Pilot Papermaking with Malaysian Oil Palm Empty Fruit Bunch Pulp: Part 3

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ABSTRACT

At the Tappi 2015 and 2016 PEERS conferences, we presented the results for pulping and bleaching Malaysian oil palm empty fruit bunch (EFB) at the bench scale and the pilot scale, respectively. In this paper, we are presenting the results for pilot papermaking using the pulp produced in the pilot scale pulping and bleaching trials. Unbleached papermaking trials were attempted for two furnished: 100% EFB pulp, and 80% EFB pulp / 20% unbleached softwood kraft pulp. Bleached papermaking trials were attempted for two furnishes: 85% EFB / 15% GCC, and 70% EFB pulp / 15% bleached softwood kraft pulp / 15% GCC. Both the unbleached and bleached 100% EFB papermaking trials experienced difficulties in the paper machine, and no paper made it to the reel. Unbleached and bleached EFB papers were tested for physical and optical properties. Comparisons are made between the properties of the bleached EFB paper and a commercial bleached paper. The EFB unbleached and bleached pulps produced acceptable paper provided that softwood kraft pulp was added to the respective furnish.

Keywords: Elaeis guineensis, oil palm empty fruit bunches, papermaking, paper properties

INTRODUCTION

Oil palm (Elaeis guineensis) is cultivated on a large scale as a source of edible oil in Central and West Africa where it originated, as well as in Indonesia, Malaysia and Thailand.

Malaysia has a total of about 4.7 million hectares of palm oil plantations that annually produce about 19 million tons of palm oil and 2 million tons of palm kernel oil per year. A typical plantation yields about 20 metric tons of fruit/ ha/year but some new clones yield up to 28 metric tons/ha/year.

Oil palm plantations generate a significant amount of biomass in the form of fronds from harvesting and pruning, trunks and canopy from replanting, and empty fruit bunches (EFB). Fronds have no significant commercial uses and are typically returned to the soil as mulch. Trunks and canopy are typically pulverized and returned to the soil; but some trunks are converted to plywood in combination wood veneers. Empty fruit bunches (EFB) have been commercially used to produce low value products such as construction materials, fiberboard and molded fiber products. However, most EFB is returned to the plantations as mulch. Estimates of Malaysian EFB production vary but it is conservatively estimated at about 20 million tonnes per year, or about 4.3 tonnes/ha/year [1].

This study was carried out as part of a 3 year program to establish the unbleached and bleached papermaking capability of EFB pulps and to determine the paper properties.

EXPERIMENTAL

All work was carried out at the North Carolina State University (NCSU) Department of Forest Biomaterials laboratory and pilot plant (Raleigh, NC, USA) under the direction of HurterConsult. All tests were conducted in accordance with TAPPI methods.

Fiber materials

As reported at the 2016 TAPPI PEERS conference, pilot scale pulping and bleaching trails were undertaken which produced 54 o.d. kg of unbleached EFB pulp and 74 o.d. kg of ECF bleached pulp (85.1% ISO brightness) for the papermaking trials. The physical properties of the pulps are provided in **Table I**.

For the unbleached papermaking trials, softwood brownstock was sourced from a local North Carolina kraft pulp mill.

For the bleached papermaking trials, commercial bleached softwood kraft pulp was used.

Stock preparation (unbleached paper)

NCSU's stock preparation consists of a refiner feed tank, low consistency refining using a 12 inch Bauer Twin-Flow disk refiner and refined stock tanks.

NCSU's refiner feed tank requires a minimum volume for proper agitation. For the 54 o.d. kg of EFB unbleached pulp available for refining, at the minimum volume, the highest consistency that could be obtained was 2 %. At this low consistency (normal refining is done at 3-5 % consistency), there is a danger of excessive fiber cutting. In addition, the pilot pulping and bleaching trials showed that EFB pulp was sensitive to shear. For these reasons, instead of refining to 250 ml CSF target freeness, it was decided that the unbleached EFB pulp would be run through the refiner in single passes, with a light load on the refiner. After each pass, the stock was tested for freeness, and a sample handsheet was to be made and tested for strength.

After a single pass, the unbleached EFB pulp freeness only decreased by 20 ml CSF. However, the sheet strength improved considerably compared to the unrefined handsheet with a tested burst index of 3.4 kPa $\cdot m^2/g$, well within the range of values obtained for the bench-scale strength testing. It was decided that a second pass could damage the fiber excessively without improving strength significantly so no further refining was carried out.

For the softwood brownstock, to maximize the wet-web strength and improve runnability, it was refined to 250 ml CSF freeness in a single pass with the refiner heavily loaded.

The pulps were added batch-wise into the machine chest.

Additives (unbleached paper)

The following additives were used in the trials (all dosages on o.d. fiber):

- 0.20% AKD size,
- 0.25% alum (to reduce sheet adhesion and improve runnability), and
- 0.25% cationic starch (for dry strength and as a retention aid).

