical properties, according to International Association of the Deinking Industry (INGEDE) Method 1. To determine the ink elimination, IE_{700} was measured while filtrate darkening was measured, in accordance with INGEDE Method 2.

To investigate the effect of chemicals on the deinkability of various ink–media combinations, the key steps of the process flow were kept similar to that of INGEDE Method 11, except for the deinking chemicals and the duration of the flotation, which we increased from 12 to 20 min in this investigation. Sustainable foaming can be readily achieved

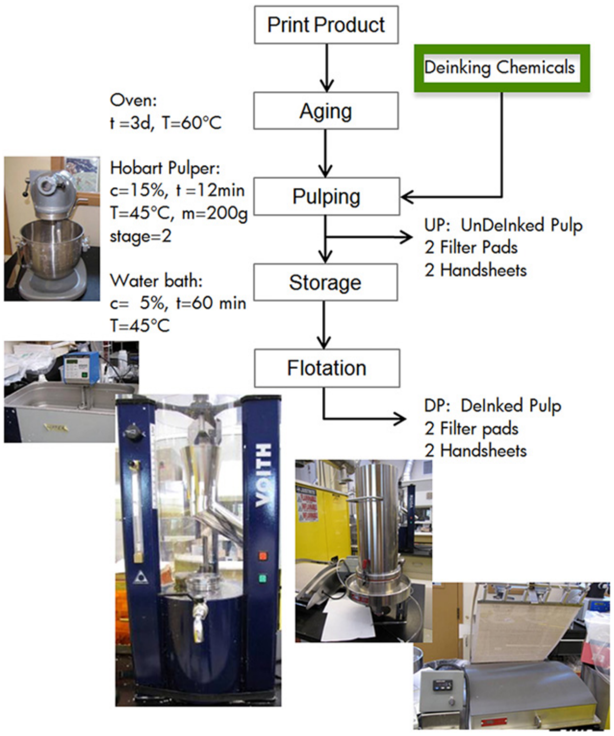

Figure 1. A schematic showing the key steps of the deinking process adopted in this work. Compared to INGEDE Method 11, the key differences are the deinking chemicals and the duration of the flotation, which we increased from 12 to 20 min in this round of our investigation. Since no significant differences were observed between the undeinked pulp retrieved after the pulping and after storage, we sampled the undeinked pulp right after the pulping stage.

during the extended flotation time. Since we have observed a similar level of performance with respect to the deinking parameters from undeinked pulp retrieved after pulping and after storage, sampling of the undeinked pulp was done before storage for all runs (although INGEDE Method 11 recommends sampling after the storage stage). In executing the proposed deinking chemistry (HPE6S4), a 'two-stage' pulping process was adopted, where an ethoxylated fatty alcohol ($\sim$0.6 wt%) such as non-ionic polyoxyethylene (20) oleyl ether was added during the first stage ($\sim$19 min) of the pulping process followed by a surfactant ($\sim$0.4 wt%) such as sodium dodecyl sulfate.[7] The near-neutral nature of the proposed chemistry was based on pH evolution, which ranged between 7 and 8 throughout the deinking evaluation. Accordingly, no pH adjustment of the pulp solutions was performed during the entire process. In contrast, when executing the alkaline deinking chemistry, we employed the chemistry as spelled out in INGEDE Method 11.

Four different HP ink–media print samples were used in this work: (1) HP Indigo ElectroInk on coated (Newpage Indigo, 118 gsm, optical brightness 92%)/uncoated (Cougar Opaque, 100 gsm, optical brightness 94%) paper, (2) HP Edgeline inkjet inks/HP Multipurpose ColorLok (HMC) paper (75 gsm, optical brightness 96%), (3) HP inkjet dye-based/HP HMC and (4) HP Colorsphere dry toner/HMC. For all runs, we adopted the INGEDE color test plots as the standard print image and single-sided print samples were used.

