USE OF A DYNAMIC SHEET FORMER (DSF) TO EXAMINE THE EFFECT OF FILLER ADDITION AND WHITE WATER RECIRCULATION ON FINE PAPERS CONTAINING HIGH-YIELD PULP

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With increased interest in using high-yield pulps (HYP) in uncoated and coated wood-free paper, there is a need to evaluate the effects of HYP under the conditions similar to commercial paper machine operations. Such tests were carried out by means of a Dynamic Sheet Former (DSF) sheet with white water recirculation, considering the high fines content of HYP and the usually high filler content in fine papers. In this study, we evaluated the use of a DSF that is equipped with a white water recirculation tank for making oriented sheets under various conditions. The effects of different factors such as operational variables, use of retention aids, and recirculation of white water were examined and clarified in terms of retention of fines and fillers as well as their impact on paper properties. The effect of HYP content on filler retention was also examined.

Keywords: High-yield pulp; Fine paper; Dynamic sheet former; Fillers; Fines; Kraft pulp

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INTRODUCTION

The effect of high-yield pulp (HYP) substitution on the properties of fine paper has been extensively studied (He et al. 2009; Hu et al. 2004, 2006, 2007; Reis 2001; Xu et al. 2008; Zhang et al. 2007, 2008, 2009a, 2009b, 2009c; Zhou 2004, 2008). The previous studies were done by making either standard handsheets or dynamic (DSF) sheets containing different levels of HYP and then testing the sheet properties. Since making standard handsheets is relatively simple, pulp furnishes with and without filler and retention aid were used to study the effect of HYP substitution on paper properties. Although the standard handsheet approach is quite useful in understanding the basic effects of HYP substitution, it has some difficulty in extrapolating the results to machine-made paper (e.g. MD vs. CD, fines/filler retention, roughness two-sidedness, etc.). In addition, the handsheets are not suitable for further sheet processing and testing such as coating, calendaring, and print quality evaluation due to the small sample size. The dynamic sheet former provides an intermediate step between a conventional handsheet system and a pilot paper machine, requiring small quantities of pulp samples, yet obtaining a large enough sheet to calender and print reproducibly (Amiri et al. 1993; Anczurowski et al. 1983; Bernard and Bouchayer 1975; Charles and Waterhouse 1988;

Sauret and Lanvert 1965). Compared with conventional handsheets with random fibre orientation, the oriented DSF sheets can provide information concerning the paper surface and printability that well suit the purpose of furnish comparison in this study.

The previous work on the effect of HYP in fine paper using DSF sheets (Hu et al. 2004, 2006, 2007) has been conducted without the addition of fillers and retention aids as well as without white water recirculation, as they make the sheet making process complex and difficult to control. However, the use of fillers and retention aid is crucial to determine the effect of HYP in a true papermaking process. Therefore, there is a need to develop an appropriate approach based on a dynamic sheet former system that most closely simulates the real papermaking process.

The objective of this study was to identify the effect of filler addition and white water recirculation on the properties of HYP-containing DSF basesheets. The oriented and relatively large DSF sheets made in this study can be further processed to evaluate the effect of HYP on coating application and printability of coated paper, and the results will be published in the furture.

EXPERIMENTAL

Materials

Three different types of pulps, bleached softwood (spruce) kraft pulp (SWKP), bleached hardwood (eucalyptus) kraft pulp (HWKP), and aspen HYP (BCTMP, 325/85), were obtained from a mill in Eastern Canada. SWKP and HWKP were refined separately with an Escher Wyss low-consistency (LC) refiner at a 3.5% pulp consistency. To simulate co-refining practice in paper mills, a pulp mixture consisting of 61.5% HYP and 38.5% HWKP was also refined with the same refiner. Table 1 lists the properties of these refined pulps. Precipitated Calcium Carbonate (PCC, Albacar HO) from Specialty Minerals Inc. and CPAM (Percol 292) from Ciba were also used in this study.