All additives except the retention aid were added batch-wise into the machine chest. The retention aid was metered continuously into the headbox feed.

For surface sizing, a 6% solution of cooked corn starch was made up for application in the inclined nip puddle press.

Stock preparation (bleached paper)

The same stock preparation equipment mentioned above was use for the bleached pulps.

The freeness of the bleached EFB pulp was already low, 201 ml CSF and the sample handsheets had fair, but not good, strength (**Table 1**). It was decided that further refining could cause more problems (i.e. increase in fines, fiber damage) than could be tolerated so the bleached EFB pulp was not refined prior to the papermaking trials.

For the commercial bleached softwood kraft pulp, to maximize the wet-web strength and improve runnability, it was refined to 250 ml CSF freeness in a single pass with the refiner heavily loaded.

The pulps were added batch-wise into the machine chest.

Additives & Color Matching (bleached papermaking)

The bleached paper was to have a bluish-white color similar to a sample of copy paper commercially available in Malaysia which was sent to HurterConsult (the “Standard”).

Shade matching tests were done at the Shanghai R&D centre of Clariant Chemicals (China) Ltd. using samples of the pilot-scale bleached EFB pulp from NCSU and the commercial paper sample. Clariant’s shade matching test report recommendations are provided in **Table II**. However, they noted that, for the tinting pigments and the OBA, “The formulation in the laboratory is usually excessive dosage on the paper machine. It is recommended to start with 75% of these dosages and make changes depending on the results.”

Starting with Clariant’s recommendation, three bench-scale shade matching and OBA trials were carried out at NCSU. Feedback and recommended adjustments on each trial were provided by Clariant until a close match was developed. **Table III** provides the additives, tinting pigments and OBA charges used by NCSU for the three trials, and **Table IV** provides the trial results.

Fig. 1 is the SpectraMatch analysis provided by Clariant for NCSU Trial 3 and shows a close match to the Standard. Based on this close match, Trial 3 conditions were used for the pilot-scale additives, tinting pigments and OBA usage.

Pilot Paper Machine

The pilot papermaking trials were carried out using NCSU’s pilot paper machine with the features described in **Table V**.

Previous experience with nonwood fiber pulps has shown that many of them have poor machine runnability. Problems may include the following:

- poor drainage on the wire
- fines and parenchyma in the slurry mesh into the forming wire, making it difficult to get the sheet to release from the wire
- poor wet web strength, making it difficult for the sheet to successfully cross the 15 cm open draw between the couch roll and the first press
- severe sticking to the first press roll (high adhesion due to fines and parenchyma)
- severe sticking to the first three dryer cylinders
- high linting in the dryers
- excessive adhesion to the size press rolls once starch is applied

To avoid these problems as much as possible, the following steps were taken:

- the couch roll vacuum level was reduced to a minimum (to promote sheet release)
- the first press roll and the first three dryer cylinders were buffed with a rubbing compound and treated with three layers of a polymeric release agent (to prevent sheet sticking)

RESULTS AND DISCUSSION

Paper machine trials target basis weights and furnishes

The target basis weights and furnishes for the pilot papermaking trials are provided in **Table VI**.

Papermaking Trial 1 - 100% EFB unbleached paper, 70 gsm

It was immediately obvious that this furnish could not be run successfully. The sheet, while appearing to have fair wet web strength, was so firmly enmeshed in the forming wire that it could not be made to leave the wire and thread into the press section. Even when the basis weight was increased and the couch vacuum was reduced to a lower level, the sheet could not be made to leave the wire. To avoid wasting the limited EFB fiber, the 100 % EFB trial was halted, and the trial with softwood pulp was started.

Papermaking Trial 2 - 80% EFB / 20% softwood kraft unbleached paper, 40 gsm

The inclusion of 20% highly-refined softwood kraft was immediately evident in the behavior of the wet web. It was possible to get the sheet to leave the wire and thread into the first press section. Unfortunately, it became impossible to get the sheet to stop sticking to the first press roll. In fact, at no point in the run could the sheet be made to release.

Because the NCSU machine uses a “reversing press” for the second press (i.e. the sheet is run backwards through the second press, so that the wire side of the sheet also sees a smooth press roll), it was decided to by-pass the first press and run the sheet straight into the second press. When this was done, the sheet released from the second press, and it became possible to make paper. This behavior indicates that the EFB fines and possibly parenchyma cells were making the sheet too sticky for traditional press rolls because the wire side of the sheet usually has significantly lower content of these materials (i.e. they wash out of the bottom side of the sheet unless a large amount of retention aid is used). During the run, a heavy deposition of fines was noted on the second press roll.

After pressing, the sheet tried to adhere to the first three dryer cylinders despite the presence of release agent. It became necessary to turn down the temperature of the three cylinders to reduce this problem and, later in the trial, a machine attendant had to continuously apply a thin film of release agent in order to keep the sheet running.