RESULTS AND DISCUSSION

In the current laboratory-scale deinking evaluation, two major steps were involved—pulping and flotation. During the pulping, the print media is swelled by the aqueous deinking chemicals and the ink particles are detached either from the fibers or from the media coatings. Simultaneously, the detached ink particles are mechanically broken down and made hydrophobic by their interactions with the added surfactants. Ink particle removal occurs next during the flotation process. The detached ink particles interact with the air flow generated bubbles and float to the top of the flotation cell. Foams are created and are removed by a scooping action. It is crucial that the air bubbles provide the desired interfacial ink–surfactant interaction and facilitate sufficient buoyancy to carry the attached ink particles to the top of the flotation cell where they can be removed as overflow. Hence, the choice of surfactants and their individual roles as a collector and a dispersant in the pulping and flotation stages are critically important toward the outcome of a deinking process.[8,9]

As shown in Figures 2–6, the proposed near-neutral deinking chemistry successfully serves as a dispersant and a collector (i.e. displector) during the pulping and flotation stages to facilitate efficient detachment and removal of the ink particles from the fibers. Although the five key parameters of the ERPC's deinking scorecard were evaluated for overall deinkability based on alkaline deinking chemistry, we employed the same grading system for the purpose of comparison.

Fig. 2 shows the significantly smaller dirt area (i.e. ink speck contamination on a handsheet made from the deinked pulps) achieved using the proposed chemistry (HPE6S4) for the various print samples as compared to using alkaline-based chemistry. It is noteworthy to mention that the present chemistry works particularly well for the HP Indigo ElectroInks on both coated and uncoated media. Compared to the alkaline deinking chemistry, it brings the ink speck contamination to well within the target level of less than 600 mm/mm^2 for all print media. Interestingly, in the case of the IJ print samples, a corresponding increase in the average speck diameter of IJ ink particles was observed, suggesting efficient agglomeration of the submicron size pigment particles and dye molecules using our approach. Through repetitive runs, we found that ink specks with sizes between 5 and 200 μm work well with the present near-neutral deinking chemistry. It is noted that the pH level was maintained at between 7 and 8 during the deinking process, regardless of the ink–media combination.

Fig. 3 shows the low filtrate darkening level ΔY, an indication of the discoloration of the processing water, achieved with the proposed approach. Unlike the alkaline chemistry, it resolves an outstanding issue with inkjet pigment- and dye-based inks.[10,11] The proposed chemistry consistently delivers a lower ΔY than its alkaline counterpart. Similarly,

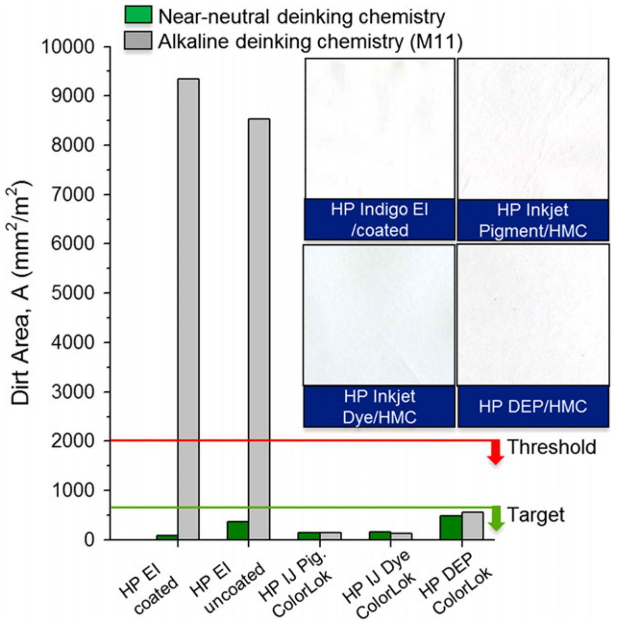

Figure 2. A dirt area plot showing the contamination levels obtained using the HPE6S4 and alkaline chemistry for the various ink–media combinations. The insets are optical images of respective handsheets that were made from the deinked pulps.