Table 1. Properties of Refined Pulps and their Corresponding Handsheets

Pulps	SWKP	HWKP	HYP/HWKP
	Spruce	Eucalyptus	61.5%/38.5% HYP/HWKP
Net LC refining energy (kWh/t)	96	70	20
Freeness (CSF, mL)	561	410	338
Bulk (cm^3/g)	1.78	2.15	2.45
Tensile index (N.m/g)	54.8	29.7	29.2
TEA index (mJ/g)	1470	373	298
Tear index ($mN.m^2/g$)	16.8	4.6	4.1
ISO brightness (%)	86.7	87.0	84.0
*b**	2.5	3.0	5.0

Experimental Procedure

The percentage of SWKP in paper furnish was fixed at 35%. Unless specified, the HYP percentage in paper furnishes was fixed at 30%, and the remaining was HWKP. HYP (aspen BCTMP) was co-refined with HWKP as in a typical mill practice and then blended with SWKP in a tank to have 30% HYP in the final paper furnish.

A Dynamic Sheet Former (DSF, originally made by Noram, Pointe-Claire, Quebec and extensively modified at FPInnovations) which has been described in detail elsewhere (Amiri et al. 1993; Anczurowski et al. 1983; Bernard and Bouchayer 1975; Charles and Waterhouse 1988; Sauret and Lanvert 1965), was used to form sheets. The wire speed was 1000 m/min, the nozzle speed was set at 800 rpm, and the nozzle pump pressure was 30 psi. A 25L tank was used to collect the white water from the DSF. To make the DSF sheet, the required amounts of various pulps were first added into the side pulp tank of the DSF. Then, it was diluted by either fresh water or white water to a 0.2% pulp consistency. For samples with filler addition, PCC at a 30% level was added into the mixed paper furnish, followed by the addition of 0.05% CPAM. Once a DSF sheet was formed, it was pressed two times in a presser using 80 and 100 psi pressure, respectively. Finally, the pressed DSF sheets were dried in a rotating cylinder dryer in 150 ºC for 5 min.

The strength properties of DSF sheets were measured using a L&W Tensile Tester. The optical properties, including ISO brightness, light scattering coefficient, and opacity, were determined using a TechniBrite™ Micro TB-1C Tester. The surface roughness of DSF sheets was measured using Parker Print Surf (PPS) tester, and air permeability was tested by following the Gurley-Hill method. Fines contents in DSF sheets were obtained on a FQA, and the white water consistency was measured though the weighted filter papers. The ash contents of DSF sheets were tested at 525 ºC in an electric muffle furnace. All the measurements were conducted according to the relevant TAPPI test methods.

Experimental Design for Making DSF Sheets

Table 2. Experimental Design to Examine the Effect of Filler Addition, Retention Aids, and White Water Recirculation on Paper Properties

No.	White water	PCC	CPAM	Notes
#1	No	No	No	------
#2	No	Yes	No	The effect of fillers can be seen by comparing #2 with #1 without white water circulation or CPAM.
#3	No	Yes	Yes	(1) The effect of retention aids can be seen by comparing #3 with #2 without white water circulation. (2) The effect of filler and CPAM can be seen by comparing #3 with #1 without white water circulation.
#4	Yes	Yes	Yes	(1) The effect of white water circulation can be seen by comparing #4 with #3 with filler addition. (2) The effect of retention aids and white water circulation can be seen by comparing #4 with #2.

For making uncoated and coated wood-free papers, a large amount of fillers (up to 20 to 30% based on dry mass) is typically added to the basesheet furnish, and the presence of fillers can have significant effect on the strength, optical, and surface properties of finished papers. Also, the white water recirculation is used in the papermaking process to recover fillers and pulp fines as well as to reduce water usage. To examine the effect of filler addition, retention aids, and white water recirculation on paper properties, four sets of DSF sheets were produced using the conditions outlined in Table 2. The target basis weight of the DSF sheets was 70 g/m^2.

