Effect of Dispersion and Flotation Sequence on Optical and Mechanical Properties of Deinked Computer Printout

Shademan Pourmousa*

The effects of dispersion and flotation deinking sequences on the optical and mechanical properties of recycled computer printout deinked pulp were studied. To find the optimized conditions for providing a deinked pulp with higher brightness, preliminary tests were designed and run at three stages with different ratios of fatty acid and surfactant. Deinking with 1% fatty acid and 0.4% surfactant was found to be the optimum conditions based on statistical analysis. According to the results the brightness of deinked pulp obtained by dispersion and flotation sequences was 11.8 % ISO higher than that of undeinked pulp. It was found that a dispersion stage with 30% consistency and at 75°C, performed before flotation stage, considerably increased the efficiency of flotation through reducing the amount of ink specks in deinked pulp and increasing the pulp brightness by 5.4% ISO. Despite the loss of mechanical strength, the resultant deinked pulp is appropriate for producing high-quality papers.

Keywords: Dispersion; Flotation; Computer printout; Optical and mechanical properties

Assistant professor , Department of Wood and Paper Science and Technology, Faculty of Agriculture and Natural Resources, Karaj Branch, Islamic Azad University. Karaj, IRAN.
** Corresponding Author: sh.pourmousa@gmail.com*

INTRODUCTION

Considering the shortage of forest raw materials (Bajpai 2010) and growing demand for paper products (Pathak *et al.* 2011), it is important to study on exploitation newly introduced lignocellulose resources. Methods for using wastepaper and recycling technologies in the pulp and paper industry provide ways to help slow down the depletion of natural resources. Most countries, especially industrial countries, have already paid particular attention to the use of wastepaper in the production of different types of paper products despite all limitations on the final product quality.

Deinking is a complementary phase in the technology for recycling of printed wastepaper, during which the ink is removed from the fibers. In chemical deinking processes, the efficiency of deinking depends on the printing method and conditions, ink type, and the nature of the paper material (Bolanča 2004). Deinking is usually carried out by flotation and washing methods separately or combined. During deinking, some ink and specks invariably remain in the deinked pulp (Göttsching and Pakarinen 2000). Therefore, complementary methods are used to decrease the visible impact of specks.

Using disperser systems, the pulp will look like original pulp and in particular, the ink specks will be reduced so much that they will be invisible to the naked eye. The brightness and whiteness will decrease due to the dispersion of specks and ink particles as well. This is because the tiny ink particles and specks will cover a greater area and will absorb more radiation, resulting in lower brightness and whiteness. Furthermore, dispersion reduces not only the size of ink particles but also the size of stickies, waxes and covering substances (Kankaanpaa and Soini 2001; Holic 2006). Dispersion reduces the brightness, and if it is carried out in the presence of bleaching agents such as hydrogen peroxide, the decreasing of brightness will not be as great; if dispersion is followed by secondary flotation, brightness will be increased considerably (Ortner and Fisher 1990).

Flotation systems have been used to apply many chemicals for efficient removal of inks and others by optimizing the systems (Beneventi *et al.* 2009), controlling ink/fiber drainage in the froth phase (Zhu and Tan 2005; Beneventi *et al.* 2006), or using chemical additives (Beneventi *et al.* 2008). One of the important classes of chemicals in flotation process is surfactants. The multiple functions of surfactants (Zhao *et al.* 2004) are to release particles, aggregate dispersed particles and/or modify the surface properties of released particles, and improve the overall ink removal of a flotation line. The chemical structure of surfactants used for flotation deinking may differ significantly; they can be cationic, anionic, nonionic amphoteric. However, anionic fatty acids and nonionic surfactants are more commonly used. The hydrophile-lipophile balance value has gained acceptance in the paper industry for characterizing surfactants (Ferguson 1992). One of the most commonly used additives in the flotation deinking process is fatty acid. Generally, fatty acids react with calcium ions in the system to form calcium soaps with can absorb on to the ink surface and provide the collector action (Somasundaran *et al.* 1999).

