Advances in Bioresearch
Adv. Biores., Vol 6 (5) September 2015: 204-210
©2015 Society of Education, India
Print ISSN 0976-4585; Online ISSN 2277-1573
Journal's URL:http://www.soeagra.com/abr.html
CODEN: ABRDC3
ICV 7.20 [Poland]

Advances in Bioresearch

ORIGINAL ARTICLE

The Impact of Furnish Type and Chemical Dosage on the Optical Properties of Recycled Paper

Shademan Pourmousa
Department of Wood and Paper Science and Technology, College of Agriculture and Natural resources, Karaj Branch, Islamic Azad University, Karaj, Iran.
Corresponding Author: Sh.Pourmousa@gmail.com or, Sh.Pourmousa@kiau.ac.ir

ABSTRACT
The present study focused on how the appearance and optical properties of deinked recycled paper were affected by different raw materials (such as chemical and mechanical waste paper sorted), as well as by the dosages of the deinking and bleaching chemicals. In the laboratory, a flotation deinking and bleaching system was used. The results indicated that, according to the brightness and dirt index, the optimum condition to achieve 95% chemical waste paper + 5% mechanical waste paper is the application of a flotation and bleaching chemical composed of 0.5% NaOH + 0.5% H_2O_2. The specific conditions for the combination of 90% chemical and 10% mechanical waste paper are flotation with a composition of 0.5%NaOH + 0.5%H_2O_2 and bleaching with a composition of 0.5% NaOH + 1% H_2O_2. The optimum combination level for solutions of 85% chemical + 15% mechanical waste paper was found to have a flotation composition of 1%NaOH +1%H_2O_2 and bleaching composition of 0.5%NaOH +0.5%H_2O. The optimum combination level for 80% chemical + 20% mechanical waste paper was found to be flotation with a composition of 1% NaOH + 1% H_2O_2 and bleaching of 1% NaOH + 1% H_2O_2.With increasing of mechanical waste paper ratio in furnishes, the flotation and bleaching should be applied with higher consumption of chemicals. The other combinations of these furnishes can be applied to products with lower brightness and upper degree of dirt index.
***Keywords**: Chemical Waste paper ; Mechanical waste paper; Chemical dosage; Optical properties.*

Received 12.04.2015 Accepted 07.09.2015

How to cite this article:
Shademan Pourmousa. The Impact of Furnish Type and Chemical Dosage on the Optical Properties of Recycled Paper. Adv. Biores., Vol 6 [5] September 2015:204-210**.** DOI: 10.15515/abr.0976-4585.6.5.204210

INTRODUCTION

The steady and continuing efforts to preserve forest resources, as well as to reduce the cost of municipal waste disposal, have sparked an increase in the recovery of waste papers and their utilization in paper production. Consequently, recycled paper has become an important source of fibers in the development of papermaking [1-4] **.** Furthermore; the application of recycled paper provides both environmental and operational benefits, compared to the cost of virgin pulp production. Pulp production from recycled paper requires less energy and fewer chemicals compared to the production of an equivalent volume of virgin pulp [5].

Paper recycling to produce deinked pulp consists of three main unit operations: pulping, flotation deinking, and bleaching. First, the recycled paper should be slushed in water to produce a uniform fiber suspension, with the ink and dirt particles dispersed as much as possible. The chemicals are added to the pulper to prepare the pulp for flotation deinking. Then, during the flotation deinking stage, the ink particles are separated from the suspension. An increase in the pulp brightness, coupled with an elimination of ink particles, takes place during the deinking stage [5]. Even though the unit operation in the deinking system seems simple, many factors, such as fiber furnish type and chemical management; impart significant effects on the performance of the system.

Different research groups have studied the effect of the furnish type, chemicals, and deinking process parameters on the quality of the final deinked pulp[6-17]. In this respect, different chemicals (H_2O_2, NaOH, Na_2SiO_3, soaps, *etc.*) are injected either into the flotation cell or at other points up to the bleaching stage. However, in newer systems, chemicals are added during the dispersing and bleaching stages.