In normal practice, a sheet is first established with no surface sizing - that is, the sheet is run through the size press without the size being applied. Then size is gradually introduced. For the EFB trial, it was possible to get a well-formed unsized 70 gsm sheet to the reel in a reasonable amount of time. Once this was benchmark was achieved, the starch solution was introduced to the size press. No problems were encountered initially, but, just as the collection of samples was to begin, two problems became evident. The first was that the sheet started sticking to the first dryer section rolls intermittently and, each time the sheet stuck, it would produce an edge tear that would cause the sheet to break when size was applied. The second problem was that the EFB sheet, with size applied, turned out to be much stickier than wood-based sheets, and the sheet stuck to and fouled the second dryer section cylinders.

When it was evident that the supply of furnish was dwindling, it was decided to bypass the size press and try to make an adequate sample of unsized 70 gsm EFB sheet. It was possible to do so, and the sheet turned out to have good formation, fair strength, and a smooth surface after the size press. Unfortunately, the sticking problems in the first dryer section began to get worse, and it was not possible to produce an acceptable reel of paper without breaks. Several kilos of calendared and uncalendared paper were produced, and the appearance and properties appear promising.

Given the problems encountered on the heavier sheet, it deemed was not possible to run the 40 gsm sheet.

Papermaking Trial 3 - 85% EFB, 15% GCC Bleached Paper, 80 gsm

Table VII provides the furnish and additives for Trial 3.

Although considerable preparation was done for this trial, it did not go very well.

The machine was started up with a line speed of 14 metres/minute at a basis weight of 80 gsm. If the 80 gsm sheet was successful, then the basis weight would have been reduced to 60 gsm for the next trial - a standard practice for weak sheets (the heavy sheet threads easier, then the basis weight is backed down slowly).

The sheet released from the forming wire with no problems, unlike the trial on unbleached EFB. However, it still stuck to the first press roll. The machine was stopped and polymer tape was applied to the first press roll. This stopped the sticking, but it imparted a heavy mark on the sheet. The sheet released from the second press roll, but then stuck to the smoothing press (an unfelted press used to "buff out" wire and seam marks) which had to be bypassed.

The dryer section caused further runnability problems. If the temperature of any steam cylinder was increased to above 88 ^{0}C, the sheet would pick and stick to the cylinder surface causing a sheet break. This occurred even though several layers of release agent had been applied to the cylinders prior to the run.

When the temperature of all of the steam cylinders had been turned down to the temperature that prevented sticking, the sheet was not dry enough to enter the size press because, if the sheet has much more than about 2% moisture entering the size press, it picks up too much size and breaks.

It was decided to bypass the size press, in an effort to produce some quantity of paper using the wood-free furnish. That way, the second dryer section could be used to complete the drying prior to the calendar stack.

Unfortunately, the sheet was so weak that it could not make the long draw between the first and second dryer sections. Any small flaw in the sheet such as a press felt seam mark was enough to break it.

The trial was terminated after two hours to avoid wasting any further EFB pulp. Of the original 74 kg of bleached EFB pulp, only 47 kg remained for further papermaking trials.

This trial was much better than the one for 100% unbleached EFB pulp. Bleaching the EFB fiber appears to have removed some portion of parenchyma and sticky material, and the inclusion of filler seemed to help. Nonetheless, it was not possible to produce paper from this furnish.

If a larger quantity of bleached EFB pulp had been available to permit experimentation, it may have been possible to get a small quantity of paper to the reel. However, there is no doubt that the sheet would have been of poor quality and unsuitable for typical printing and writing applications.

Given that trial 3 for the 80 gsm sheet was unsuccessful, trial 4 for the 60 gsm sheet using the same furnish was not attempted.

Papermaking Trial 5 - 70% EFB, 15% BSKP, 15% GCC Bleached Paper, 60 gsm

Bleached softwood kraft refined pulp was added to the machine chest and mixed with the remaining slurry in the machine chest. Additional quantities of additives were mixed in to account for the increased amount of fiber to maintain the additives loadings per **Table VII**.

The contribution of the softwood pulp was evident immediately. There was significantly less sticking on the first press roll (although the polymer tape was left on it from the previous trial).

While sticking in the first dryer section was much less severe than for the previous trial, it was still necessary to keep the cylinder temperatures lower than 88 ^{0}C. At this temperature, the sheet was still somewhat wet coming out of the first dryer section, so it was not possible to go through the size press. It was decided to produce some reels of paper from the furnish, and then run the fully-dried paper from the reels back though the size press later.

Overall, the trial went pretty well. It was possible to produce about 25 OD kg of paper. The paper had reasonable formation and seemed to be of good quality.

It was concluded that this furnish could be made on a commercial machine successfully.

Off-Line Size Press Trial

One reel of fully-dried paper from Trial 5 was mounted on the unwind stand of the inclined, flooded-nip size press. Ethylated starch was prepared at 10% solids for surface application to the sheet. The second dryer section was heated very slightly, to dry the starch applied to the sheet.

