Effects of Paper on LEP Digital Print Deinking with Alkaline and Neutral Chemistries

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Abstract

Conversion of analog to digital technology is occurring at an ever increasing speed in the commercial printing industry. Digitally printed papers, as a consequence, are becoming a larger proportion of the incoming waste paper stream to the recycling industry. Deinking of digital prints involve deeper understanding of the ink and their interaction with various types of substrates. In this paper, a comparative study of alkaline deinking and neutral deinking of LEP prints with a variety of substrates is presented. The results show that the preferable neutral chemistry is always successful in deinking, while the alkaline chemistry appears to be more complicated.

Introduction

Liquid Electrophotography (LEP) is a form of digital printing technology that uses isoparaffinic oil based liquid toners and can produce high quality printed materials. With the continuing analog to digital transformation in printing, the amount of such digital prints entering the post-use recycling stream is also rising. Due to the nature of LEP prints' film-forming characteristics on the surface of the paper substrate instead of being fused into the substrate, as in some other printing technologies, e.g. dry electrophotography (DEP), the deinking dynamics of such prints may necessitate a deeper understanding of the LEP printing process and deinking chemistries. Deinking of LEP digital prints has been described in recent publications [1, 2] using a near-neutral chemistry (termed as HPES) and an alkaline chemistry (termed as HPMF). In the HPES, 0.6 wt% (relative to dry paper weight) nonionic surfactant polyoxyethylene (8) stearate (tradename MYRJ 45) is used during pulping and a small amount (no more than 0.1 wt%) anionic surfactant (e.g., SDS) is used during flotation. In alkaline chemistry HPMF, 0.8 wt% erucic acid, in addition to enough NaOH and 3 times Na_2SiO_3 to maintain a pH of 9.5 ± 0.5 after pulping, are added. Both of these methods represent two broad classes of chemistries used in the deinking industry. In particular, we have shown that both HPES and HPMF effectively remove the inks from LEP prints, as well as other digital and analog prints. Although HPES and HPMF chemistries were shown to work well, a comparison of their deinking performances is lacking. It is well known in the print industry that the substrates used in any particular printing technology play a substantial effect on the adhesion of ink to the substrate and fundamental insight into LEP adhesion has been discussed in the literature [3]. It is therefore expected that printing substrates or media will have influential effect on deinkability of LEP prints.

In this paper, we present a comparative study of HPES and HPMF deinking results of LEP print samples using a variety of coated and uncoated substrates commonly used in North America and Europe. Our results identify three most important factors affecting the deinkability of LEP prints.

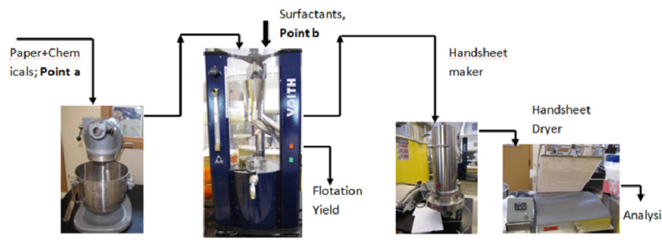

Figure 1: Schematic of Deinking Study.

Laboratory Scale Deinking Process

Figure 1 shows the key steps involved in the laboratory scale deinking study. Except for the chemistry, it is similar to the lab scale deinking evaluation (i.e. INDEGE Method 11p) as recommended by deinking signatory INGEDE. The chemicals and their entry points during the deinking process are shown as follows:

HPES: At point "a" only polyoxyethylene (8) stearate is used. Two variations are tried: In the first variation non-ionic surfactant TX-100 is used at point "b". In the second variation anionic surfactant sodium dodecyl sulfate (SDS) is used at point "b".