Currently, computer printout is one of the types of paper which has least often been recycled. The main reason that computer printout is not often recycled is that it is difficult to collecting them from banks and the other institutes due to the legal and security concerns of customers. Nowadays most of the documents are recycled after passing their shelf life. Computer printout is usually gathered in two versions, the first version being printed by impact printers and the second one with lower proportion being printed by carbon paper as transferring paper. The appropriate strength properties and glossiness of computer paper, its special printing process, and their abundance make it necessary to use them for producing high-quality paper products. Most studies have been done on the effect of either dispersion or flotation on optical and mechanical properties of mixed wastepaper, although some researchers have mentioned the sequence of flotation-dispersion or flotation-dispersion-flotation as the most comprehensive deinking process (McBride1992). In order to combine dispersion and flotation, it was attempted in the present study (i) to eliminate the initial flotation because of the type of computer printout, and (ii) to use dispersion without oxidative bleaching agents at the initial stage after pulping by one-step washing and concentrating it to 30% consistency and then to use flotation as a complementary process. It seems that the optical and mechanical properties of deinked computer printout can be improved by this pattern in the new laboratorial design.

EXPERIMENTAL

Computer printout of the first and second version were separated, chopped, and kept under laboratorial conditions to allow their moisture to reach equilibrium with the surroundings. Then they were separately put in plastic bags to stop their moisture exchange with the environment. During application, the moisture of the ground samples was measured, and all calculations were based on the dry weight of the wastepaper. To do deinking tests, 20 g of paper scrap (on the basis of oven dry weight) was randomly taken from the plastic bag and was weighed with the precision of 0.0001 g.

Flotation was used in combination with dispersion in the present study. At the first phase, preliminary tests were run to check the increase in pulp brightness with the deinking process. Then, optimum conditions were selected to conduct final tests on the comparison and assessment of optical and mechanical properties.

NaOH was used as fiber swelling agent to create the conditions for deinking. An emulsion of fatty acid and a nonionic surfactant known as ethoxylate fatty acid was used as an ink particles collector agent, and $CaCO_3$ was used for lowering water hardness (Table 1).

Table 1. Conditions under Which the Treatments Were Applied

Research conditions	Time (min)	Temp °C	Consistency %	pH	NaOH (%)	$Ca(OH)_2$ %	Freeness (SR)	Water hardness (ppm)	Fatty acid (%)	Surfactant (%)
Pulping	3.5	45	7	7	-	-	-	-		
Dispersion	20	75	30	10.6-10.7	0.8	0.6	35	100-120	1	0.4
Flotation	15	45	1	9-9.5	0.8	0.6	35	100-120	1	0.4

Water hardness is based on calcium carbonate.
In primary experiments, fatty acid was designed at three levels (0.5, 1, and 1.5%) and surfactant at four levels (0, 0.2, 0.4, 0.6, and 0.8%) on the basis of oven weight of digital paper.

The pulping was carried out with a laboratorial mixer with slow rotation and 7% consistency at 45°C for 3.5 minutes. To do the dispersion process, the consistency of the pulp was increased to as high as 30% by a laboratorial screen with 80 ASTM mesh (0.18 mm holes). Then the pulp was dispersed with a single-axis laboratorial machine at 110 RPM. Firstly, the temperature of the concentrated pulp was increased to 75 °C, and the chemicals (including NaOH and emulsion of fatty acid and surfactant), which had been precisely calculated on the basis of wastepaper oven dry weight, were applied to the pulp. Then, the pulp was dispersed for 20 minutes with 30% consistency at 75°C and pH of 10.6 to 10.7.

After dispersing the pulp, for the flotation first the consistency was reduced by dilution water, and then the hardness was lowered with hydrated lime calculated on the basis of paper oven dry weight. The flotation was carried out using a laboratory flotation cell at 45°C at 1% pulp dryness, a pH of 9 to 9.5, and a total hardness of 100 to 120 ppm (on the basis of calcium carbonate) for 15 minutes. After flotation, the pulp was washed at three stages at 1% consistency and was washed with laboratorial screen with 80 ASTM mesh with the creation of vacuum. After preparing the paper pulp sample, handsheets with grammage of 60 g m^{-2} was prepared in accordance with TAPPI T205 om-88.

Afterwards, the data were analyzed, and the percentage of NaOH, fatty acid, surfactant and $Ca(OH)_2$ on the basis of 0.8, 1, 0.4, and 0.6% of wastepaper oven dry weight, respectively, was determined, the final tests were conducted with three replications with the following objectives:

- Deinking with and without dispersion to find its effect with 70:30% ratio of first and second versions of computer printout,
- Deinking with the mixture of 100% of computer printout with impact printer, and
- Deinking with the mixture of 100% of computer printout as transferring paper.

