Research paper

# Effects of White Water Recirculation on the Performance of Optical Brightening Agents

Yuan-Shing Perng,[1) I-Chen Wang,[2,4) Meng-Kuan Hsiao,[1) William Hao-San Huang[3)

## 【Summary】

In this study, we investigated the effects of the number of white water recirculation rounds on the whitening performance of added optical brightening agents (OBAs). The results could be useful in practical mill application to determine the variability estimates when using OBAs in printing and writing paper production. The variables of this study included OBA types [disulfo-OBA (2S-OBA) and tetrasulfo-OBA (4S-OBA)], dosage (0, 0.3, 0.6, 1.2, and 2.4% of the dry pulp), and the number of white water recirculation (0~7) rounds. The particle charge (PCD), pH, OBA retention, etc. of the white water samples were tested. The brightness, apparent whiteness, and ash content of the handsheets prepared from each round were tested. Results of this study indicated that during the stock preparation process, the bleached hardwood kraft pulp (BHKP) and calcium carbonate filler did not notably affect the electrical charge of white water; while the addition of OBA and cationic starch modified the white water charge balance. The addition of 4S-OBA significantly influenced the PCD; while the effect of adding 2S-OBA was less significant. Adding either OBAs had no appreciable effect on the white water pH value. In the 2S-OBA group, the OBA dosage and number of white water recirculation rounds had little effect on the PCD of the white water; whereas in the 4S-OBA experimental group, with an increasing dosage and number of white water recirculation rounds, the PCD moved toward more-negative charges. The recirculation retention rates of the 2S-OBA and ash (filler) increased with its dosage and the number of white water recirculation rounds; those of the 4S-OBA, however, decreased with increasing dosage and number of white water recirculation rounds. Under the same dosage, the 4S-OBA tended to have a better whitening effect than the 2S-OBA. Also, the tonal stability of the 4S-OBA was superior to that of the 2S-OBA.

**Key words:** optical brightening agents, white water recirculation, whiteness, brightness, effect on whiteness.

**Perng YS, Wang IC, Hsiao MK, Huang HS. 2010.** Effects of white water recirculation on the performance of optical brightening agents. Taiwan J For Sci 25(4):277-90.

---

[1) Department of Environmental Engineering, Dayeh University, 168 University Rd., Datsuen, Changhwa 51591, Taiwan. 大葉大學環工系，51591彰化縣大村鄉學府路168號。

[2) Division of Wood Cellulose, Taiwan Forestry Research Institute, 53 Nanhai Rd., Taipei 10066, Taiwan. 林業試驗所木材纖維系，10066台北市南海路53號。

[3) TFM International Co., Ltd., 84 Minzhu West Rd., Taipei 10365 Taiwan. 德豐銘國際股份有限公司，10365台北市民族西路84號。

[4) Corresponding author, e-mail:iwang@tfri.gov.tw 通訊作者。

Received May 2010, Accepted July 2010. 2010年5月送審 2010年7月通過。

研究報告

# 白水迴流對於螢光增白劑增白效果的影響

彭元興[1)]　王益真[2,4)]　蕭孟官[1)]　黃哲維[3)]

## 摘　要

本研究主要探討手抄紙迴流白水次數對於OBA影響紙張增白效果的影響，以作為OBA實廠應用時對於紙張白度變化的推估依據。實驗變數為OBA種類(2S-OBA及4S-OBA)、添加量(0、0.3、0.6、1.2、2.4%)及白水迴流次數(0~7次)，白水檢測PCD電荷、酸鹼值、OBA保留率，手抄紙檢測白度及灰份。實驗結果顯示，在配料過程中，闊葉木漿及$CaCO_3$不會明顯影響白水電荷，OBA及陽性澱粉為影響白水電荷的主因。4S-OBA會明顯影響PCD，但2S-OBA則影響不明顯。OBA種類或添加量對pH不會有明顯的影響。2S-OBA組中OBA添加量或迴流白水次數，對於白水中PCD及pH的影響不明顯。4S-OBA組中的PCD隨著OBA添加量及迴流白水次數而更趨負電性。迴流白水次數對於pH的影響則較不明顯。2S-OBA組的OBA迴流留存率及灰份隨著添加量增加而上升；而4S-OBA組則隨著添加量增加而下降。在相同添加量下，4S-OBA組的增白效果較2-OBA組為佳，同時4S-OBA組的色調穩定度較2S-OBA組為高。

**關鍵詞**：螢光增白劑、白水迴流、造紙、濕端添加、紙張白度、增白效應。

**彭元興、王益真、蕭孟官、黃哲維**。2010。白水迴流對於螢光增白劑增白效果的影響。台灣林業科學 25(4):277-90。

## INTRODUCTION

In the manufacture of printing and writing paper grades, market preference dictates that the papers must have high apparent whiteness. Thus, papermakers often opt to add optical brightening agents (OBAs) at the wet end. The function of OBAs is to absorb ultraviolet radiation and re-emit blue light, causing the human eye to perceive increased whiteness. The OBAs used in papermaking wet end are typically the disulfo- (or 2S)-, and tetrasulfo- (or 4S)-OBAs (Scott et al. 1995). The 2 types have different sulfonated functional groups on a stilbene backbone, leading to different solubilities in water and affinities to pulp fibers. When papermaking white water is recirculated, because of the changes in its electrical charges and fines content, limits to 2S- and 4S-OBA addition and the stability of the whitening effect are altered. Although these phenomena are often discussed in mill practice, there is, however, a lack of systematic investigation of the subject.