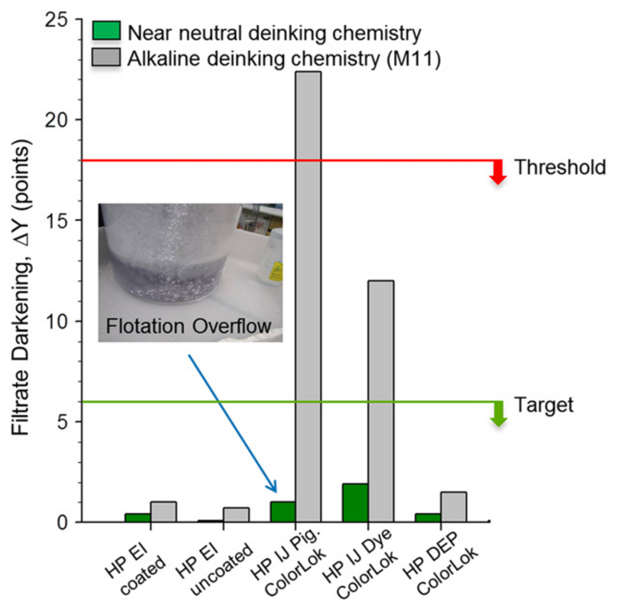

Figure 3. A filtrate darkening (ΔY) plot showing the levels of process water discoloration with the present near-neutral deinking chemistry and alkaline deinking chemistry for various ink–media combinations. The ΔY data were measured from the membrane filters. The left inset shows a photograph of the overflow collected during our deinking process.

good results were obtained in terms of ink elimination IE_{700}, see Fig. 4, which is an indicator of ink removal efficiency. In all cases, the near-neutral chemistry performs better than its alkaline counterpart. Except for the dye-based inks (still noticeably above the threshold level), all ink–media combinations score full points according to the ERPC's deinking scorecard, see Figure 7.

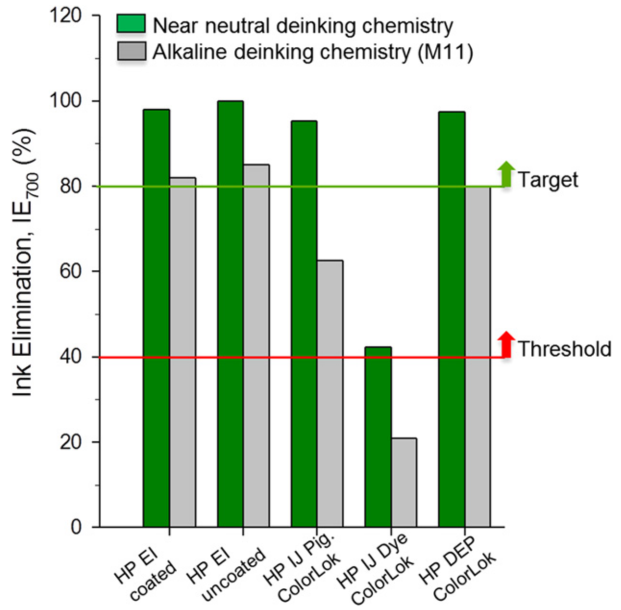

Figure 4. An ink elimination (IE) plot showing the ink removal efficiency of both deinking chemistries. The IE data were measured from the filter pads.

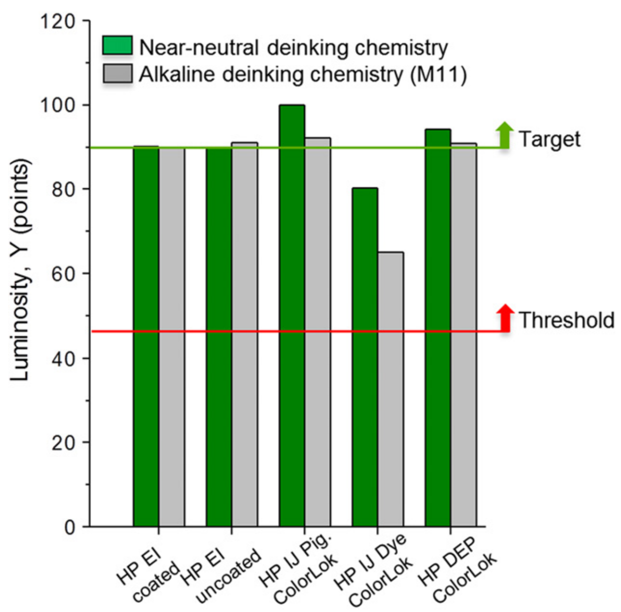

Figure 5. A luminosity (Y) plot showing the optical brightness of the handsheets with both deinking chemistries for the various ink–media combinations. The Y data were obtained from filter pads made from the deinked pulps.