HPMF: At point "a", NaOH, Na2SiO3 (pH 9 – 10 after pulping), H2O2 and Erucic acid are used. Three variations are tried: in the first variation no surfactant is used at point "b". In the second variation non-ionic surfactant Triton X-100 (TX-100) is used at point "b". In the third variation anionic surfactant sodium dodecyl sulfate (SDS) is used at point "b".

Results

The results of deinking are summarized in Table 1. Ten papers were used in this study and their organic and inorganic constituents, analyzed by TGA in an air atmosphere, are also listed in Table 1.

The deinking performance is evaluated according to ERPC deinking scorecard. The ERPC deinking scorecard

Table 1: Summary of deinking results. In the first column, paper number, origin continent, coating characteristics (C or UC), organic content, $CaCO_3$ and clay content (all three of the bulk paper) are listed. DP represents deinked pulps, A_{50} and A_{250} represent ink specks above 50 μm and 250 μm respectively. FY represents % flotation yield. If a paper meets the ERPC deinkability scorecard requirement then it is given a "P" and if it does not meet then an "F" (in the DP results) is awarded.

Paper #/ Origin/Coating/Organic/$CaCO_3$ /Clay	HPMF (no flotation additive)	HPMF+0.1% TX-100	HPMF+0.1% SDS	HPES with 0.1% TX-100	HPES with 0.1% SDS
	DP	DP	DP	DP	DP
	A_{50},A_{250},FY, P/F	A_{50},A_{250},FY,P/F	A_{50},A_{250},FY,P/F	A_{50},A_{250},FY,P/F	A_{50},A_{250},FY,P/F
1/NA/C/65/23/11	186,84, 74% **P**	100,61, 77% **P**	61,36, 75% **P**	171,50, 73%, **P**	155,146, 78%,**P**
2/NA/UC/77/23/0	1.3E3.1.1E3, 85%,**F**	401,334, 71%,**P**	39,0, 75%, **P**	401,334, 71%,**P**	71,44, 70%, **P**
3/NA TMP/UC/83/6/10	92,88,85%, **P**	80,50,83%, **P**	67,44,85%, P	291,178, 85%, **P**	88,51, 88%, **P**
4/NA/C/74/18//8	721,549,79% **P**	434,361,78.5%, **P**	434,361,77%,**P**	270,206,76%,**P**	79,35, 78%,**P**
5/EU/C/49/48/0	8.E3,6.7E3, 84%, **F**	4.9E3,4.3E3, 62%,**F**	371,288, 60%,**P**	3.2E3,2.4E3, 60%,**F**	173,93, 72%, **P**
6/EU/C/55.4/40.6/3	1.6E3,1.2E3, 88%, **F**	590,315, 80% **P**	585, 64.5, 72%, **P**	177, 80, 82%,**P**	97,67, 76%, **P**
7/EU/C/53.2/42.3/4	1.5E4,1.3E4, 90%, **F**	4.8E3,4.1E3, 70%, **F**	648,582 ,71%, **P**	749,562, 65%, **P**	268,178, 65%, **P**
8/EU/C/53/45/0	3172,2912, 60%, **F**	4290,3885, 56%, **F**	883, 664, 55%,**F**	1622, 1063, 58%, **F**	54, 24, 56%, **P**
9/EU/UC/73.4/19.7/0	1.8E3,1.5E3, 93%, **F**	380,339, 77%, **P**	48,20, 77%, **P**	48,20, 77%, **P**	113,34, 74%, **P**
10/EU/UC/73/22/0	215, 175, 94%, **P**	77, 37, 76.5%, **P**	74, 30, 75%, **P**	74, 26, 72%, **P**	84, 30, 71%, **P**

stipulates a variety of criteria [4] for deinking evaluation. For LEP, the most important measures are A_{50} and A_{250}. These are ink specks of equivalent diameter of 50 μm or above and 250 μm or above, respectively, left on the deinked pulp (DP) handsheets. These two parameters are represented in mm^2/m^2 and have a strict upper threshold of 2000 (A_{50}) and 600 (A_{250}) for passing.