Crouse and Snow (1981) reviewed the chemical principles of OBAs and their whitening mechanisms. OBA molecules are absorbed by pores on the fiber surface, forming hydrogen bonds with the fibers. The performance of an OBA is affected by the stock consistency, drying conditions, and papermaking additives. The whitening effect of an OBA can be quenched by the presence of cationic polymers. When an OBA is added to a mechanical pulp-containing stock, the chemical absorbs UV light and abates the intensity on the fiber substrate, reducing the yellowing of the pulp due to aging (Roltsch and Lloyd

1987, Ragauskas et al. 1998, Bourgoing et al. 2001). Zhang et al. (2007a, b, c, 2009) investigated the effects of wet end applications of OBAs in bleached chemithermomechanical pulp (BCTMP)-containing paper in a series of papers and examined variables such as the whitening efficacy, OBA retention rate, contact time with the furnish, process water hardness, furnishing, anionic trash, fines, precipitated calcium carbonate (PCC) filler, etc. The results indicated that with the OBA contact time with furnish of at least 5 min and a water hardness of < 25 ppm produced a better performance. Furnishes containing BCTMP had poorer OBA retention rates than did pure chemical pulp. The anionic trash and fines entrained by the BCTMP slightly affected the OBA retention. Adding a PCC filler did not affect OBA retention, but the whitening effect of the OBA was adversely affected. In practical applications, at a BCTMP content of < 30% and an OBA dosage of < 0.5%, the OBA retention rate should exceed 90%.

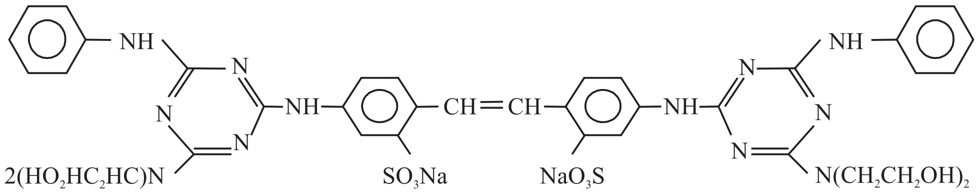
The purpose of this study was to investigate the effects of the number of rounds of white water recirculation on the electrical charge and pH of the water and the whitening efficacy of the added OBA dosages. The chosen OBAs were those commonly used in the papermaking wet end; 2S- and 4S-OBAs. The wet end indicators examined included the PCD, pH, OBA retention rate, first-pass retention rate, and ash content. The physical parameters examined for the resulting handsheets from each round included the brightness, apparent whiteness, and CIE L*a*b* values.

## MATERIALS AND METHODS

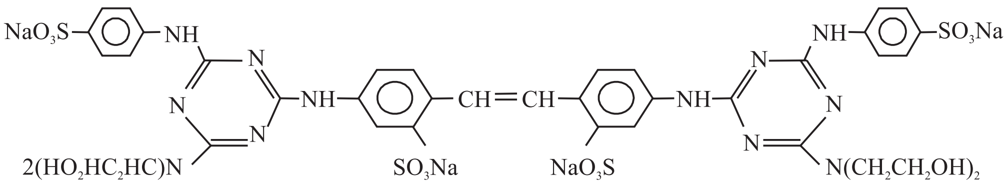
As noted above, the purpose of this study was to determine the influences of white water recirculation on the performance of an important additive, OBA, which is increasingly used to enhance the visual perception of paper whiteness that consumers demand in a typical printing and writing papermaking system. The practice's impacts on white water quality and the resulting paper handsheets were investigated. Changes in the white water electrical charge balance and pH of each round of recirculation were measured. Two types of commonly used OBAs, 2S- and 4S-OBAs, were separately added to the papermaking furnishes and the variables were their dosages and number of recirculation rounds. Other additives were added to each round at fixed dosages, i.e., 20% (to dry pulp) of dry-ground calcium carbonate (GCC), 1.0% of cationic starch, 0.8% of an alkyl ketene dimer (AKD) sizing agent, and 0.015% of a retention aid polymer, polyacrylamide (PAM). The OBA dosages were 0, 0.3, 0.6, 1.2, and 2.4% of the dry pulp. In making the handsheets, the first round used clean tap water, then drained filtrate beneath the forming wire was collected and used to disperse the next round of pulp furnish and for making handsheets, and so forth to simulate actual mill practices. In total, 7 rounds of recirculation were carried out.

### Materials

Bleached hardwood pulp with a freeness of 587 mL CSF and an average brightness of 87.0±0.3% ISO was obtained from the Taiwan Pulp and Paper (Hsinyin, Taiwan). Dry-ground calcium carbonate (GCC), applied as a powder with a solids content of 86~88%, was from An-jung Minerals and Chemicals (Taipei, Taiwan). The 2 types of OBAs, 2S- and 4S-OBAs were from the TFM International (Taipei, Taiwan). Chemical structures of the 2S- and 4S-OBAs are shown in Fig. 1 (Crouse and Snow 1981). The former was a powder with an absorbance of 0.370 Abs. at



**2S-OBA**



**4S-OBA**

**Fig. 1. Chemical structures of 2S- and 4S-optical brightening agent (OBAs).**

a 30 ppm concentration and HPLC purity of 92.229%, an E-strength denoted by 0.370/30 x 10000 x 0.92229 = 113.7, and a salt content of 0.077%. The latter was a liquid with an absorbance of 1.433 Abs. at a 30 ppm concentration and HPLC purity of 97.816%, an E-strength of 1.433/30 x 10000 x 0.97816 = 467.2, and a salt content of 1.816%. The cationic starch used was CT3035 with nitrogen content of 0.30~0.35%, and an electrical charge of +0.22~0.26 meq $g^{-1}$, from the Yu-ho Agricultural Products (Ilan, Taiwan). The AKD sizing agent with an electrical charge of +0.16~18 meq $g^{-1}$, was Hercon T-15 made by Hercules Chemicals (Taipei, Taiwan), and the retention aid polymer with an electrical charge of +1.20 meq $g^{-1}$, was Percol 182 made by Ciba Specialty Chemicals (Taipei, Taiwan).