Besides the ink speck contamination level, the optical properties of the recycled fibers play a determining role in the grade of the recycled paper. To achieve high quality recycled media for graphics, office and writing applications, stringent optical characteristics have to be met. As shown in Fig. 5, high luminosity or optical reflectance was observed for all cases using the proposed approach. The present chemistry delivers luminescent (Y) values either on a par with or better than the alkaline chemistry. More remarkably, it achieves high

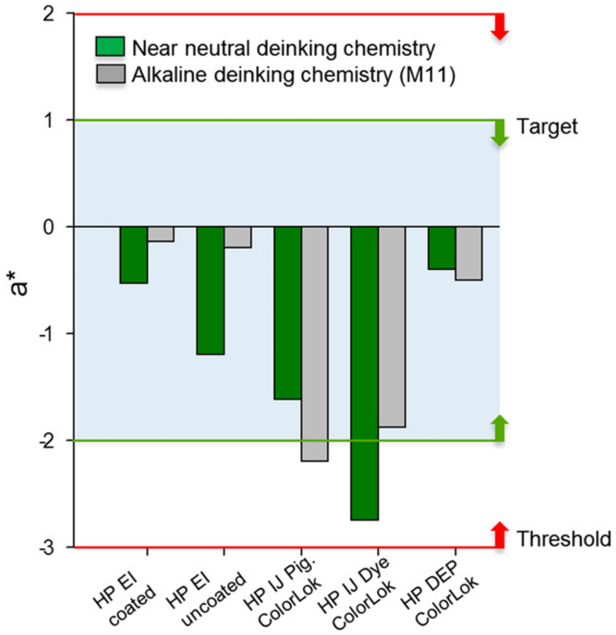

Figure 6. A color shade (a^*) plot showing its evolution with different ink–media combinations.

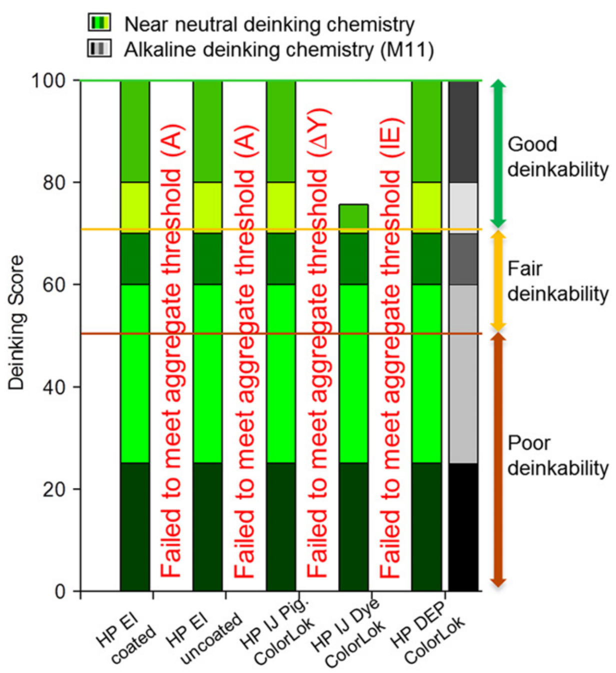

Figure 7. Deinkability scores, graded according to the specifications as spelled out in Ref. 5, of the various ink–media combinations for both deinking chemistries.