The brightness of handsheets papers was measured with Elerpho 2000 in accordance with the TAPPI standard method (T452 om-98). To find the amount of specks, the handmade papers were scanned and were processed with Digimizer (ver. 4.1.1.0) image analysis software package. This software is used for precise measurement of the specks on scanned images of the papers. The area of specks with the size of >0.04 mm as compared to a specific area of the handmade papers was measured with this software package.

Mechanical properties were determined in according to TAPPI standard methods and the relevant guidelines. These properties included paper basic weight (T410 om-88), dry tensile index (T456 om-10), bursting index (T403 om-91), tearing resistance index (T414 om-04), and breaking length (T320 om-88).

The data were statistically tested with the analysis of variance based on a Completely Randomized Design, and the means were grouped by Duncan Multiple Range Test with SPSS software package at the 95% significance level.

RESULTS AND DISCUSSION

Preliminary Results

To find the best deinking conditions for the dispersion and flotation processes, tests were first run by changing the deinking chemicals, fatty acid and surfactant (ethoxylate fatty acid) without dispersion. Statistical analysis revealed significant differences among the preliminary treatments in terms of the application ratio of fatty acid and surfactant for improving the brightness of wastepaper during deinking. Higher brightness of deinked computer printout was obtained when using higher dosages of fatty acid. The application of surfactant to a certain dose of fatty acid increased brightness, but as the dose of surfactant was increased, the rate of the increase in brightness decreased (Fig. 1: based on Mean ±S.D). The fatty acid and surfactant are expensive, and the level of 1% fatty acid and 0.4% surfactant were selected based on the final quality and economical aspects, as shown in Fig. 1. When the consumption rates of surfactant increased, the increasing of fatty acid showed a curved behavior. At first with the increasing of fatty acid, the brightness went up, and with the further consumption of it, the brightness decreased little by little.

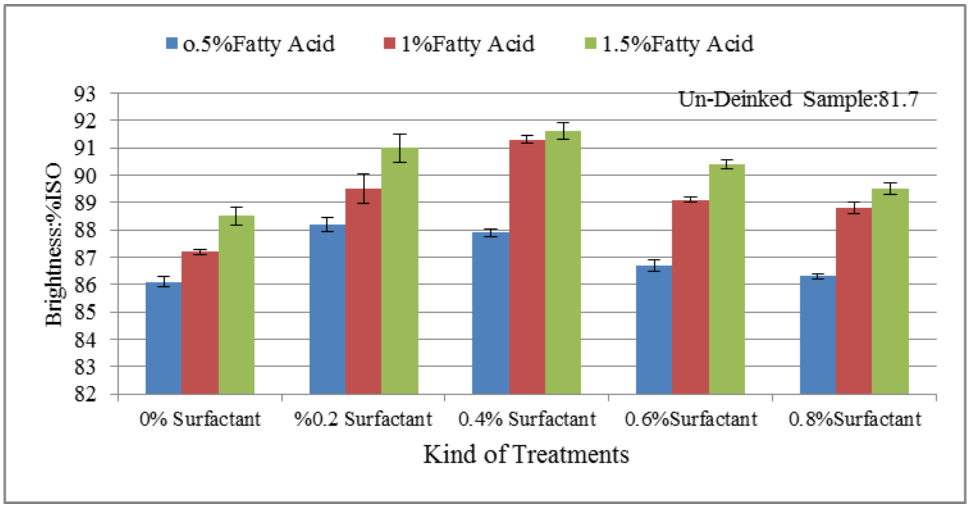


Fig. 1. The interaction effect of fatty acid and surfactant on the brightness improvement in preliminary tests

Final Results

To find the strength properties of deinked pulp of computer printout, the appropriate treatment of dispersion and flotation with 1% fatty acid and 0.4% surfactant was selected, given the appropriate brightness, economy scale, and suitable process control. The effect of dispersion with flotation process on optical and mechanical properties of deinked pulp was studied in comparison with single flotation process. Undeinked pulp and unprinted computer printout pulp were studied and compared to specify the effect of deinking process on optical and mechanical properties of fibers.

Effect of Dispersion and Deinking on Mechanical Properties of Computer Printout

Bursting strength varied in the range of 2.8 Kpa.m^2/g for deinked pulp without dispersion to 3.4 Kpa.m^2/g for unprinted paper pulp. Duncan grouping at the 95% level showed four different groups of the means (Fig. 2a).