Recently, there has been a rapid increase in the utilization of prime quality recycled paper. Consequently, the shortage of such recycled papers has forced the papermaking industry to divert its raw material chain toward mixed recycled paper that contains both chemical and mechanical fibers, which exhibit different behaviors during the deinking and bleaching phase. The new systems and equipment have facilitated the processing of the mixed recycled paper; however, many machines fail to reach an appropriate combination of furnish type and chemical dosages. Furthermore, the additional points necessary to achieve the best results and overcome operation obstacles are still lacking. In such practices, two additional points are usually used in hydrogen peroxide injections: one procedure is based on split hydrogen peroxide addition used in both before flotation and bleaching, and in the second procedure, hydrogen peroxide is added in the final bleaching stage. Each procedure has advantages and disadvantages. If hydrogen peroxide is added at prior to flotation, the machinery is safer and the shives content of the pulp is lower. Additionally, the pulp's yellowness is strongly controlled, but chemical consumption will be higher compared to the procedure in which hydrogen peroxide was added during the bleaching stage. The weaknesses of the second procedure lay in the difficulties in controlling the brightness, as well the reduction of the fine dirt particles in the final pulp. When a higher portion of the mechanical waste paper is used, obtaining a higher degree of brightness becomes increasingly more difficult.

Therefore, the objective of this research was aimed at finding a suitable solution to the utilization of mixed recycled paper, including the combination of chemical and mechanical recycled papers, which suggest the appropriate dosages of the chemicals and the injection points in the process. Based on the laboratory scale of results, the researchers can propose the optimization solution for applied goals.

MATERIAL AND METHODS

The recycled papers containing mechanical (MWP) and chemical waste papers (CWP) were collected from a local tissue paper producing company, operating its own deinking plant. Five different combinations of the recycled papers were prepared, as defined in Table 1. All of the chemicals used were industrial grade and supplied by the local tissue producing company.

Table 1. Deinking Furnish Composite and Related Optical Mixture Properties as control samples

Item	CWP (%)	MWP (%)	Brightness (%)	Yellowness (%)	Dirt index loop evaluation
1	95	5	81.44[a]	-28.84[a]	13
2	90	10	79.92[b]	-21.40[b]	12
3	85	15	71.82[c]	-12.34[c]	11
4	80	20	65.28[d]	-7.02[d]	10
5	75	25	61.24[e]	-1.34[e]	10

First, each furnish mixture was slushed in tap water and mixed for 4 min at 5% consistency using a laboratory pulper. The pulping temperature was 45 °C, and the associated pH level was 6.8 to 7.3 (Table 2). After the slush, the suspension was discharged into a plastic container, and the required chemicals were added to the suspension. The suspension was left at an ambient temperature for 30 min prior to flotation to allow the chemicals to react.

The flotation deinking process was carried out using a laboratory flotation cell. The flotation parameters and chemical dosages are shown in Table 2. As the froth gathered, it was carefully collected from the top of the flotation using a special low flow and low-pressure pump. Flotation was followed by a washing stage at 1% consistency, using a 120 mesh screen and fresh tap water. Four different chemical charges were used for each chemical strategy (Table 2).

The washed, deinked pulp was bleached in a thermally controlled container (bleaching conditions outlined in Table 2), and the bleached pulp was thoroughly washed with tap water. Finally, the pulp was manually dewatered, stored in plastic bags, and refrigerated until used for hand sheet preparation. Three replications were conducted for each pulping, deinking, and bleaching trial. Each kind of pulps that combined different chemical and mechanical waste paper ratio, deinked through one of flotation condition. After sampling and recognizing the optical properties of hansheets, all of the bleaching treatments were run separately after each flotation and the hand sheets tested.