RESULTS AND DISCUSSION

Stability of Recirculated White Water Consistency

In the experiments to examine the white water recirculation, the main concern is the stability of recirculated white water consistency as this may have a significant effect on the variation in the properties of the DSF sheets.

As shown in Fig. 1, the consistency of recirculated white water can reach a steady-state after 4 or 5 cycles without the addition of filler or CPAM. With the addition of PCC filler and CPAM, Fig. 2 shows that an even faster equilibrium can be reached. However, the white water consistency was slightly lower with the PCC filler and CPAM than that without CPAM, indicating a better retention of fines and fillers. Therefore, four cycles were used in the subsequent experiments with white water recirculation.

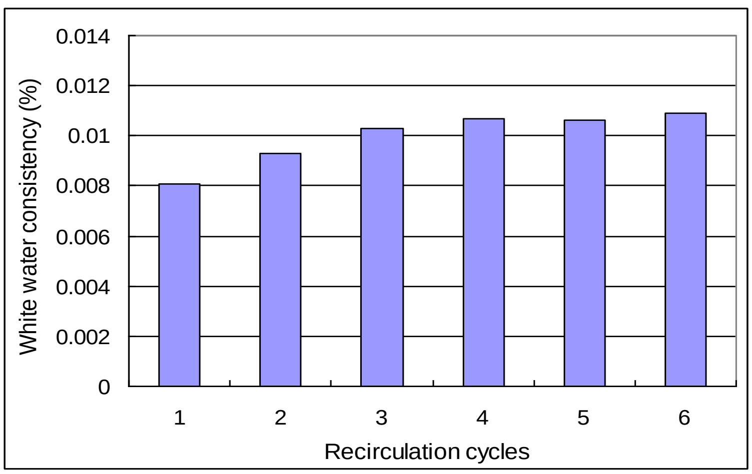

Fig. 1. Effect of recirculation cycles on the white water consistency (without PCC or CPAM)

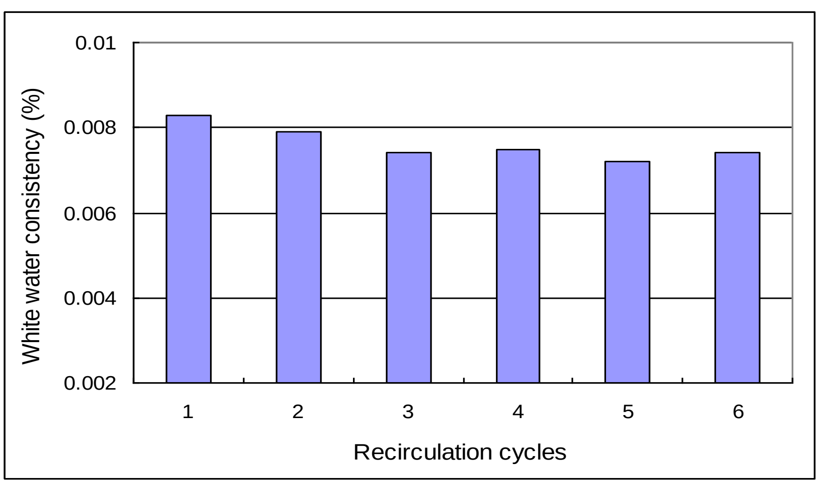

Fig. 2. Effect of filler addition on the white water consistency (with 30% PCC and 0.05% CPAM)

Table 3 shows the number of nozzle scans and the DSF sheet grammage when PCC filler and CPAM were used. The grammage of the DSF sheets ranged from 68.9 to 71.1 g/m^2 at the same number of scans of 102. The variation in grammage was about 3% or less.