Multiple attempts were made to surface size the sheet. Upon entering the flooded nip of the size, the sheet would pick up so much sizing that it would stick to the size press rolls or break immediately.

It became evident that the internal AKD sizing of the sheet likely had not been effective. A water drop test on the base sheet confirmed that there was practically no resistance to penetration. Evidently, the low temperatures (max. 88 ^{0}C) required for the first and second dryer sections to prevent sticking did not allow the AKD size to cure.

Unbleached EFB Paper Properties

Table VIII provides a comparison of the properties of 70 gsm unbleached EFB paper with the properties of commercially available 80 gsm bleached paper from Malaysia.

The unbleached EFB paper which was not surface sized exhibits properties similar to those of a paper produced using a high content of nonwood pulp such as cereal straw or sugarcane bagasse. Breaking length and tensile index are on the low side, but tear index is good.

The commercial paper has better breaking length and TEA, but the EFB paper has better tear index, and they have similar burst index.

This indicates that the EFB pulp should make a reasonably good quality bleached paper.

Bleached EFB Paper Properties

Table IX provides a comparison of the properties of 64 gsm and 74 gsm bleached EFB papers with the properties of commercially available 80 gsm bleached paper from Malaysia. Due to the failure of the AKD size to cure properly, these results should be interpreted with caution.

Comparing the 64 gsm bleached EFB paper with the 80 gsm commercial paper, as would be expected from the lower basis weight, the 64 gsm bleached EFB paper generally exhibits lower physical properties than those of the 80 gsm paper.

The 74 gsm bleached EFB paper exhibits physical properties more similar to those of the 80 gsm paper, in particular the TEA.

Brightness of both bleached EFB papers was higher than the commercial paper, and the opacity of the three samples was similar.

SUMMARY & CONCLUSIONS

The EFB pilot-scale papermaking was only partially successful, but still provided valuable information regarding this potentially low cost fiber resource. The papermaking trials showed:

1. It is evident that the EFB pulps contain significant quantities of fines, and likely parenchyma, making the sheet have high adhesion as compared to wood pulp. For high EFB pulp content furnishes, the paper machine design and felt selection will need to take this into consideration.

2. It is doubtful that a sheet consisting of 100 % EFB fiber (with or without GCC filler) can be made to run reliably at a commercial scale, without the use of specialty additives and special wet-end and dry-end design. It is recommended that a reinforcing fiber such as softwood kraft pulp is used in the furnish.

3. The unbleached sheet consisting of 80 % EFB pulp and 20 % softwood kraft brownstock was well-formed and appeared to have acceptable strength and surface properties. The sheet is light brown in color, with no excessive shives, dirt or foreign bodies.

4. The bleached sheets consisting of 70% bleached EFB pulp, 15% bleached softwood kraft pulp and 15% GCC filler were well-formed and appeared to have acceptable strength and surface properties. The sheets were bluish white and had high brightness, with no excessive shives, dirt or foreign bodies.

5. However, due to the low temperatures used to avoid sticking, it was not possible to surface size the sheet as the internal AKD size had not cured properly. If the sticking problems can be resolved through paper machine design and felt selection, and the dryer temperatures increased, surface sizing should be possible. Another possibility for resolving the sticking problems may be increasing the amount of softwood kraft pulp used in the furnish.

6. Given the test results for the EFB papers, with a larger amount of EFB pulp (say 500 kg) that would allow more experimental time on the pilot paper machine to overcome the sticking problems and perhaps a modified furnish with about 5 - 10% more softwood kraft pulp, we believe that paper grades with physical properties similar to the commercial paper could be produced.

Test	Units	Unbleached Pulp					DEpD Bleached Pulp			
Beating	rev	0	750	1500	2250	3000	0	1000	2000	3000
Freeness	CSF, ml	513	385	302	246	180	201	164	145	132
Basis weight	g/m^2	65.0	66.2	66.9	66.2	62.7	65.2	65.3	64.9	64.9
Thickness	µm	151.8	116.6	109.8	97.0	83.2	96.8	80.2	80.4	79.6
Bulk	cm^3/g	2.34	1.76	1.64	1.47	1.33	1.50	1.20	1.20	1.20
Density	g/cm^3	0.427	0.568	0.610	0.680	0.752	0.667	0.833	0.833	0.833
Tear Index	$mN \cdot m^2/g$	7.35	9.37	9.49	8.85	8.17	9.6	8.8	8.2	7.4
Burst Index	$kPa \cdot m^2/g$	1.75	3.54	4.21	4.25	4.72	4.1	4.4	4.5	4.6
Tensile Index	Nm/g	27.95	41.38	45.76	48.11	49.29	49.19	50.48	54.86	53.52
Fold		13	51	122	368	570	310	946	1397	1238
Stiffness	mN	7.1	6.8	6.8	5.7	4.1	n/a	n/a	n/a	n/a
TEA	J/m2	51.3	138.2	166.2	138.1	115.0	156.0	108.5	120.0	85.3
Stretch	%	3.60	6.34	6.85	5.50	4.72	5.95	4.10	4.20	3.23
Smoothness	Sheffield, s	387	344	302	280	228	322	241	226	n/a
Porosity	Gurley, s	0.88	5.59	9.99	27.94	74.87	3.45	18.7	101.0	n/a
Notes: 1. Tear Index based on 4 ply 2. Fold test based on M.I.T. Double Fold (2.5P) 3. Stiffness test based on Gurley 1" * 1-1/2" test										