## Methods

The experimental procedure entailed dispersing the bleached hardwood pulp at a 1.0% consistency in a standard pulp disintegrator for 1 h with the impeller rotating at 3000 rpm. The dispersed pulp was adjusted to a consistency of 0.3% with tap water. The PCD and pH of the suspension were measured. Then 2 OBA series at dosages of 0, 0.3, 0.6, 1.2, and 2.4% (with respect to the dry pulp) were individually added to pulp suspensions, and upon homogenization, the PCD and pH of the suspensions were again measured. Subsequently, at 1-min intervals under continued stirring, each of the 1% cationic starch, 0.8% AKD, and 0.015% PAM was sequentially added to the pulp suspension. In order to increase the retention of OBA on the paper sheet, common mill practice was simulated and the handsheets from each treatment were prepared using a British sheet mold, making handsheets of 200 g $m^{-2}$ grammage each for at least 5 sheets. From the second round on, white water from the wire pit of the sheet mold was used to disperse the pulp with minimal tap water makeup. Thus, each experimental set contained 8 runs with 40 handsheets. At each round, the PCD, pH, and OBA content of the white water were determined. Handsheet properties tested including sheet brightness, apparent whiteness, CIE L*a*b* values, and ash content. There were 9 sets of experiments with 360 handsheets prepared for one complete run of the experiment. From the runs one set (8 conditions) for each OBA group was randomly selected to be replicated twice more (i.e., 2 degrees of freedom for each condition) to estimate the experimental standard deviations.

The instruments and facilities used in the experiment included a disintegrator for dispersing pulp into suspension, model 306-2, Lien-sheng (Gueishan, Taiwan); a standard British sheet mold for making round handsheets of 200 cm$^2$, model 306-A, Lien-sheng; a pulp freeness instrument, model 306-7, Lien-sheng; an oven for pulp dry weight determination, model RL10-452, accurate to ±3℃, Risen (Taipei, Taiwan); a balance, capable of weighing 0~220 g, with an accuracy of ±2.0 mg, model AB204-S, Mettler-Toledo (Küsnacht, Switzerland); a particle charge detector (PCD) unit, model PCD 02, accurate to ±3%, Mütek (Herrsching, Germany); a pH meter, accurate to ±0.01 units, model MP220, Mettler-Toledo; a muffle-furnace for ashing samples, accurate to ±5℃, model Lab-line 4806-1, Heatech (Taipei, Taiwan); a spectrophotometer, model DR/4000, measuring 190~1100 nm, accurate to ±1 nm, Hach (Loveland, CO, USA); and a brightness/whiteness/CIE L*a*b* meter, model TB-1C, Technibrite Micro, by Technidyne (New Albany, IN, USA).

The methods adopted for the experimental work included the pulp freeness measurement according to the TAPPI-T227 standard method; the pH measurement according to NIEA W424.51A standard; the PCD measurement according to the instruction manual of the manufacturer; and the OBA content determination carried out by observing the light absorbance at 346 nm and 347 nm of the spectrophotometer for the 2S- and 4S-OBAs, respectively. A calibration line for each compound was constructed using solutions of 0, 0.5, 1.0, 2.0, 5.0, and 10.0 ppm as shown in Figs. 2 and 3. The actual OBA content in white water samples was then determined by interpolation of the respective calibration lines. In order to prevent interference with the measurement of OBA by fibers and filler particles, a 200-mL sample of the white water was taken in a sample bottle and placed in a cool, shaded place for 24 h. Then ~5 mL of the clear supernatant was withdrawn for the OBA determination. The OBA retention rate was determined using the equation:

[(dosage added + residual carryover from white water of last round) – residual content in this round of white water] / (dosage added + OBA in the white water of last round) x 100%.

The ash contents of the white water and handsheets were determined according to

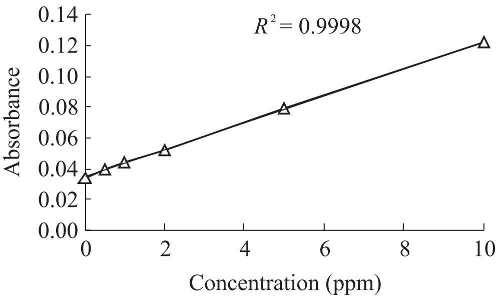


**Fig. 2. Spectrophotometric calibration curve for the 2S-optical brightening agent (measured at 346 nm).**

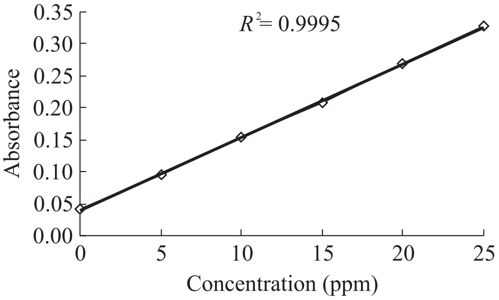


**Fig. 3. Spectrophotometric calibration curve for the 4S-optical brightening agent (measured at 347 nm).**

the TAPPI-T211 standard method; handsheet brightness was measured according to the TAPPI-T560 standard method; and the CIE L*a*b* values were determined according to the TAPPI-T452 standard method.

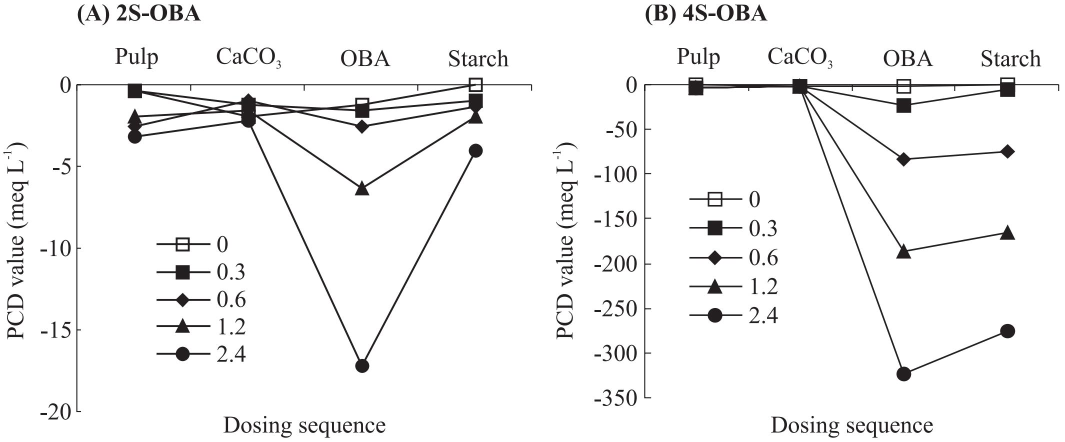
## RESULTS AND DISCUSSION

### Effects of the stock preparation process on the PCD and pH of the pulp suspensions

Effects of additives added to the pulp furnish, including pulp, GCC, 2S- and 4S-OBAs, and starch on the PCD and pH values of the white water are presented in Figs. 4 and 5. The pooled standard deviations were 0.15 meq $L^{-1}$ and 0.16 in the 2S-OBA group, and 3.33 meq $L^{-1}$ and 0.09 in the 4S-OBA group for the PCD and pH, respectively.