Table 2. Pulping, Deinking, and Bleaching Process Variables

Process variables / Unit operation	H_2O_2 (%)*	NaOH (%)*	DTPA (%)*	Temp. (°C)	Cons. (%)	Time (min.)	pH
Pulping	-	-	-	45	5	5	6.8-7.3
Flotation: F1	0	0.5	-	40-45	1	15	9-9.2
Flotation: F2	0.5	0.5	0.3	40-45	1	15	9-9.2
Flotation :F3	0	1	-	40-45	1	15	9-9.2
Flotation :F4	1	1	0.3	40-45	1	15	9-9.2
Bleaching :B1	0.5	0.5	-	75-80	25	40-45	11-11.2
Bleaching :B2	1	0.5	0.3	75-80	25	40-45	11-11.2
Bleaching :B3	0.5	1	-	75-80	25	40-45	11-11.2
Bleaching :B4	1	1	0.3	75-80	25	40-45	11-11.2

*Based on oven dry weight of the paper; 1% Na_2SiO_3 was applied in all deinking and bleaching trails; 0.7% soap was used in all deinking and bleaching trails.

Handsheets of 60 g/m^2 were prepared during each stage of pulping, deinking, and bleaching. Replication was conducted according to TAPPI test method 205.om-88. Handsheets were stored at 65% relative humidity and 21 °C prior to testing.

The brightness and yellowness of the hand sheets were measured as defined in the TAPPI standard test method T452.om-98. The dirt index was evaluated using the loop mechanism as a quality method, on a scale ranging from zero (worst) to 20 (best). Three measurements were done for each property, and the average was recorded.

ANOVA analysis was used to determine the impact of the variables on the measured properties. All statistical tests were conducted at a confidence level of 95%. In case a difference was observed between the averages, the Duncan Multiple Range Test was used to group the averages.

RESULTS AND DISCUSSION

Paper recycling, particularly the deinking of recycled papers, necessitates the application of papers containing higher percentages of mechanical fibers, especially in tissue production. Of course, the utilization of such fibers both imposes restrictions and provides advantages. The water absorption capacity of mechanical fibers is superior to that of chemical fibers, which helps to improve the absorption capacity of the final product. However, the brightness of mechanical fibers is usually low (Table 1) and to reach the required brightness in the final product, mechanical fibers become harder to bleach. Therefore, more bleaching chemicals are needed.

Hydrogen peroxide is most the common bleaching agent used in the prior and final bleaching of deinked pulp. When subjected to alkaline conditions, hydrogen peroxide decomposes and generates perhydroxyl anions (HOO^-), which are the active agents in the bleaching process and in turn increase the brightness of the mechanical fibers. However, the additional charge of the hydroxide peroxide will minimize the effectiveness of the chemical, and the final brightness may decrease. Therefore to reach the required efficiency of hydrogen peroxide at the bleaching stage, precautions must be implemented to find the appropriate chemical dosages [18]. The use of stabilizers such as DTPA, capable of inhibiting the decomposition of Hydroxide peroxide compounds cased the brightness of waste paper pulp to increase [11]. Alkaline additives, especially sodium hydroxide are common chemicals for repulping and deinking of waste paper. Sodium hydroxide improves the swelling of fiber, saponifying and dissolving the carrier parts of ink and pigments easily release from fiber [17]. The injection of hydrogen peroxide to flotation cell increase the brightness, improve the yellowness and decrease the ink dirt on hand sheets.

Figures 1 to 5 show the results of different deinking and bleaching trials as applied to different combinations of recycled paper furnishes. First, the recycled pulps were deinked, applying the chemicals and conditions mentioned in Table 2 (Figs. 1 to 3 based on Averages±SD). Then, the deinked pulps were bleached, using the conditions specified in Table 2 (Figures 4 to 6). The results indicated that as the ratio of mechanical papers in the deinking furnish increased, brightness of the deinked and bleached pulp decreased. However, for any given furnish, if the hydrogen peroxide was charged in the flotation cell, a higher brightness level was reached. Additionally, if a higher charge of combined deinking and bleaching chemicals was added to the recycled paper, 1% NaOH + 1% H_2O_2 compared to conditions of 0.5% NaOH +0.5% H_2O_2), a higher brightness level was achieved.