In addition to these two parameters, the ERPC deinking scorecard has requirements for brightness, ink elimination, color shade of DP and filtrate darkening. These parameters, although critical for inkjet prints, are not problem areas for LEP prints.

In addition to A_{50} and A_{250} of DP handsheets, Table 1 also shows the flotation yield (marked by FY in Table 1) in each of the cases.

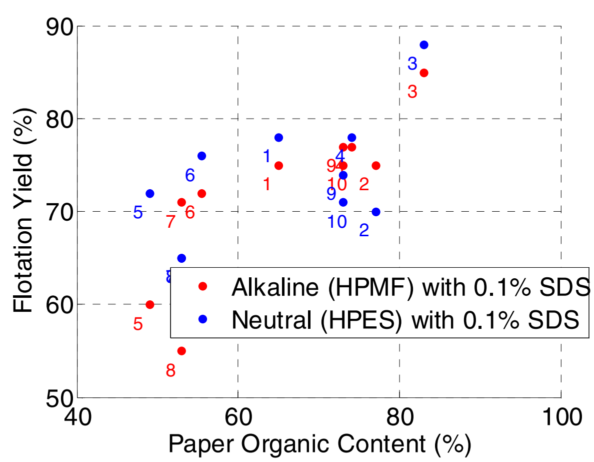

Figure 2:Flotation Yield vs. Paper organic content. Paper organic content is measured by TGA in air atmosphere. The numbers inside the figure represent paper numbers.

With the ERPC deinking scorecard criteria, each of the deinking run is judged pass (P) or fail (F) and is also listed in Table 1. It is seen that every paper can be deinked with both HPES and HPMF (one paper, namely #8 was seen as a difficult paper with even SDS). In most cases, a surfactant is needed at the flotation stage point b. Some papers, especially #1 and #3, can be deinked easily without any surfactant.

An investigation of Table 1 shows that all of the papers investigated here are easily deinkable with the HPES chemistry and often with high flotation yield. In general, the alkaline chemistry's success is much more complicated.

Before further discussion of paper deinkability with different chemistries, a review of yield will be provided. Figure 2 shows flotation yield for two different chemistries and the ten papers studied in this paper. This is, indeed, a graphical representation of some of the data in table 1.

It is seen from Figure 2 that the higher the organic content of the paper (the organic content of a paper is mostly cellulose), the higher the flotation yield. The uncoated papers (papers #2, #3, #8 and #10) have higher organic content than coated papers and consequently have higher flotation yields. Of course, flotation yield involves many complicated phenomena, e.g. fiber entrapment and filler attachment to inks and some results seen in Table 1 and in Figure 2 cannot be easily understood or explained.

Paper #8 does not have the smallest organic content, but has lower yield than paper #5. Also, alkaline and neutral chemistry yields are comparable but no specific trend in their yield differences can be concluded.

Returning to the results shown in Table 1, three NA papers and only one EU papers were seen to be deinkable without any surfactant during flotation. For some papers, for example paper #2 (a NA uncoated paper), the generation and availability of foam was seen as very limited. The foam bubbles were seen to agglomerate and burst easily. It is possible that certain chemicals added during paper manufacturing were acting as a "defoamer" during flotation. For this paper #2, addition of a small amount of ubiquitous liquid nonionic surfactant TritonX-100 (polyoxyethylene octyl phenyl ether) can successfully complete the deinking. The addition of TX-100 during flotation helped in many cases, but not all. In almost all of the cases, where TX-100 was not effective, addition of a small amount of anionic surfactant SDS (sodium dodecyl sulfate) was effective. Interaction of TX-100 and SDS with cellulose has been discussed by Paria et. al [5]. For paper #8 it is found that even addition of 0.1 wt% SDS is not enough to deink LEP prints on this paper.