Figure 4 shows that the bleached hardwood pulp and GCC filler did not affect the electrical charge balance of the white water, which were in the range of 0 to -4 meq $L^{-1}$. The OBAs and cationic starch, however, were the main causes of changes in white water electrical charges. Figure 4A indicates that along with the increasing 2S-OBA charge, the charge balance shifted toward the negative, reaching -17 meq $L^{-1}$ at a 2.4% dosage. The unit addition effect was limited to -7 meq $L^{-1}$ $\%^{-1}$ 2S-OBA, and the effect was insignificant. In Fig. 4B, however, the negative charge of the white water appreciably increased with the charge of 4S-OBA, and at the maximum dosage studied, 2.4%, the PCD reading was as high as -324 meq $L^{-1}$, with unit addition of ca. -140 meq $L^{-1}$ $\%^{-1}$ 4S-OBA. The higher sulfonated groups on the 4S-OBA apparently produced a greater negative charge to the pulp suspension (Crouse and Snow, 1981). Cationic starch, on the other hand, was capable of reducing the PCD charge of 4S-OBA by 27~32 meq $L^{-1}$, compared to a moderation of 1~13 meq $L^{-1}$ for the 2S-OBA group.

Figure 5 shows that the pH of the white water did not significantly change with the addition of either types of OBA or their dosages. Upon the addition of GCC, however, the pH showed a slight decrease from 8.5 to 8.1. The cationic starch had no apparent effect on the pH. During the stock preparation pro-



Dosing sequence: Pulp + $CaCO_3$ + OBA + Cationic Starch

**Fig. 4. Effects of various wet end additives and optical brightening agent (OBA) dosage on the electrical charge (PCD) of the white water during the sequential stock preparation steps.**

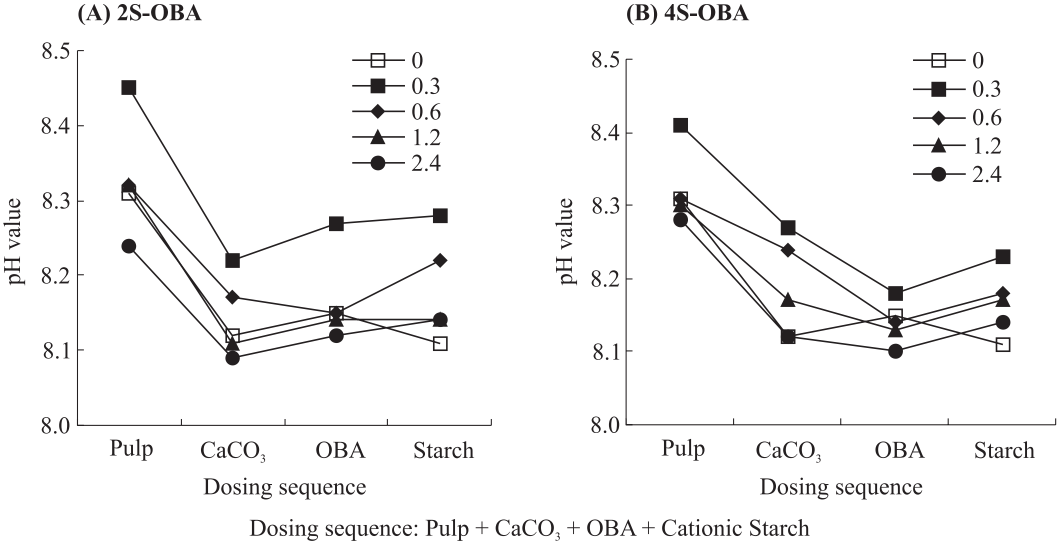


**Fig. 5. Effects of wet end various additives and optical brightening agent (OBA) dosage on the pH of white water during the sequential stock preparation steps.**

cess, the pH of pulp suspension consistently remained at 8.1~8.5.

### Effects of recirculating the white water

#### PCD

Figure 6 shows the effects of the number of white water recirculation rounds and OBA dosage on the PCD charge. The pooled PCD standard deviations were 0.25 meq $L^{-1}$ in the 2S-OBA group and 0.71 meq $L^{-1}$ in the 4S-OBA group. As shown in Fig. 6A, the relatively weak negative charge of the 2S-OBA did not significantly affect the white water PCD charge due to either the number of white water recirculation rounds or the dosage; the lack of change was also probably due to the high chemical retention of the fibers, leading to a lower presence in white water (Crouse and Snow, 1981). Figure 6B, on the other hand, shows that the PCD charge of the 4S-OBA group shifted with both the number of recirculation rounds and the dosage toward more-negative values. The probable cause of the change was a poorer affinity of the chemical with the wood pulp, as evidenced by the gradual accumulation of the chemical in the white water with an increased number of recirculation rounds. The shift in the PCD charge with the 4S-OBA dosage and recirculation rounds were both significant and occurred in a linear fashion. This phenomenon of the PCD should have significance in the control of the 4S-OBA retention system. However, there is a lack of information on the subject in the existing literature.