The tearing resistance of computer printout samples with Duncan grouping is presented in Fig. 2b. The lowest tear resistance was related to deinked pulp without dispersion, and the highest one to undeinked pulp (Fig. 2b).

According to means comparison, the measurement of tensile resistance showed that deinked pulp without dispersion had the lowest strength and unprinted pulp had the highest strength (Fig. 2 c,d).

The application of chemicals in the process of dispersion with deinking and deinking without dispersion resulted in lower resistance to bursting, tearing, and tensile strength and breaking length as compared to undeinked or unprinted handsheets. Pala *et al.* (2006) stated that chemical treatment of mixed office waste increases the burst and tensile indexes and decreasing the tear resistance. Many variables as pH level, the swelling ability of sodium hydroxide and amount of chemicals play a role in chemical treatment.

In the process of dispersion with deinking as compared to deinking without dispersion, the mechanical strength of the handsheets was increased. Seemingly, suitable dispersion removes the unwanted particles that can interfere with the bonding ability between fibers and forms a homogenous texture improving the mechanical resistance. McKinney (1995) stated that dispersion and kneading of pulp with a high speed can substitute pulp processing because they can improve the mechanical properties of paper. Furthermore, Kankaanpaa and Soini (2001) described the effect of dispersion similar to the effect of refining and stated that dispersion increased tensile resistance.