A closer investigation of the detached ink specks during alkaline deinking unravels few of the mysteries. Figure 3 shows one ink speck of paper #1 and one ink speck of paper #8. The differences seen in the optical micrographs in this figure are striking. Paper #1 ink particles are generally clean and only contain thin and small amount of material (generally white in color) most possibly fragments of paper coating.

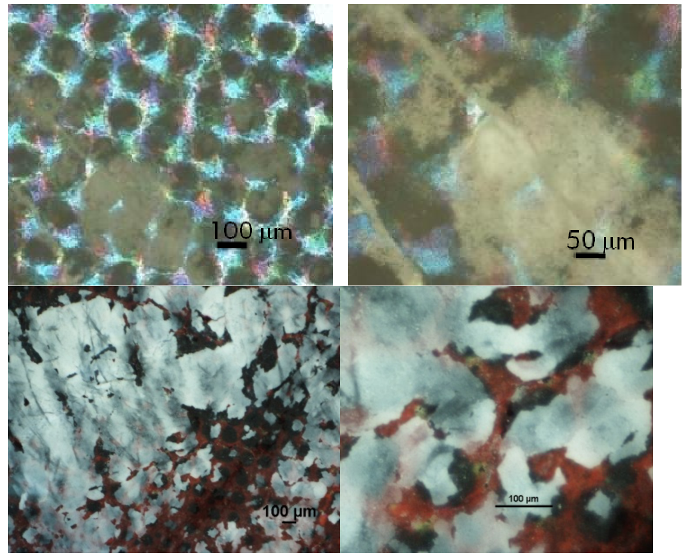

Figure 3: Ink specs seen in HPMF deinking; paper #1 is shown in the top two optical micrographs and paper #8 is shown in bottom two optical micrographs.

Paper #8, on the other hand, contains lot of thick (also white) material. It is, of course, not clear what these white materials are. To identify these materials more definitively, FTIR of ink specks were done on a ThermoNicolet spectrometer. Comparison of ink specks obtained from paper #1 and paper #8 are shown in figure 4. In this figure, FTIR spectra of precipitated calcium carbonate (PCC, Albagloss S from Specialty Minerals Company), kaolin clay (Kaofine 90 from Thiele Kaolin Company) and a thick layer of ink from an LEP print are also shown (this ink specimen was specially printed on an LEP press and did not come into contact with any of deinking chemicals). The FTIR spectrum of a typical ink speck from paper #1 and a comparison with the three reference FTIR spectra of Figure 4 shows that this ink contains mainly the original LEP ink and clay (and also a very small amount PCC). A typical ink speck from paper #8 HPMF chemistry undeinked pulp, on the other hand, contains large amount of PCC covering the underlying ink.

PCC, when attached with ink specks, not only changes their buoyancy but also lowers their hydrophobicity. As a result, these more hydrophilic ink specks are not easily removed in flotation removal. J. Penfold and coworkers have investigated surfactant adsorption on hydrophilic silicon surfaces [6] and have observed that anionic surfactant like SDS do not adsorb on hydrophilic surfaces and a nonionic surfactant (Penfold et. al. reported using hexaethylene monododecyl ether) is needed for adsorption of SDS. It is thus no surprise that our HPES chemistry works for all papers, as it should be pointed out that a nonionic surfactant (polyoxyethylene (8) stearate) and SDS are both present in this chemistry.

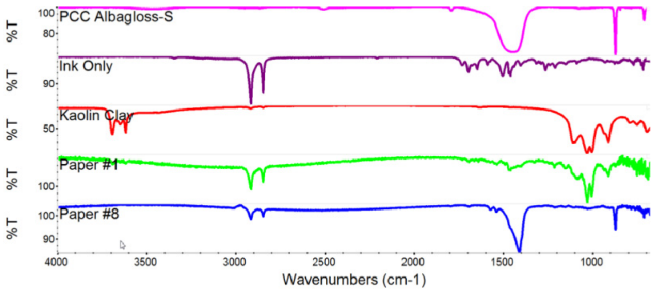

Figure 4: FTIR measurement of ink specks from paper #1 and paper #8 are shown. FTIR of PCC, clay and LEP ink are also shown.