Table 3. Number of Nozzle Scans and Grammage for DSF Sheet Making (the other conditions: 0.2% pulp consistency, 30% PCC filler, 0.05% CPAM)

No.	Number of nozzle scans	Grammage (g/m^2)	Dilution of pulp
1	106	71.9	Fresh water
2	104	69.7	w.w. from 1st DSF sheet making
3	102	68.9	w.w. from 2nd DSF sheet making
4	102	69.5	w.w. from 3rd DSF sheet making
5	102	71.1	w.w. from 4th DSF sheet making
6	102	69.4	w.w. from 5th DSF sheet making
7	102	70.6	w.w. from 6th DSF sheet making

DSF Sheet Properties

Optical properties

Similar to the papers produced from commercial paper machines, DSF sheets also have two-sidedness between the wire and the felt side (top side), but the difference is small (Neimo 1999). Figures 3 to 5 show the effect of filler and/or CPAM, and white water recirculation on the optical properties. In each case, two or more replicated data sets are shown here. Figure 3 shows the brightness on the top side with or without PCC fillers, CPAM, and white water recirculation. As shown in Fig. 3, the brightness of the control (without PCC filler, CPAM, or white water recirculation) was about 85% ISO. When the PCC filler was added, the ISO brightness could be increased to about 87%.

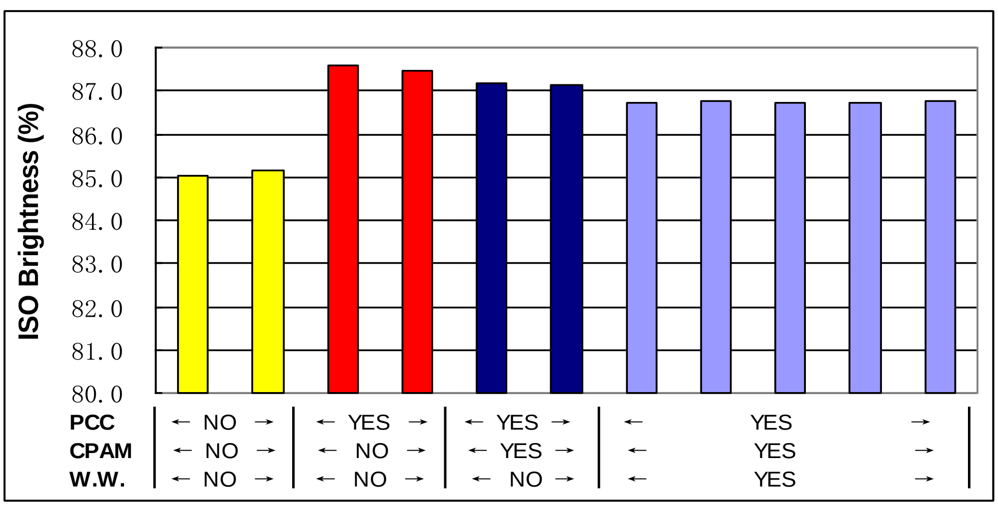

Fig. 3. Effect of filler and/or CPAM, and white water circulation on the brightness of DSF sheets (top side)