The optimum brightness of deinked pulp to be used for facial tissue production is approximately 88%-90% ISO. The initial brightness for 95% chemically recycled paper is usually high and near to acceptable. Therefore in this particular case, the bleaching ought to eliminate the darkening caused by the ink.

However, the critical point for determining the optimum dosages of chemicals is related to the elimination of dirt, ink, and other fine contaminants.

As the ratio of mechanical papers to furnish increased, the initial brightness of the pulp suspension was reduced (Table 1), and the combination of hydrogen peroxide and sodium hydroxide at both the floatation and bleaching stages improved final brightness. When the ratio of mechanical paper was increased to 20%, the final brightness of the produced pulp, regardless of any additional chemical combinations, did not improve the brightness of the bleached pulp to the degree required for facial tissue. However, such pulp can be used for lower grade products, such as toilet paper.

The applied deinking and bleaching conditions improved the yellowness of the final pulps, and with higher dosages of hydrogen peroxide, yellowness was more diminished. However, when hydrogen peroxide consumption exceeded a certain level, the yellowness of the final products decreased because of more alkaline conditions and alkali darkening [19]. Lignin is sensitive to higher pH, and since mechanical paper contains more lignin than does chemical paper, furnishes containing high ratios of mechanical pulps can be extremely vulnerable to alkali darkening. However, with increasing dosages of hydrogen peroxide, the yellowness of furnishes with 100% chemical papers was improved (Figure 2 and 5).

The limits of yellowness for tissue products generally range from -13 to -16 % ISO. Therefore based on industrial practices, furnishes containing more than 15% mechanical paper will not meet the requirement, and higher dosages of chemicals must be applied.

Dirt and specks are the major contaminants that cause adverse effects to the quality of tissue products. Therefore, in any deinking and bleaching process for re-use of recycled paper, the elimination of these undesired contaminants and improvement in the appearance of the final product is essential. The dirt count showed that after deinking, the residual pigments and ink particles still remained in furnishes. Sodium hydroxide is used to reduce the bonding strength between fibers and inks, as well as to separate ink particles from fibers. A higher charge of sodium hydroxide peroxide breaks the ink particles into smaller sizes. The dirt index was evaluated here using a quality control method called the loop mechanism; therefore, a statistical analysis of the treatments was not done. In this method, the deinking was considered efficient if the treatment scored above a 20 in terms of quality evaluation.

The governing factors of accepting the appearance of a product produced using waste paper are the combination of suitable brightness and the dirt index. The yellowness measurement showed that due to the presence of lignin in the mechanical paper, the yellowness of the final products was at an acceptable level. Of course, this property can be affected by unbalanced chemical usage. However, applying flotation and bleaching chemicals with a composition of 0.5% NaOH + 0.5% H_2O_2 would achieve optimized conditions for the brightness and dirt index of 95% chemical + 5% mechanical waste paper. The proper condition for the combination of 90% chemical +10% mechanical waste paper is flotation with a composition of 0.5% NaOH + 0.5% H_2O_2 and bleaching with a combination of 0.5% NaOH + 1%H_2O_2. The optimum combination level for 85% chemical + 15% mechanical waste paper was found to be flotation with a composition of 1% NaOH + 1% H_2O_2 and bleaching of 0.5% NaOH + 0.5% H_2O_2. The combinations of the other furnishes cannot be applied for facial tissue products because of lowered brightness and an unacceptable degree of dirt index. This investigation proposed that these furnishes should be used as toilet paper or other colored products (Figs. 3 and 6). In Table 3, the suitable combination of chemical usages and the kind of waste papers are shown.