I. Pilot-scale EFB pulp physical properties

Furnishes Tested			
a) 80% EFB bleached pulp + 20% Chinese GCC			
a) 65% EFB bleached pulp + 15% BSKP + 20% Chinese GCC			
Tinting Pigments (wet end)		**Additives Used**	
Cartaren Violet BN paste		Percol 182 powder (wet end)	
Cartaren Blue AN F-CN		Cationic Starch (wet end)	
OBA		AKD (wet end)	
liquid (wet end)		Perfectcat 975 of Avebe (size press) - tapioca starch	
Leucophor SAC liquid (size press)			
Order of Addition			
Furnish→GCC→Cationic Starch→Leucophor AP→Tinting Pigments→AKD→Percol 182→ handsheet→size press			
Addition Rates for Good Match to Both Furnishes			
Cationic starch	10 kg / o.d. mt	AKD	10 kg / o.d. mt
Leucophor AP	8 kg / o.d. mt	Percol 182	450 g / o.d. mt
Cartaren Violet BN paste	138 g / o.d. mt	Perfectcat 975	36 - 38 kg / o.d. mt
Cartaren Blue AN F-CN	41 g / o.d. mt	Leucophor SAC	10 kg / o.d. mt

II. Clariant dye shading & OBA recommendations

Furnish Tested			
80% bleached EFB pulp + 20% GCC			
Order of Addition			
Furnish→GCC→Cationic Starch→Leucophor AP→Tinting Pigments→AKD→Percol 182→ handsheet→size press			
Addition Rates for Good Match to Both Furnishes			
	Trial 1	**Trial 2**	**Trial 3**
Cationic starch	10 kg / OD mt	10 kg / OD mt	10 kg / OD mt
Leucophor AP	8 kg / OD mt	32 kg /OD mt	16 kg / OD mt
Cartaren Violet BN paste	138 g / OD mt	552 g / OD mt	179.4 g / OD mt
Cartaren Blue AN F-CN	41 g / OD mt	164 g / OD mt	53.3 g / OD mt
AKD	10 kg / OD mt	10 kg / OD mt	10 kg / OD mt
Percol 182	450 g / OD mt	450 g / OD mt	450 g / OD mt

III. NCSU additives, tinting pigments and OBA charges - bench-scale trials

	Standard	Trial 1	Trial 2	Trial 3
1. L*a*b* testing (D65 illuminant at 2 degrees for L*a*b*, C illuminant for ISO)				
L*	91.98	92.28	87.61	92.18
a*	5.09	4.49	8.42	5.81
b*	-13.99	-11.66	-22.58	-15.61
D65 B	100	97.29	101.8	103
ISO B	91.7	88.9	89.9	92.1
Spectral Curve				
400 nm	52	49.97	32.28	37.95
420 nm	96.86	93.57	87.68	93.36
440 nm	109.27	106.32	115.76	115.73
460 nm	99.86	96.97	102.42	103.22
480 nm	93.93	91.35	91.4	95.13
500 nm	88.25	85.93	80.6	87.75
520 nm	83.7	82.78	73.7	83.09
540 nm	79.76	80.5	69.51	80.03
560 nm	77.35	79.36	67.16	78.56
580 nm	76.39	78.68	65.93	77.75
600 nm	76.84	79.25	66.57	78.22
620 nm	79.83	80.49	68.66	79.69
640 nm	85.39	82.71	72.68	82.17
660 nm	89.77	84.98	77.16	84.68
680 nm	91.52	85.9	79.16	85.76
700 nm	92.21	86.73	80.56	86.54

2. Flourescence testing (D65 illuminant at 10 degrees / UVEX)								
	Standard		**Trial 1**		**Trial 2**		**Trial 3**	
	D65	**UVEX**	**D65**	**UVEX**	**D65**	**UVEX**	**D65**	**UVEX**
L*	92.4	91.4	92.58	91.61	88.28	86.74		
a*	2.87	0.12	2.92	0.17	4.99	1.11		
b*	-13.42	-3.5	-11.19	-0.96	-21.32	-7.51		
B	100.1	84.5	97.2	81.6	101.6	79.5		