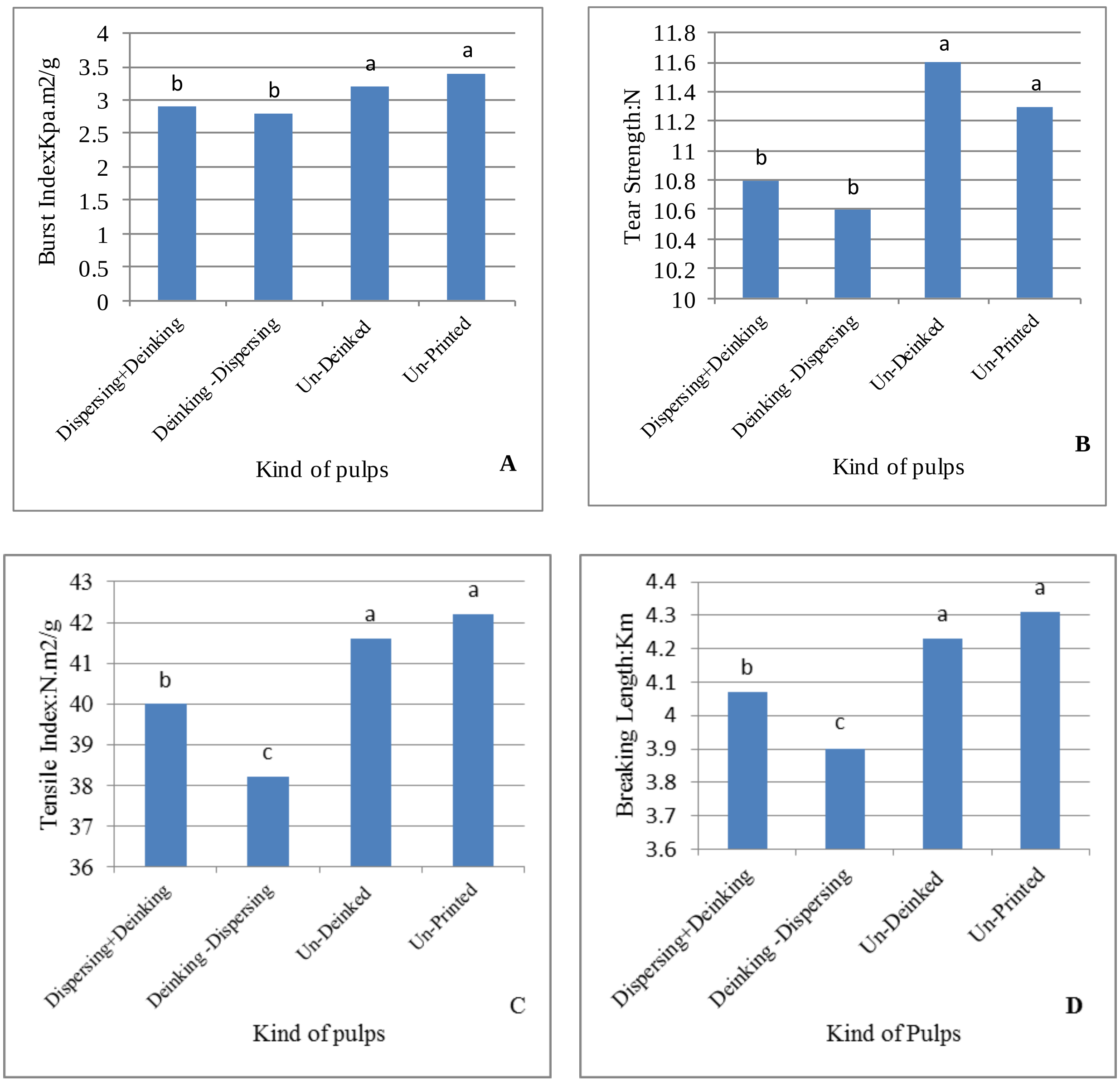


Fig. 2. Effect of different treatments on mechanical properties of laboratorial handsheets

Effect of Dispersion and Deinking on Optical Properties of Computer Printout

In most studies, dispersion is carried out after flotation. Therefore, the findings regarding the loss of brightness and the increase in tiny ink specks in pulp is associated with the research methodology. In the present study, using a disperser before flotation allowed more suitable efficiency for flotation cells, which naturally led to higher brightness and lower number of specks in final handsheets. As can be seen in Fig. 3 a,b, the use of dispersion before deinking improved the brightness and reduced the percentage of ink specks on handsheets (Gao *et al.* 2012). However, researchers have related the loss of brightness during dispersion to the reduction of specks size. In the present study, since dispersion was run before flotation, the brightness was increased.

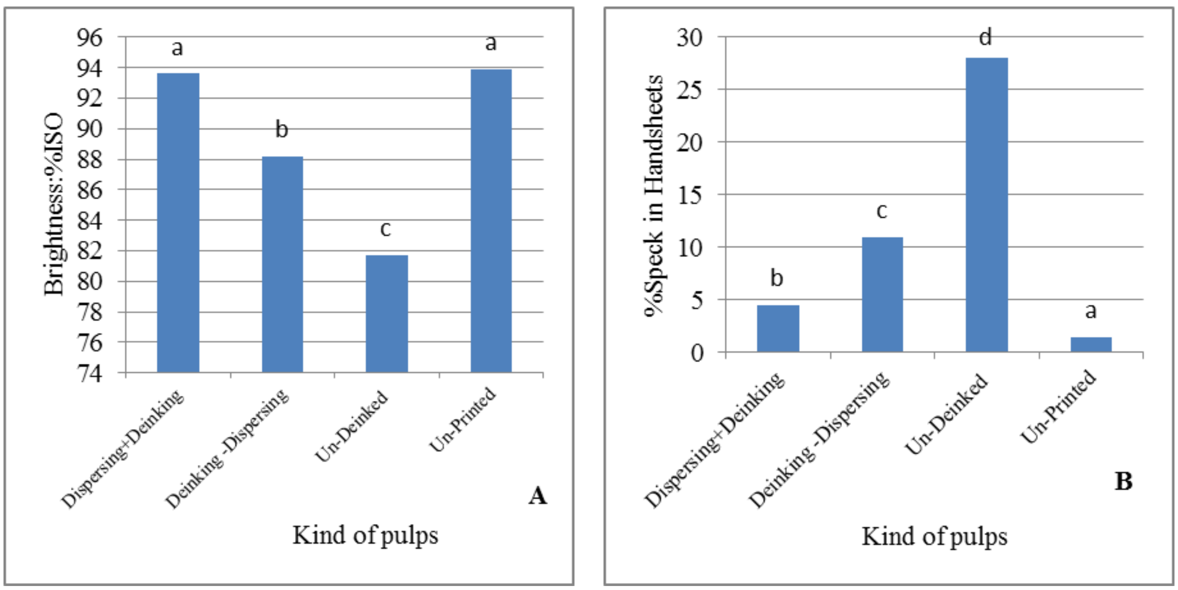
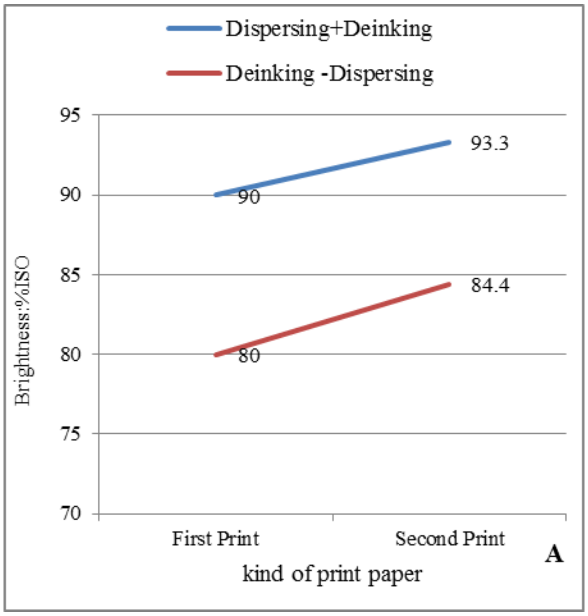