Table 3. Recommended Combination of Chemical Dosages and Furnishes to Produce Deinked Pulp for Tissue Paper Production

Furnish	Dirt index	Brightness	Yellowness	Recommendation
95%CWP+5% MWP	(F_2B_1 –B_4, F_3B_3-B_4, F_4, F_4B_1-B_4)	OK		F_3B_3 is suitable as economically aspects.
90% CWP +10% MWP	(F_2B_2, F_2B_4)	OK		F_2B_2 is suitable
85% CWP +15% MWP	(F_4B_3, F_4B_4)	OK		F_4B_3 is suitable
80% CWP +20% MWP	(F_2B_4, F_4B_4)	NOK	NOK	F_2B_4 and production of color products
75% CWP +25% MWP	F_2B_2, F_4B_1, F_4B_4	NOK	NOK	

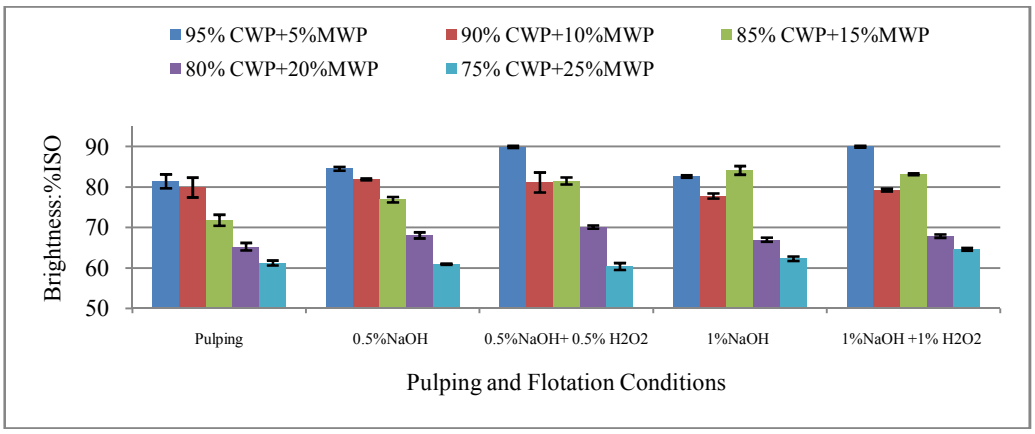

Fig. 1. Influence of the furnish type and chemical dosage on the brightness of the deinked pulp after flotation

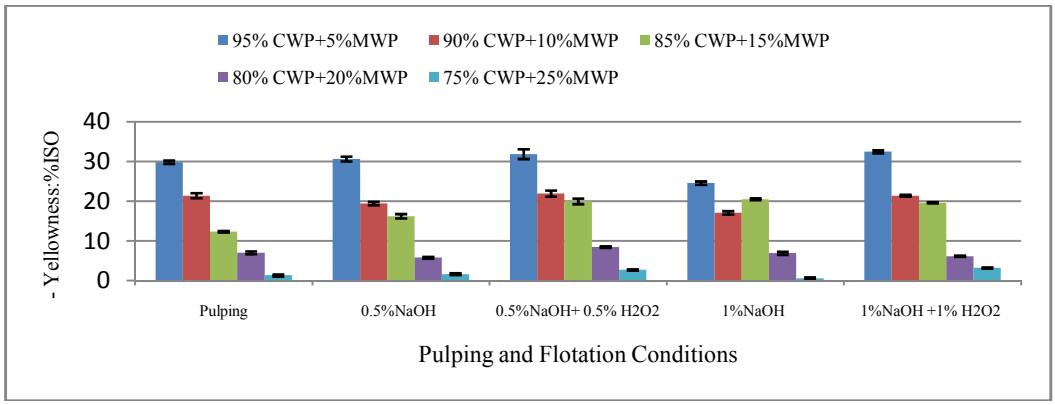

Fig. 2. Influence of the furnish type and chemical dosage on the yellowness of the deinked pulp after flotation