To investigate whether our HPES success and the data presented by Penfold et. al. [6] has a similar origin, a surfactant combination of polyoxyethylene (8) stearate and SDS with different molar ratios was tried on paper #8. Figure 5 shows the result of deinking of paper #8 using HPMF chemistry and addition of a blend of MYRJ45 and SDS during flotation. For all the experiments done using this blend, the total surfactant addition during flotation was set at 0.1 wt% to be consistent with all other deinking shown in table 1.

Even though paper #8 is the most difficult paper to deink with the alkaline chemistry, a blend of nonionic and anionic surfactant may be more efficient in removing the ink specks. The ink specks were seen to be "severely" contaminated with paper filler material and the nonionic and anionic surfactant blend binds better with the charged ink contaminants. With this limited investigation, it was found that 50%:50% ratio of the two surfactants worked most efficiently. This result is in disagreement with the speculation of Penfold et. al that the chemical ratio should correspond to the molar weight ratio of the two surfactants.

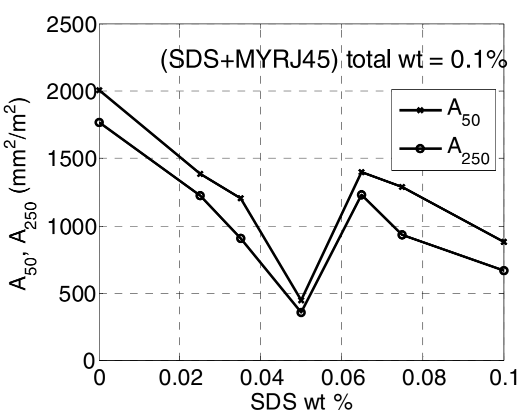

Figure 5: A blend of nonionic surfactant (MYRJ 45) and anionic surfactant (SDS) is added during flotation. The chemistry of pulping was HPMF. Total weight of surfactant was kept at 0.1 wt%. This at the point where SDS wt% is 0, MYRJ 45 wt% is 0.1.

Discussion

Based on this work, it was found that three factors are most important for deinking of LEP prints. In the order of importance they are: (i) Availability of foam during flotation. This can be affected by the presence of defoaming agent used during paper manufacturing, which could quench the foam formation. This is detrimental for flotation deinking, especially in the case of LEP prints. A layer of foam has to be present at the top of the flotation cell to entrap the ink. In such papers there is no alternative to adding extra surfactant during flotation. Only paper #1, paper #3, paper #4 and paper #10 were found to have good foam. (ii) Cleanliness of detached ink particles. It was found that sometimes paper coating layers do not bind strongly with the base layer of the paper. During pulping the ink layer and coating material (also with underlying fiber) detach together. In such cases, the ink particles become somewhat hydrophilic to be carried away by the foam. Surfactants or surfactant blends that can adsorb more efficiently with such ink particles become important. (iii) The size of ink specks is the third factor. If the ink specks, somehow, can be broken into small pieces, the deinking will be easier. Ink specks in uncoated paper samples are, generally, smaller and as a result deinking of uncoated papers are also easier. HPES chemistry, also, is more efficient in breaking down LEP inks into smaller particles, and in part, contributes to its superiority. In some cases, some extra shear-producing steps, such as kneading or disperging can also break up the ink particles. This will improve LEP deinkabilty even more.

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Author Biography

Manoj K Bhattacharyya obtained a PhD in Electrical and Computer Engineering from Carnegie-Mellon University, Pittsburgh, PA. Since his graduation, Dr. Bhattacharyya has worked in Hewlett Packard Laboratories in a variety of research topics including thin film magnetic recording, spintronics and digital commercial printing. He is a Principal Scientist at HP Labs.

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