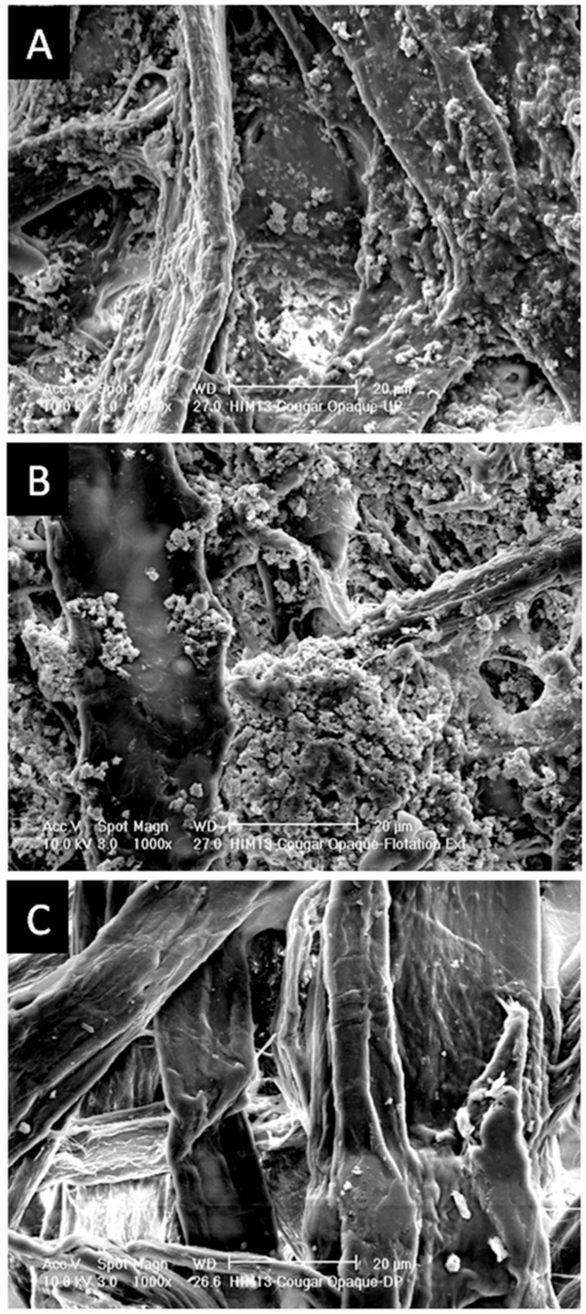

Figure 8. Scanning electron microscopy of the undeinked pulps (A), flotation overflow (B) and deinked pulps (C) for the HP Indigo ElectroInk media. The respective scale bar is shown in each panel.

Y in the absence of a bleaching agent. We suspect that the original high luminosity of the media could also contribute to the observations. Irrespective of the deinking chemistries, the color shade, a^*, falls within the threshold level for all ink–media combinations, as shown in Fig. 6. While taking these five parameters into consideration and comparing the results against the threshold and target values for the 'toner prints on woodfree papers' category, all samples using the near-neutral chemistry obtained ERPC ratings that suggest good deinkability, see Fig. 7.

It is expected that with any new deinking chemistry, the flotation yield can be impacted. In the present study, we observed flotation yield ranges from 58 to 70% for our print samples while using the near-neutral deinking chemistry. A slightly higher flotation yield, ranging between 65 and 75%, was observed using the alkaline deinking chemistry under the same conditions. One of the possible reasons may be attributed to the extended flotation duration. The increased foaming as a result of the present dosage of the near-neutral deinking chemistry could be another possible contributing factor to the lower flotation yield. We anticipate that the flotation yield could be improved by optimizing surfactant dosages and reducing flotation duration.

The improved deinkability of digital prints by using the proposed near-neutral deinkng chemistry is further supported by observing the structural content of the recovered pulps. Using the HP Indigo ElectroInk media as an example, see Figure 8, scanning electron microscopy (SEM) of the undeinked pulps shows the presence of fibers, mineral pigments, filler materials and ink particles. The mineral pigments are predominantly found in the flotation overflow waste, with a small amount of fibers. Deinked pulps, on the other hand, consist mainly of fibers, with a small amount of residual mineral pigments.

CONCLUSION

In conclusion, we showed that good deinkability at the laboratory scale of various digital printed media from various digital printing technologies can be achieved with an appropriate selection of deinking chemistry. It is also noteworthy to point out that the proposed near-neutral deinking chemistry is applicable to traditional offset prints, including heatset and coldset offset inks. Good deinkability at the laboratory scale has been obtained in a recent study.[6] A long-term goal of our work is to investigate the applicability of the proposed near-neutral deinking chemistry for a wide range of digital and analog ink–media combinations. The present deinking study was conducted under conditions that do not closely resemble those of recycling mills. It is necessary to follow up the present study with process conditions that resemble mill-scale deinking processes and draw meaningful correlation between laboratory and mill scale observations.

ACKNOWLEDGMENT

The authors would like to acknowledge fruitful discussions with Doris Chun, Howard Tom, Nathan Moroney, Minedys Macias, Gregg Lane, Nils Miller, Jeffrey Belson, Marc Aronhime, Yossi Rosen, Pinni Perlmutter, Greg Smith, Sandeep Bangaru, Kelly Ronk, William Houle, Glen Hopkins and Frank Drogo.

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