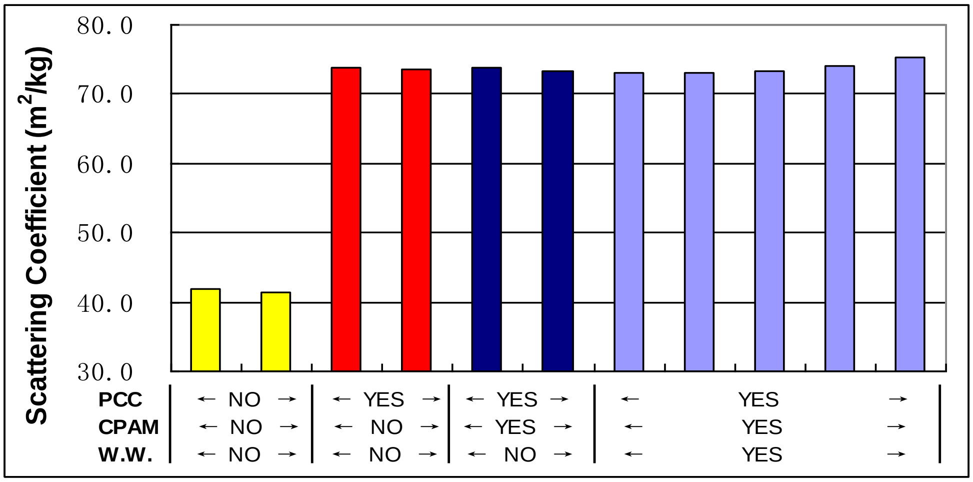

Fig. 4. Effect of filler and/or CPAM, and white water circulation on light scattering of the DSF sheets

Figure 4 also shows that the PCC filler could significantly increase the scattering coefficient of the filled sheets, from 41 m^2/kg to 73 m^2/kg. Corresponding to the signify-cant increase in scattering coefficient, the sheet opacity increased from about 80% to 90% with the addition of PCC filler, as shown in Fig. 5. The CPAM addition and white water recirculation had negligible effect on the opacity.

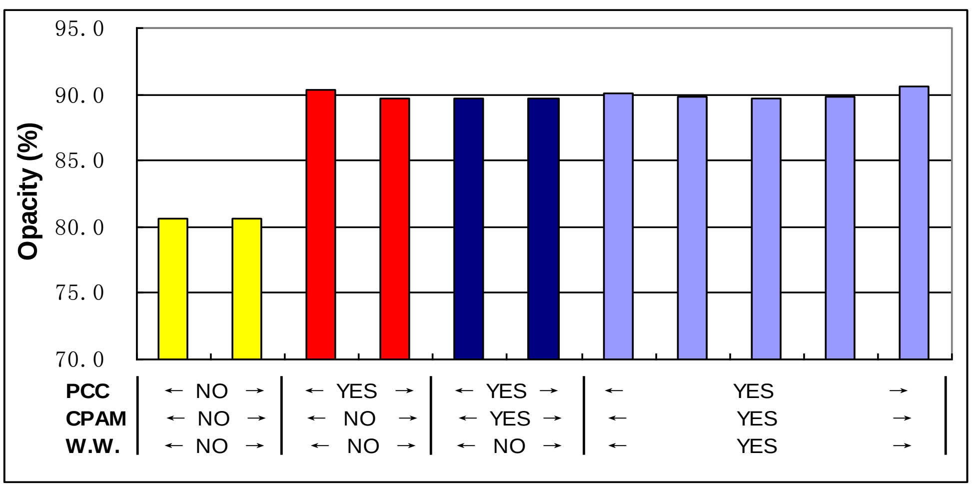

Fig. 5. Effect of filler and/or CPAM, white water circulation on the opacity of the DSF sheets

Surface roughness

Table 4 shows the effect of PCC, CPAM, and white water recirculation on PPS roughness of the DSF sheets. It was found that the roughness of both sides was improved slightly with the addition of PCC; however, the addition of PCC filler increased the two-sidedness slightly, which is most likely due to the retention difference of fines and/or PCC on the paper surface between the wire and felt side. There tends to more fines and/or filler retention on the felt side of machine-made paper sheets (Ford 1988; Neimo 1999).

The use of CPAM and white water recirculation had a positive effect on reducing the sheet roughness and two-sidedness. This is mainly attributable to the improved retention of fines.

Table 4. Effect of Filler and/or CPAM, and White Water Circulation on PPS Roughness of the DSF Sheets

Processing type			Roughness (um)		Δ Roughness (um) (wire side–top side)
PCC	CPAM	White water	Wire side	Top side	
NO	NO	NO	7.58	7.02	0.55
			7.54	7.02	0.52
YES	NO	NO	7.22	6.43	0.78
			7.03	6.40	0.63
YES	YES	NO	6.95	6.55	0.40
			6.92	6.49	0.42
YES	YES	YES	7.00	6.62	0.38
			6.93	6.50	0.43
			6.87	6.52	0.35
			6.97	6.57	0.40
			6.89	6.56	0.33

Physical properties

Table 5 shows the physical properties of the filled or unfilled DSF sheets. There was a large difference between the machine direction (MD) and cross-machine direction (CD) for DSF sheets, which is similar to the paper made on commercial paper machines.