#### pH

The influences of white water recirculation rounds and OBA charge on the pH of the white water are presented in Fig. 7. The pooled pH standard deviations were 0.07 in both the 2S- and 4S-OBA groups. In Fig. 7A, the pH results indicated that neither the dosage nor the number of white water recirculation rounds significantly affected the pH with 2S-OBA addition. In Fig. 7B, however, when the dosage of the 4S-OBA exceeded 0.3%,

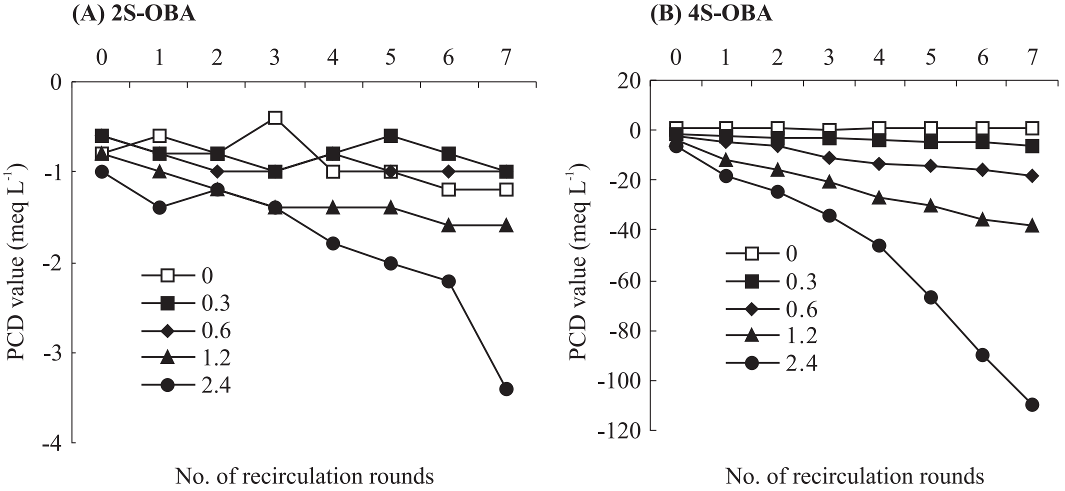


**Fig. 6. Effects of the number of white water recirculation rounds and optical brightening agent (OBA) dosage on the white water electrical charge balance (PCD value).**

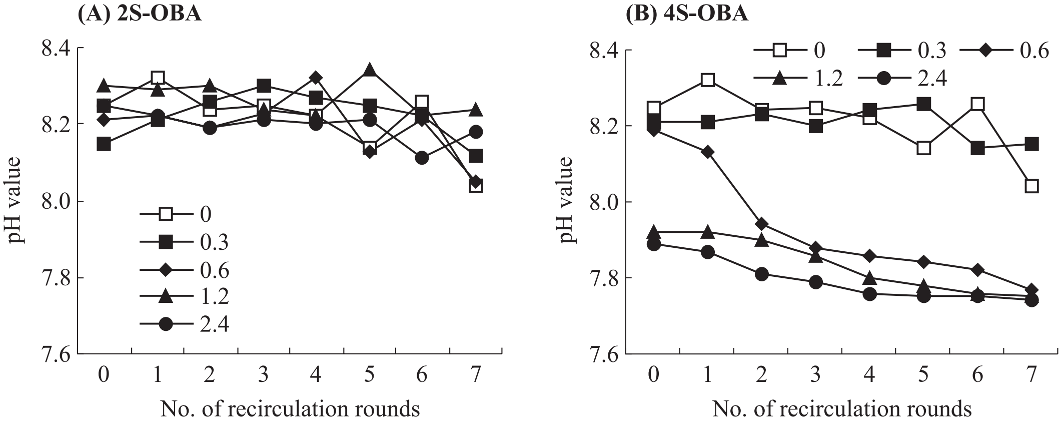


**Fig. 7. Effects of the number of white water recirculation rounds and optical brightening agent (OBA) dosage on the pH of white water.**

the pH of the white water decreased from the original value to a pH of 7.7~7.9. The number of white water recirculation rounds with the 4S-OBA, on the other hand, did not appear to notably influence the white water pH.

## OBA retention

The effects of the number of white water recirculation rounds and OBA dosage on the OBA retention during recirculation are shown in Fig. 8. The pooled OBA retention standard deviations were 1.11% in the 2S-OBA group and 4.22% in the 4S-OBA group. Figure 8A shows that the 2S-OBA recirculation retention rate decreased with increasing recirculation rounds; but nevertheless maintained a rate of > 90%. The results were similar to those observed by Zhang et al. (2007a, b). The OBA recirculation retention tended to increase with increasing dosage, but at the maximum 2.4% dosage, the OBA recirculation retention was at a minimum, suggesting that the dosage had

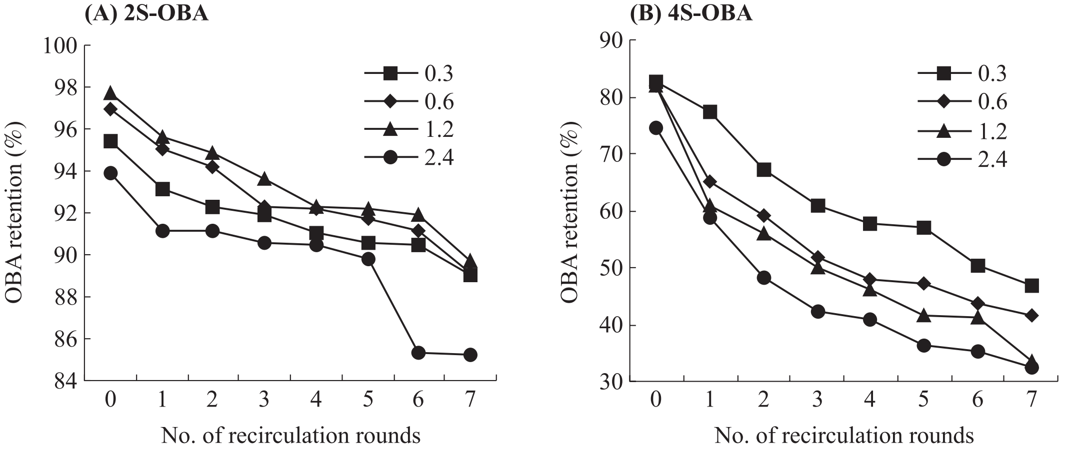


**Fig. 8. Effects of the number of white water recirculation rounds and optical brightening agent (OBA) dosage on the recirculation retention rate of the OBAs.**

exceeded the limits of the chemical's affinity to cellulosic fibers, causing a decrease in the OBA recirculation retention. In Fig. 8B, however, the OBA recirculation retention of 4S-OBA decreased more notably with recirculation and at the last recirculation round studied, the OBA recirculation retention decreased to as low as 35~55%. In addition, different from that of the 2S-OBA group, the 4S-OBA recirculation retention rate decreased with increasing dosage. The results suggest that 2S-OBA has a much-higher affinity with the cellulosic substrate than does the 4S-OBA, hence the higher OBA recirculation retention rates.