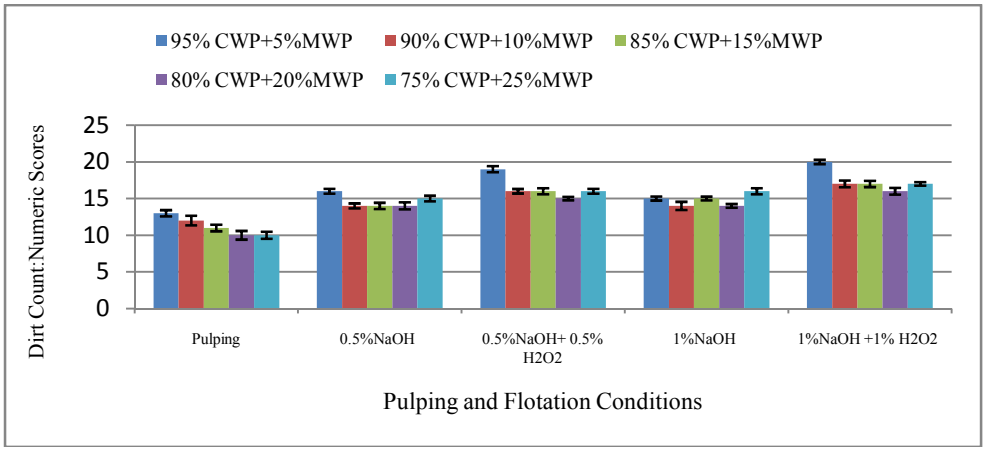

Fig. 3. Influence of the furnish type and chemical dosage on the dirt count of the deinked pulp after flotation

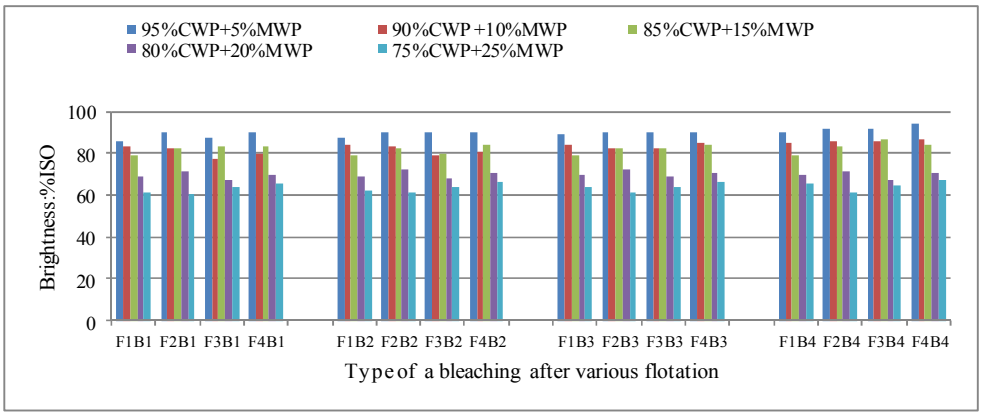

Fig. 4. Influence of the furnish type and chemical dosage on the brightness of the deinked pulp after special flotation