Table 5. Effect of Filler and/or CPAM, and White Water Recirculation on the Physical Properties

Properties	No PCC, no CPAM, no w.w.		Adding PCC, no CPAM, no w.w.		Adding PCC and CPAM, no w.w.		Adding PCC and CPAM, with w.w.	
	MD	CD	MD	CD	MD	CD	MD	CD
Tensile index (N.m/g)	54.1	22.4	25.3	11.4	30.1	13.3	27.7	13.8
Stretch (%)	2.09	3.97	1.08	2.40	1.53	2.81	1.35	2.90
TEA index (mJ/g)	772	661	180	200	313	273	252	297
Elastic modulus (km)	673	240	456	149	448	165	444	168
Tensile index (GEOMEAN, N.m/g)	34.81		17.02		19.97		19.53	
Elastic modulus (GEOMEAN, km)	401.80		260.85		272.13		273.28	
Gurley air Resistance (s/100ml)	6.5		4.2		4.2		4.5	

As shown in Table 5, the addition of PCC had a largely negative effect on paper tensile strength. The MD tensile index of the filled sheets decreased from 54.1 N.m/g to 25.3 N.m/g, and the Gurley air resistance decreased from 6.5 s/100mL to 4.2 s/100mL. With the addition of CPAM and white water recirculation, the tensile strength and Gurley air resistance were recovered slightly. Similar trends were also observed for the CD strength and the geometric means of tensile index and elastic modulus. This is likely due to a good fines retention after the CPAM addition and white water recirculation, as shown in Fig. 6.

The Ash and Fines Content in DSF Sheets

Fines content

Figure 6 shows that the fines content of the DSF sheets increased from 23.4% to 29.0 % with the addition of CPAM. With the white water recirculation, the fines content can be even higher (by additional one or two more units). Higher fines content in paper led to a higher strength and lower roughness, as shown in Tables 4 and 5.

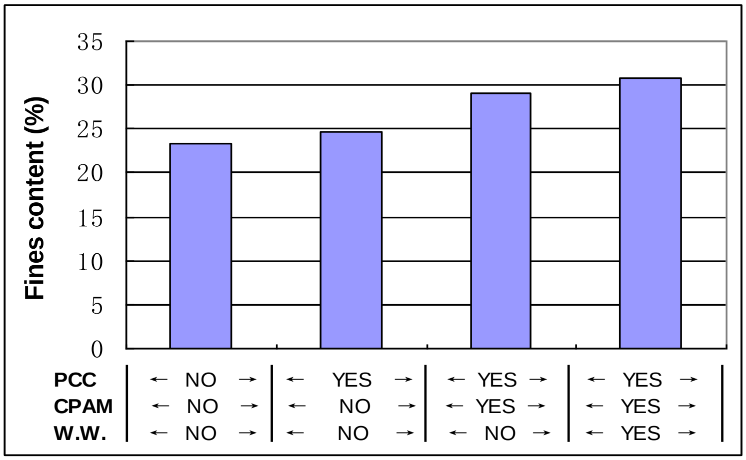

Fig. 6. Effect of filler and/or CPAM, white water recirculation on the fines content in DSF sheets

Ash content

Figure 7 shows the effect of filler addition, CPAM, and white water recirculation on the ash content of DSF sheets. It is clear that adding 30% PCC to the pulp mixture increased the ash content of the paper sheets to about 22%. The addition of CPAM further increased the ash content slightly, while the white water recirculation had negligible effect on the ash content.