### Ash content

The effects of the number of white water recirculation rounds and OBA dosage on the ash content of handsheets during recirculation are shown in Fig. 9. The pooled ash retention standard deviations were 0.30% in the 2S-OBA group and 0.26% in the 4S-OBA group. Figure 9A shows that the ash content of handsheets in the 2S-OBA group significantly increased after the 1st recirculation. The ash content stabilized with the number of recirculation rounds. The set with 0.3% 2S-OBA dosage had a similar ash content to the control, whereas at other dosages, the ash retention increased with the OBA dosage. Figure 9B indicates that in the 4S-OBA group, the ash content of the handsheets also appreciably increased after the 1st white water recirculation round, and stabilized with subsequent recirculation rounds. The ash content of handsheets with the lowest OBA dosage was greater than that of the control. But the ash content tended to decrease with increasing 4S-OBA dosage, which contradicts the situation with 2S-OBA. The difference was probably related to the number of sulfonate groups on the OBA molecules, as the higher negative charges repel the attachment of anionically charged filler particles. Overall, except for the 0.3% dosage, the 2S-OBA had higher handsheet ash retention than did the corresponding 4S-OBA, which might reflect their PCD variations shown in Fig. 6.

### Handsheet brightness/whiteness

Effects of the number of white water recirculation rounds and OBA dosage on the resulting handsheet brightness are shown in Fig.

10. The pooled brightness standard deviations were 1.72% ISO in the 2S-OBA group and 1.83% ISO in the 4S-OBA group. The figure shows that regardless of the OBA types, at the 1st recirculation (2nd round of handsheet forming), the brightness tended to decrease. Afterwards, the handsheet brightening effect gradually stabilized. The phenomenon illustrates that when the white water system has yet to reach stability, the brightness of the handsheets is subject to certain disturbances. In Fig. 10A, the 2S-OBA results indicated that along with an increasing number of recirculation rounds and dosage, the handsheet brightness also increased up to the highest dosage tested. There was an indication that the greening point was not reached at the dosage range studied. Figure 10B, however, suggested that in the 4S-OBA series, dosages of 1.2 and 2.4% showed no appreciable brightening difference, and that at or near the 1.2% dosage, the system had reached the greening point. The 4S-OBA series also indicated that after 2 rounds of recirculation, the handsheet brightness stabilized and at dosages below 1.2%, the 4S-series produced better brighten-

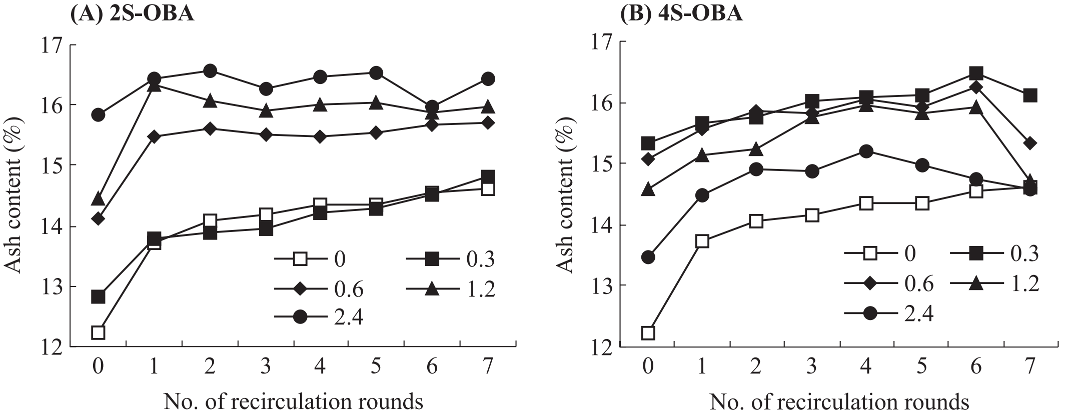


**Fig. 9. Effects of the number of white water recirculatin rounds and optical brightening agent (OBA) dosage on the ash retention of white water.**

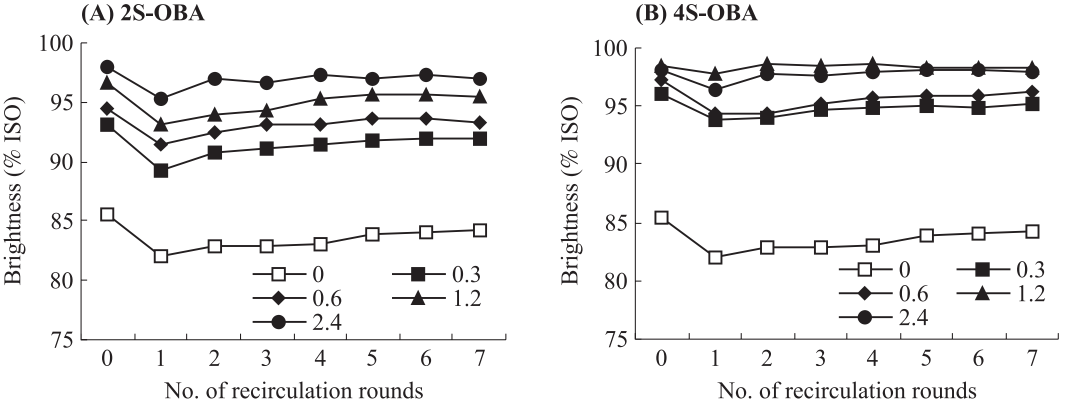


**Fig. 10. Effects of the number of white water recirculation rounds and optical brightening agent (OBA) dosage on the ISO brightness of the resulting handsheets.**

ing efficacies than did the 2S-OBA, with a gain of 1.1% ISO. The brightness of the resulting handsheets reached 98% ISO at a 4S-OBA dosage of 1.2%, which was not attained by the 2S-OBA series until the 2.4% dosage.