IV. NCSU shade matching & OBA test results – bench-scale

Operating parameters	Basis weight range	33 – 325 g/m^2
	Speed range	9 – 45 m/min
	Production rate	23 – 46 kg/hour (machine dried)
	Deckle width	14 – 15 in.
	Reel width	9 – 12 in.
Wet end	Headbox	Atmospheric
	Former	Fourdrinier type
	Wet end shake	Included for good formation
	Table rolls	
	Vacuum flat boxes	4
	Dandy roll	Included
	White water system	Complete recirculation loop
	Additives system	High-shear makedown tanks, continuous metering to multiple points in wet end
Press section	1st press	Forward type, felted
	2nd press	Reversing type, felted
	3rd press	Smoothing type, unfelted
Dry end	1st dryer section	8 steam heated cylinders
	Size press	Metering type, inclined, flooded-nip
	2nd dryer section	5 steam heated cylinders
	Scanner	Measurex 2002 with basis weight and moisture control
	Calendar stack	2 hard nips, 1 soft nip

V. Pilot Paper Machine Description

	Trial	Basis Weight, g/m^2	Furnish	Surface Sizing
Unbleached paper	1	70	100% EFB pulp	Yes
	2	40	80% EFB pulp, 20% softwood kraft brownstock	No
Bleached paper	3	80	85% EFB pulp, 15% GCC filler	Yes
	4	60	85% EFB pulp, 15% GCC filler	Yes
	5	60	70% EFB pulp, 15% softwood kraft, 15% GCC filler	Yes

VI. Paper machine trial target basis weights and furnishes

Furnish	
80% EFB bleached pulp, 20% GCC	
Order of Addition	
Furnish→GCC→Cationic Starch→Leucophor AP→Tinting Pigments→AKD→Percol 182	
Addition Rates	
Cationic starch	10 kg / OD mt
Leucophor AP	16 kg / OD mt
Cartaren Violet BN paste	179.4 g / OD mt
Cartaren Blue AN F-CN	53.3 g / OD mt
AKD	10 kg / OD mt
Percol 182	450 g / OD mt
Note: 20% GCC filler was added to the furnish to account for wire losses.	

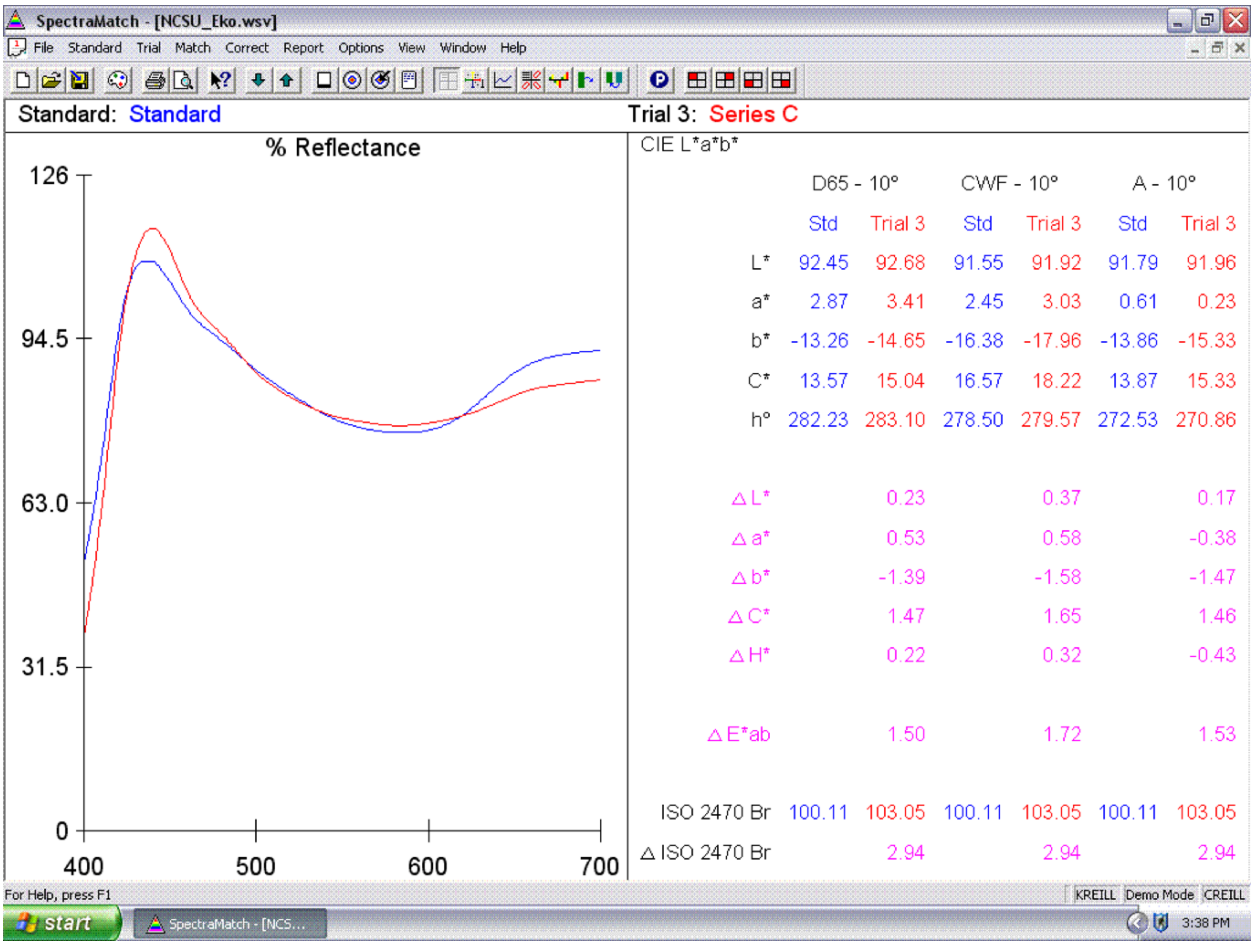
VII. Papermaking Trial 3 Furnish & Additives