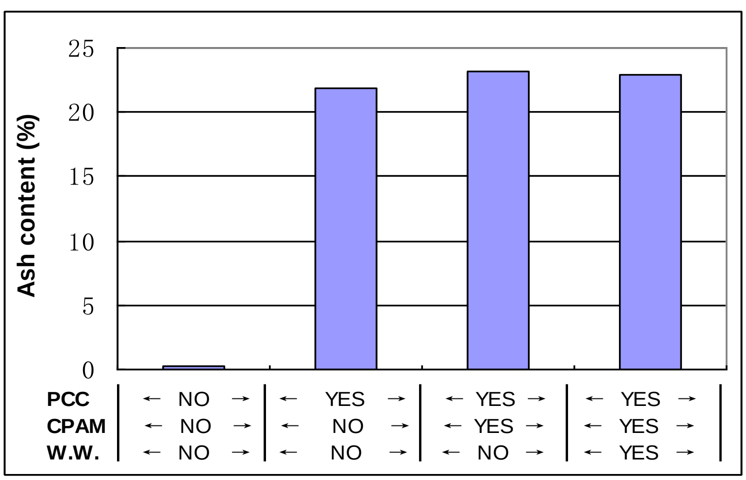

Fig. 7. Effect of filler and/or CPAM, and white water recirculation on ash content of DSF sheets

Effect of HYP substitution on the ash content of the filled DSF sheets

An important difference between HYP and hardwood kraft is their fines content. HYP, which has a much higher fines content than hardwood kraft, may affect the filler retention when used to substitute hardwood kraft. Table 6 compares the samples with and without HYP substitution in terms of the ash content of the filled DSF sheets. We examined two cases: HYP substitution levels of 0% and 30%. In each case, five parallel samples were chosen to determine the ash content. Table 6 shows that there was almost no difference in the ash content between DSF sheets with and without HYP. This is different from early results using a DDJ (Dynamic Drainage Jar) system, where it was found that the first pass ash retention (FPAR) decreased with the increase of HYP substitution level (Lin et al. 2007; Zhang et al. 2007).

Table 6. The Ash Content in Filled DSF Sheets with Different HYP Content

No.	35% SWBKP+ 65% HWBKP	35% SWBKP+ 35% HWBKP+ 30% HYP
1	22.8%	22.8%
2	22.6%	22.3%
3	22.9%	22.7%
4	22.7%	22.7%
5	22.7%	22.9%
Average	22.7%	22.6%

Note: (1) The ash content is measured with the TAPPI method at 525 ^{0}C for 4 hrs;
(2) 30% PCC and 0.05%CPAM were used with the white water recirculation.

It is noted that the FPAR in both cases in Table 6 was about 76%, which is much higher than the FPAR of 40 to 66% in the DDJ system (Zhang et al. 2007). In the present study, which was conducted with white water recirculation, the results should be interpreted as the filler retention at a steady state. For this reason the FPAR would be more affected by the filler loading in comparison to the fibers in the pulp suspensions.

CONCLUSIONS

Dynamically formed sheets can be made with filler addition and white water recirculation that can simulate the commercial papermaking process. Under the conditions studied, it was found that 4 cycles would be needed for the white water to reach equilibrium, such that the variation in grammage of the DSF sheets was very low when holding the number of nozzle scans at a constant value.

As expected, the addition of PCC filler increased the brightness and opacity of the filled DSF sheets due to a significantly increased light scattering from the addition of fillers. The addition of PCC filler (with retention aids) can also reduce the roughness and roughness two-sidedness that are important quality parameters for many paper grades. The strength properties of the DSF sheets were lower with the PCC addition, as expected. The retention of fines and filler in DSF sheets can be readily achieved by the addition of cationic retention aid. The white water circulation improved the fines retention, but had negligible effect on the filler retention. The results also showed that in the DSF system with white water recirculation, the HYP substitution for hardwood kraft pulp did not affect the retention of fillers.

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