Effects of the number of white water recirculation rounds and OBA dosage on the resulting handsheet whiteness are shown in Fig. 11. The pooled whiteness standard deviations were 5.15% in the 2S-OBA group and 2.18% in the 4S-OBA group. The figure shows that the whiteness had similar trends to those of brightness. In Fig. 11A, whiteness of the 2S-OBA group increased with increasing dosage, reaching a maximum of 113%. In Fig. 11B, however, even at a 0.3% dosage, the 4S-OBA attained a whiteness of 110% ISO, and the maximum (115% ISO) was reached at a dosage of 1.2%. At an even higher dosage (2.4%), the whiteness reverted to a lower value, indicating that the dosage had exceeded the greening point. Overall, the 4S-OBA provided a more-stable whiteness gain than did the 2S-OBA group, which was also reflected in the values of their pooled standard deviations. At identical dosages, the 4S-OBA produced superior whitening efficacy than did the 2S-OBA.

### CIE L*a*b* values of the handsheets

Effects of the number of white water recirculation rounds and OBA dosage on the handsheet CIE L*a*b* values are presented in Figs. 12 and 13. In the CIE L*a*b* system, L* presents the luminance or lightness, a* represents a color tone on the red (-) to green (+) axis, and b* represents the tone on the blue (-) to yellow (+) axis. The pooled L*a*b* standard deviations were 1.21, 0.12, and 0.39 in the 2S-OBA group and 0.66, 0.13, and 0.21 in the 4S-OBA group, respectively. Figure 12 shows that when OBAs were added to the pulp furnish, the resulting paper had increased a* values, indicating a shift toward a greener tone. The number of white water recirculation rounds had an insignificant effect on a* value change. Figure 12A shows that along with increasing 2S-OBA charges, a* shifted toward the green end accompanied by an L* or whiteness increase, suggesting that at the dosage range studied, the greening point was not reached. Figure 12B, however, shows that with the 4S-OBA at 1.2 and 2.4% dosages, a* values were more negative than those at the lower dosages, indicating that at the 1.2% dosage, 4S-OBA was nearing the greening point. A further point to note was

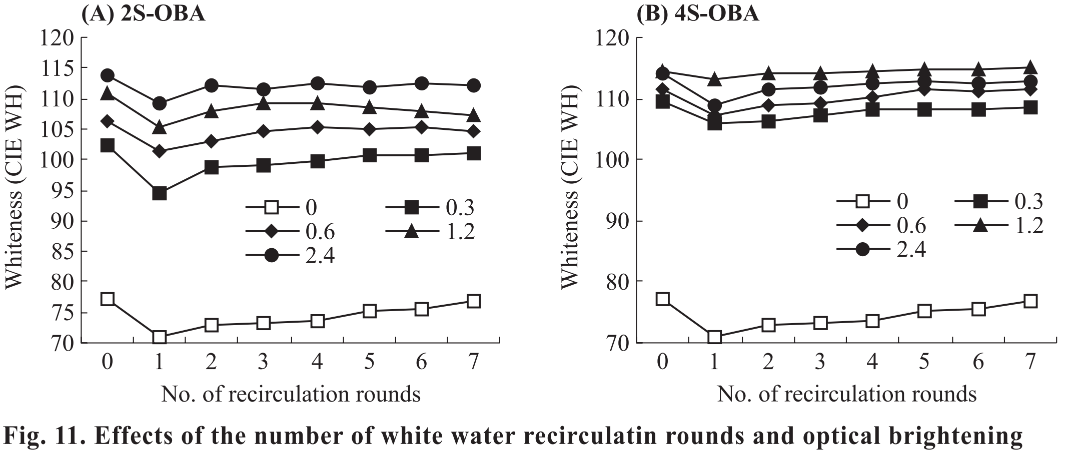


**Fig. 11. Effects of the number of white water recirculatin rounds and optical brightening agent (OBA) dosage on the whiteness of the resulting handsheets.**

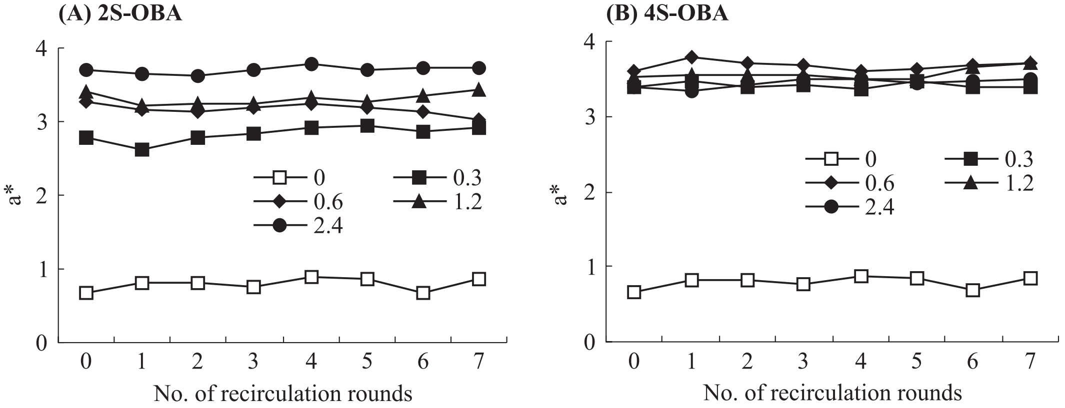


**Fig. 12. Effects of the number of white water recirculatin rounds and optical brightening agent (OBA) dosage on CIE a* values of the resulting handsheets.**