Fig. 3. Effect of different treatments on brightness (A) and speck percentage (B) in laboratorial hand sheets

As is evident in Fig. 3, deinking by a dispersion process before flotation significantly affected the increase in brightness and the decrease in the number of ink specks in the pulp. The brightness of pulp was 3.8%ISO higher in deinking with a dispersion process than in deinking without a dispersion process. Dispersion with further dispersion of ink specks improves the efficiency of flotation (Sarja *et al.* 2007; Ruzinsky *et al.* 2003, 2007). Dispersion without hydrogen peroxide can reduce brightness by 4.2 units and with peroxide hydrogen increase the brightness by 2.7% ISO (Ortner and Fisher 1990). However, since it preceded flotation in the present study, it increased the brightness even without the usage of hydrogen peroxide.

The results of the study and the comparison of the effect of deinking on the first version (printed by impact printers) and second version (printed due to transferring paper) of wastepaper under similar deinking conditions with dispersion and flotation process using a furnish containing 100% of first version and 100% of the second version and the percentages of chemicals presented in Table 2, revealed that the brightness of first-version paper pulp increased by 10 % ISO during deinking (from 80 % ISO in undeinked pulp to 90 % ISO in deinked pulp), whereas the brightness of deinked pulp of the second-version paper was increased by 8.9 % ISO (from 84.4 % ISO in undeinked pulp to 93.3% ISO in deinked pulp). Based on results the percentage of specks area decreased 6.54% and 5.8 % in first and second print version using dispersion with flotation in comparison to flotation without primary dispersion.



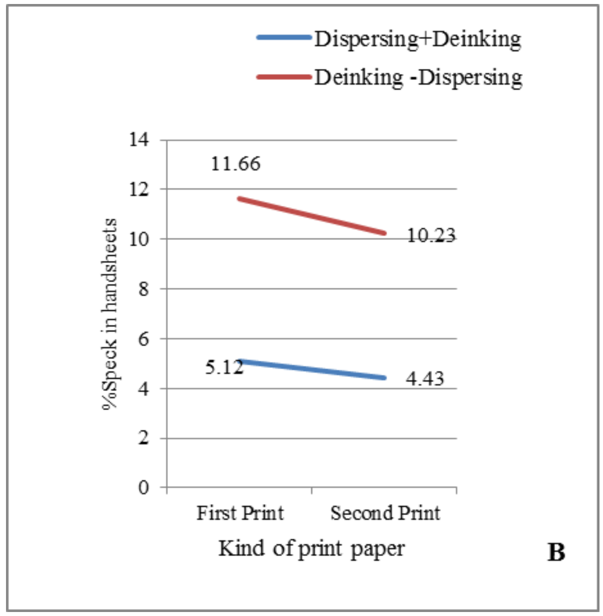


Fig. 4. Effect of two kinds of treatments on brightness and speck percentage in two kinds of computer print out

CONCLUSIONS

1. It was found that the dispersion of pulp significantly increased the efficiency of flotation improved the brightness and reduced the number of ink specks in pulp. For the systems in which flotation alone is applied, the brightness may be reduced because of the presence of tinier ink specks. But, dispersion with flotation sequence increased the brightness.
2. The brightness of deinked pulp of first version paper was 4.4% lower than that of undeinked paper of second version paper despite the fact that the volume of the print of both types of pulps was similar. In spite of quite great loss of brightness ratio of first version paper during deinking, the brightness of first version paper pulp was 1.6 % higher than that of the second version paper pulp because the carrier of pigments on a printer ribbon are fatty acid oils a part of which is transferred on the fiber surface during printing. Since deinking process involves alkaline medium, the fatty acid oils become soapy, facilitating the separation of print specks.
3. Despite the drop in mechanical strength of recycled computer printout, the recycled pulp can still be expected to be used for producing high-quality papers. If recycled

computer printout is used for producing recycled pulp, the oxidative bleaching stage can be eliminated according to the results of the present study.