		Unbleached EFB Pilot Machine Paper (Not Surface Sized, Calendared)		Commercial Paper (Surface Sized and Calendared)	
Furnish		80% unbleached EFB 20% unbleached softwood kraft			
Basis Weight	g/m^2	66.8		78.3	
Calliper	microns	118		108.1	
Apparent density	g/cm^3	0.566		0.725	
Bulk	cm^3/g	1.77		1.38	
		MD	**CD**	**MD**	**CD**
Breaking Length	km	4.56	2.51	6.69	2.77
Tensile Index	Nm/g	30.3	15.6		
Tensile Stretch	%	2.52	3.7	1.67	2.81
Tensile Energy Absorption	J/m^2	51.9	45.5	57.03	43.82
Tearing Index	$mN*m^2/g$	8.59	9.75	8.27	8.31
Taber Stiffness Units		14.3	6.96	3.6	1.7
MIT double folds (3 lb spring)		42	14		
		WS	**FS**	**WS**	**FS**
Burst Index	$kPa*m^2/g$	2.34	2.11	2.43	2.49
Wax Pick (Surface Strength)		9	6	14	13
Smoothness	Sheffield Units	220	214	119	109
Gurley Porosity	seconds	8.68	9.2	5.22	5.29
Oil (Ink) Absorption, Vanceometer	micro amps	9.7	9.9		
Hercules Size Test	seconds	925	960	39.7	36.8
Cobb Test	g/m^2	39.1	39.5	0.65	0.66
Brightness	% ISO	33.9	34.1	87.1	86.6
TAPPI Opacity	%	51	50.9	93.6	93.5
NOTES: MD - machine direction , CD - cross direction, WS - wire side, FS - felt side					

VIII. Unbleached EFB paper properties vs. commercial paper

		Bleached EFB Pilot Machine Paper (Not Surface Sized, Not Calendared)				Commercial Paper (Surface Sized and Calendared)	
Furnish		70% bleached EFB 15% bleached softwood kraft 15% GCC filler					
Breaker Stack		No Stack		Stack used after first dryer section			
General Properties							
Basis Weight	g/m^2	64.1		74.4		78.3	
Calliper	microns	85.1		99.9		108.1	
Apparent density	g/cm^3	0.753		0.745		0.725	
Bulk	cm^3/g	1.33		1.34		1.38	
TAPPI Dirt Count	ppm	10.6		32			
		WS	FS	WS	FS	WS	FS
Gurley Porosity	seconds	29.5	37.9	54.1	54.9	5.22	5.29
Oil (Ink) Absorption, Vanceometer	micro amps	21	20	21	20		
Hercules Size Test	seconds	<1	<1	<1	<1	39.7	36.8
Cobb Test	g of water gain	n/a	n/a	n/a	n/a	0.65	0.66
Physical Properties		**MD**	**CD**	**MD**	**CD**	**MD**	**CD**
Breaking Length	km	4.23	2.05	5.23	2.62	6.69	2.77
Tensile Index	Nm/g	0.431	0.209	0.533	0.267		
Tensile Stretch	%	1.86	3.38	2.15	4.08	1.67	2.81
Tensile Energy Absorption	J/m^2	33.9	32.7	56.3	61.9	57.03	43.82
Tearing Index	$mN*m^2/g$	6.1	6.99	6.1	6.89	8.27	8.31
Taber Stiffness Units		1.1	1.6	1.1	0.7	3.6	1.7
MIT double folds (3 lb spring)		544	186	764	228		
		WS	**FS**	**WS**	**FS**	**WS**	**FS**
Burst Index	$kPa*m^2/g$	1.32	1.39	1.6	1.82	2.43	2.49
Wax Pick (Surface Strength)		16	16	16	14	14	13
Surface Properties		**WS**	**FS**	**WS**	**FS**	**WS**	**FS**
Smoothness	Sheffield Units	153	181	122	132	119	109
Optical Properties		**WS**	**FS**	**WS**	**FS**	**WS**	**FS**
Brightness	% ISO	90.7	90.6	90.7	90.7	87.1	86.6
TAPPI Opacity	%	90.6		91.9		93.6	93.5
Whiteness, CIE (D65)		147	147	149	150		
Color	L*	92.2		91.7			
	a*	4.97		5.2			
	b*	-14.3		-15.1			
NOTES: MD - machine direction, CD - cross direction, WS - wire side, FS - felt side							