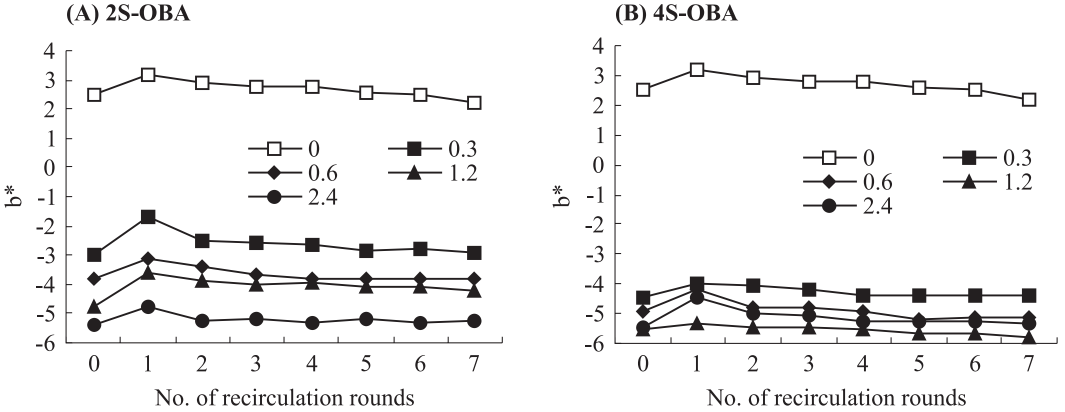


**Fig. 13. Effects of the number of white water recirculatin rounds and optical brightening agent (OBA) dosage on CIE b* values of the resulting handsheets.**

that generally a* value in the 4S-OBA series was relatively stable and often remain unchanged at different dosages.

Figure 13 illustrates the effects of white water recirculation rounds and OBA dosage on CIE b* values of the resulting handsheets. When b* changes from a positive to a negative value, the tone of the color shifts from yellow to blue. Except for the 1st recirculation, there was an insignificant effect on b* values. In Fig. 13A for the 2S-OBA series, the results indicated that along with increased OBA dosages, b* values shifted toward the negative, or became bluer. In Fig. 13B, the 4S-OBA series showed that at dosages below 1.2%, increasing dosages turned the handsheets bluer. However, at the 2.4% dosage, the b* value was higher than at the previous dosage, suggesting that the system had passed the greening point. Overall, b* values of handsheets processed with 2S-OBA showed a greater variability than those processed with 4S-OBA.

From changes in CIE a* and b* values, we can determine that in mill-site practice, the 2S-OBA had a relatively poorer stability in color tone adjustment than did the 4S-OBA. As for the dosage effect, the 4S-OBA appeared to reach the greening point at around a 1.2% dosage, while the 2S-OBA had yet to turn green at the 2.4% dosage.

## CONCLUSIONS

The purpose of this study was to delineate the effects of OBA whitening performance in a controlled white water recirculation scenario in term of both the white water and handsheet parameters. Our results indicated that in the stock preparation process, other additives did not appreciably alter the PCD charge of the pulp suspension, except for the OBAs and cationic starch. In particularly, the 4S-OBA notably shifted the PCD value toward negative charges. Most of the additives also had insignificant influences on the pH of the white water.

At the first recirculation, the brightness tended to decrease. Afterward, the handsheet brightening effect gradually stabilized. The phenomenon illustrates that when the white water system has yet to reach stability, the brightness of the handsheet it subject to certain disturbance.

The recirculation retention of the OBA and ash content of the 2S-OBA group tended to increase with an increasing dosage; whereas these parameters tended to decrease with increasing dosage in the 4S-OBA group. At an identical dosage level, the 4S-OBA had superior whitening efficacy then did the 2S-OBA. Furthermore, the 4S-OBA tended to produce better whiteness stability than did the 2S-OBA as well. The 2S-OBA had a relatively poorer stability in color tone adjustment than did the 4S-OBA. As for the dosage effect, the 4S-OBA appeared to reach the greening point at around a 1.2% dosage, while the 2S-OBA had yet to turn green at the 2.4% dosage. Overall, the 2S-OBA was inferior in tonal stability performance than was the 4S-OBA.

## ACKNOWLEDGEMENTS

A research grant from the National Science Council (NSC95-2313-13-212-012-MY3) supporting this study is hereby acknowledged.

## LITERATURE CITED

**Bourgoing S, Leclerc E, Martin P, Robert S. 2001.** Use of fluorescent whitening agents to inhibit light-induced colour reversion of unbleached mechanical pulp. J Pulp Paper Sci 27(7):240-4.

**Crouse BW, Snow GH. 1981.** Fluorescent whitening agents in the paper industry: their chemistry and measurement. Tappi J 64(7):87-9.

**Ragauskas AJ, Allison L, Li C. 1998.** Brightness reversion of mechanical pulps XIV: Application of FWAs for high-brightness, high-yield pulps. IPST Technical Paper Series no. 747. Georgia Tech. Atlanta, GA.

**Roltsch CC, Lloyd TA. 1987.** Efficient use of fluorescent whitening agents in the paper industry. Proceeding of 1987 TAPPI Papermakers Conference. Atlanta GA: TAPPI Press. p 87-99.

**Scott WE, Abbott JC, Trosset S. 1995.** Properties of paper: an introduction. p 89-110, Atlanta, GA: TAPPI Press.

**Zhang H, Hu H, He Z, Ni Y, Zhou Y. 2007a.** Retention of optical brightening agents (OBA) and their brightening efficient on HYP-containing paper sheets. J Wood Chem Tcchnol 27:153-67.

**Zhang H, He Z, Ni Y, Hu H, Zhou Y. 2007b**. Effectiveness of optical brightening agents (OBA) on high yield pulps (HYP). Proceedings, B235-40, PAPTAC Annual Meeting, Montreal, February 2007.

**Zhang H, He Z, Ni Y, Hu H, Zhou Y. 2007c**. Characteristics of dissolved and colloidal substances in high yield pulp and their impact on filler retention. Appita J. 60(5):390-5.

**Zhang H, He Z, Ni Y, Hu H, Zhou Y. 2009.** Using optical brightening agents (OBA) for improving the optical properties of HYP-containing paper sheets. Pulp and Paper Canada 110(8):T137-41.