ACKNOWLEDGMENTS

The author appreciates the financial support provided by Islamic Azad University, Karaj Branch, Karaj, IRAN.

REFERENCES CITED

Bajpai, P. K. (2010). "Solving the problems of recycled fiber processing with enzymes," *BioResources* 5(2), 1-15.

Beneventi, D., Rousset, X., and Zeno, E. (2006). "Modelling transport phenomena in a flotation de-inking column: Focus on gas flow, pulp and froth retention time," *Int. J. Mineral Process* 80, 43-57.

Beneventi, D., Allix, J., Zeno, E., and Nortier, P. (2008). "Influence of surfactant concentration on the ink removal selectivity in a laboratory flotation column," *Int. J .Mineral Process* 87, 134-140.

Beneventi, D., Zeno, E., Nortier, P., Carre, B., and Dorris, G. (2009). "Optimization and Management of flotation deinking banks by process simulation," *Ind. Eng. Chem. Res*. 48, 3964-3972.

Bolanča, M. I., and Bolanča, Z. (2004). "Chemical and enzymatic deinking flotation of digital prints," *4th International Conference Industrial Engineering-New Challenges to SME*.

Ferguson, L. D. (1992). "Deinking chemistry: Part 1," *TAPPI Journal* 7575-7583.

Gao, Y., Qin, M., Yu, H., and Zhang, F. (2012). "Effect of heat-dispersing on stickies and their removal in post-flotation," *BioResources* 7(1), 1324-1336.

Göttsching, L., and Pakarinen, H. (2000). *Recycled Fiber and Deinking*, Jyväskylä, Gummerus Printing, Finland.

Holik, H. (2006). *Handbook of Paper and Board*, Wiley-VCH Verlag GmbH and CO. KGaA, Weinhiem, P.467-474.

Kankaanpaa, V., and Soini, P. (2001). "Approach to the conical dispersion and refining of recycled fiber," Fiber and paper, 3(3), 42-45.

McBride, D. (1992). "High-deinking kneading system offers alternative to conventional deinking," *Pulp and Paper Canada* 149-152.

McKinney, R. W. L. (ed.), (1995). *Technology of Paper Recycling*, Springer.

Ortner, H., and Fischer, S. (1990). "The application of dispersion for quality improvement of deinked pulps," *Proceedings of Pulping Conference*, USA.

Pala, H., Mota, M., and Gama, F. M. (2006). "Factors influencing MOW deinking: Laboratory scale studies," *Enzyme and Microbial Technology* 38, 81-87.

Pathak, P., Bhardwa, N. K., and Singh, A. K. (2011). "Optimization of chemical and enzymatic deinking of photocopier waste paper," *BioResources* 6(1), 447-463.

Ruzinsky, F., Wang, M. H., and Bennington, C. P. J. (2003). “Characterizing dispersion in newsprint deinking operations,” *Pulp and Paper Canada* 104(8), 30-35.

Ruzinsky, F., Zhao, H., and Bennington, C. P. (2007). “Characterizing ink dispersion in newsprint deinking operations using specific edge load,” *Appita Journal* 60(1), 23.

Sarja, T., McNeil, D., Huber, P., and Niinimaki, J. (2007). “Removal of stickies in flotation,” *Progress in Paper Recycling* 16(3), 5-11.

Somasundaran, P., Zhang, L., Krishna Kumar, S., and Slepetys, R. (1999). “Flotation deinking – A review of the principles and techniques,” *Progress in Paper Recycling* 8(3), 24-36.

Zhao, Y., Deng, Y., and Zhu, J. Y. (2004). “Roles of surfactants in flotation deinking,” *Progress in Paper Recycling* 14(1), 41-45.

Zhu, Y., and Tan, F. (2005). “Dynamic drainage of froth with wood fibers,” *Ind. Eng. Chem. Res*. 44, 3336-3342.

Article submitted: December 18, 2015; Peer review completed: August 23, 2016; Revised version received and accepted: October 20, 2016; Published: December 5, 2016.