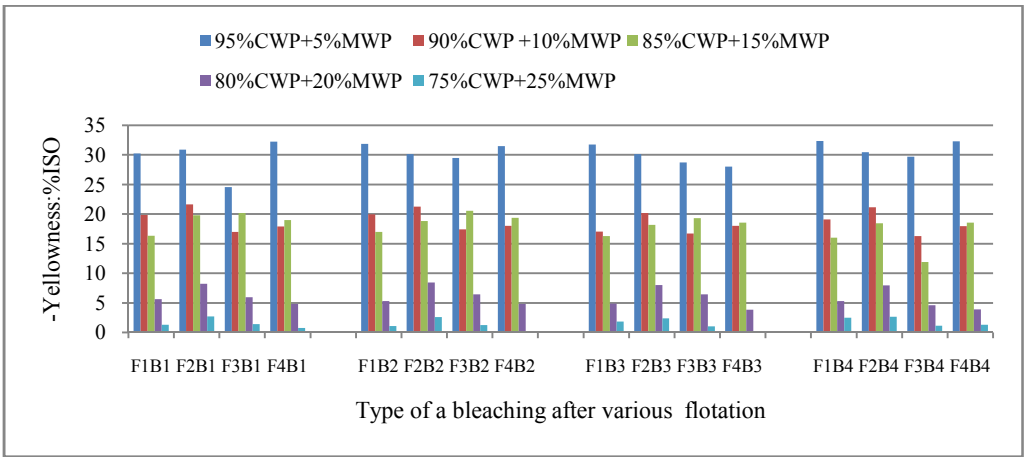

Fig. 5. Influence of the furnish type and chemical dosage on the yellowness of the deinked pulp after special flotation

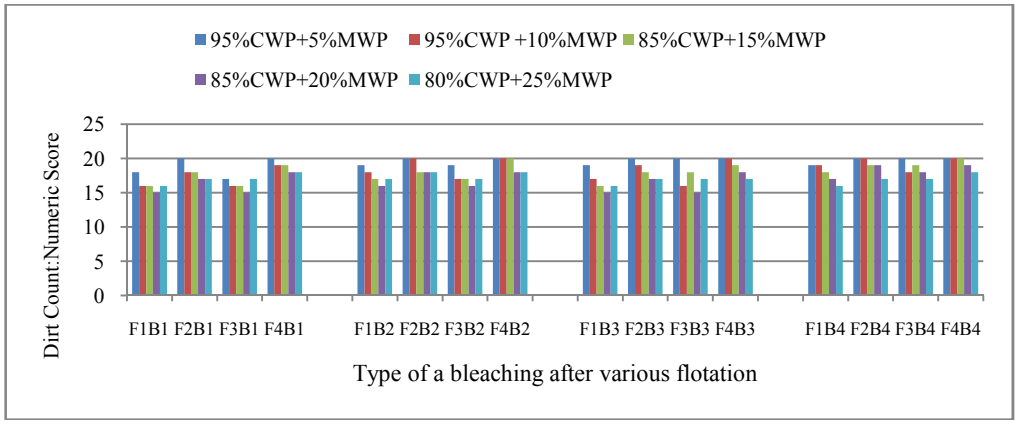

Fig. 6. Influence of the furnish type and chemical dosage on the dirt count of the deinked pulp after special flotation

CONCLUSIONS

The economic and environmental aspects of recycled paper deinking and bleaching emphasize a lower consumption of alkali and other chemicals. Otherwise, the higher mass of the cell walls would be dissolved, which would result in a lower yield and higher pollution load in plant effluent. The types of furnish and dosages of chemicals are critical during flotation deinking. If suitable combinations of furnishes and chemicals are applied, then the best outcome, both in quality and cost, will be reached. The types of furnish and dosages of chemicals affected the substance's overall brightness and yellowness. The

combination of brightness and dirt count are factors that influence the acceptance of facial tissue products. However, for the production of color products, neither of these factors is important. When the mechanical waste paper ratio exceed at furnish, for reaching the higher brightness and lower dirt count should be increased the chemicals at flotation and bleaching stages. The produced materials reached optimum quality after flotation with 0.5% NaOH + 0.5% H_2O_2 and bleaching with a composition of 0.5% NaOH + 0.5% H_2O_2. Flotation with 1% NaOH + 1% H_2O_2 may also be used alone for 95% chemical +5%mechanical waste papers. For other furnishes, the presence of hydrogen peroxide during the pulping and bleaching stages was necessary. The author proposed the extended bleaching idea for pulping or flotation stage and bleaching area. Meanwhile the considering secondary flotation cell after the bleaching stage can be affective at increasing the brightness and decreasing the dirt count [20]. Applying the disperser technology combined the secondary flotation [21-22].

ACKNOWLEDGMENTS

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

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