IX. Bleached EFB paper properties vs. commercial paper



1. SpectraMatch – Standard vs. NCSU bench-scale Trial 3

PEERS
November 5-8, 2017
NORFOLK, VIRGINIA

Pilot Papermaking with Malaysian Oil Palm Empty Fruit Bunch Pulp

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Agenda

- **Introduction**
  - Oil Palm General Facts (Malaysia)
  - Previous Work
- Experimental
- Results
- Summary & Conclusions

Palm Oil General Facts (Malaysia)

- Oil palm (*Elaeis guineensis)* originated in Central and West Africa
- Malaysia
  - 4.7 million hectares of oil palm plantations
  - 19 million tonnes of palm oil per year
  - 2 million tonnes of palm kernel oil per year
  - Typical yield about 20 tons of fruit/ha/year
  - Some new clones yield up to 28 tons/ha/year

Palm Oil General Facts (Malaysia)

- Plantations generate significant amount of biomass
- Fronds - no significant commercial uses and normally returned to soil as mulch
- Trunks and canopy - typically pulverized and returned to soil, some trunks converted to plywood in combination wood veneers.
- Empty fruit bunches (EFB) – some used commercially for low-value products such as fiberboard and molded fiber products
- Most EFB returned to plantations as mulch

Palm Oil General Facts (Malaysia)

- Estimates of Malaysian EFB production vary
- Conservative estimate - about 20 million tonnes per year
- Opportunity to produce higher value papermaking pulp

Fresh Fruit Bunch

EFB

Extracted & Dried EFB Fiber

Previous Work

- Bench-scale pulping and bleaching of EFB fiber – reported at 2015 PEERS conference
- Pilot-scale pulping and bleaching of EFB fiber – reported at 2016 PEERS conference
- Paper published in Tappi Journal, June 2107, Vol. 16, No. 6

Agenda

- Introduction
- **Experimental**
  - Pulps
  - Stock preparation
  - Additives & color matching
  - Papermaking
- Results
- Summary & Conclusions

Pulps

EFB pulps:

- Produced in NCSU pilot plant using 2,300 liter direct steamed rotary globe digester
- Soda cooking
- DEpD bleaching
- 54 o.d. kg unbleached pulp
- 74 o.d. kg bleached pulp
- Details on pilot pulping & bleaching presented at 2016 PEERS

EFB Pulps

Test	Units	Unbleached Pulp	DEpD Bleached Pulp
Freeness	CSF, ml	**513**	**201**
Basis weight	g/m^2	65.0	65.2
Density	g/cm^3	0.427	0.667
Tear Index	$mN \cdot m^2/g$	7.35	9.6
Burst Index	$kPa \cdot m^2/g$	1.75	4.1
Tensile Index	Nm/g	27.95	49.19
Fold		13	310
Stiffness	mN	7.1	n/a
TEA	J/m2	51.3	156.0
Stretch	%	3.60	5.95
Smoothness	Sheffield, s	387	322
Porosity	Gurley, s	0.88	3.45

Other Pulps

Unbleached papermaking trials

- Softwood brownstock sourced from a local North Carolina kraft pulp mill.

Bleached papermaking trials

- Commercial bleached softwood kraft pulp

Stock Preparation System

LC Refining System

- Normal operation: 3 – 5% consistency

Stock Preparation – Unbleached Paper

Unbleached EFB Pulp

- 54 o.d. kg
- Starting freeness: 513 CSF
- Refining consistency: 2%
- EFB pulp susceptible to mechanical action
- Run single passes with light refiner load and test burst index
- Single pass: 3.4 kPa $\cdot m^2/g$
- No further refining

Softwood Brown Stock

- Refined to 250 ml CSF freeness in a single pass with refiner heavily loaded

Stock Preparation – Bleached Paper

Bleached EFB Pulp

- 74 o.d. kg
- Starting freeness: 201 CSF
- No refining

Commercial Bleached Softwood Kraft Pulp

- Refined to 250 ml CSF freeness in a single pass with refiner heavily loaded

Additives – Unbleached Paper

Additive	Dose, on o.d. fiber	Addition Point	Purpose
AKD size	0.20%	Machine chest, batch-wise	Internal sizing
Alum	0.25%		Reduce sheet adhesion
Cationic starch	0.25%	Headbox, continuous	Dry strength retention aid
Cooked corn starch	6% solution	Size press	Surface sizing

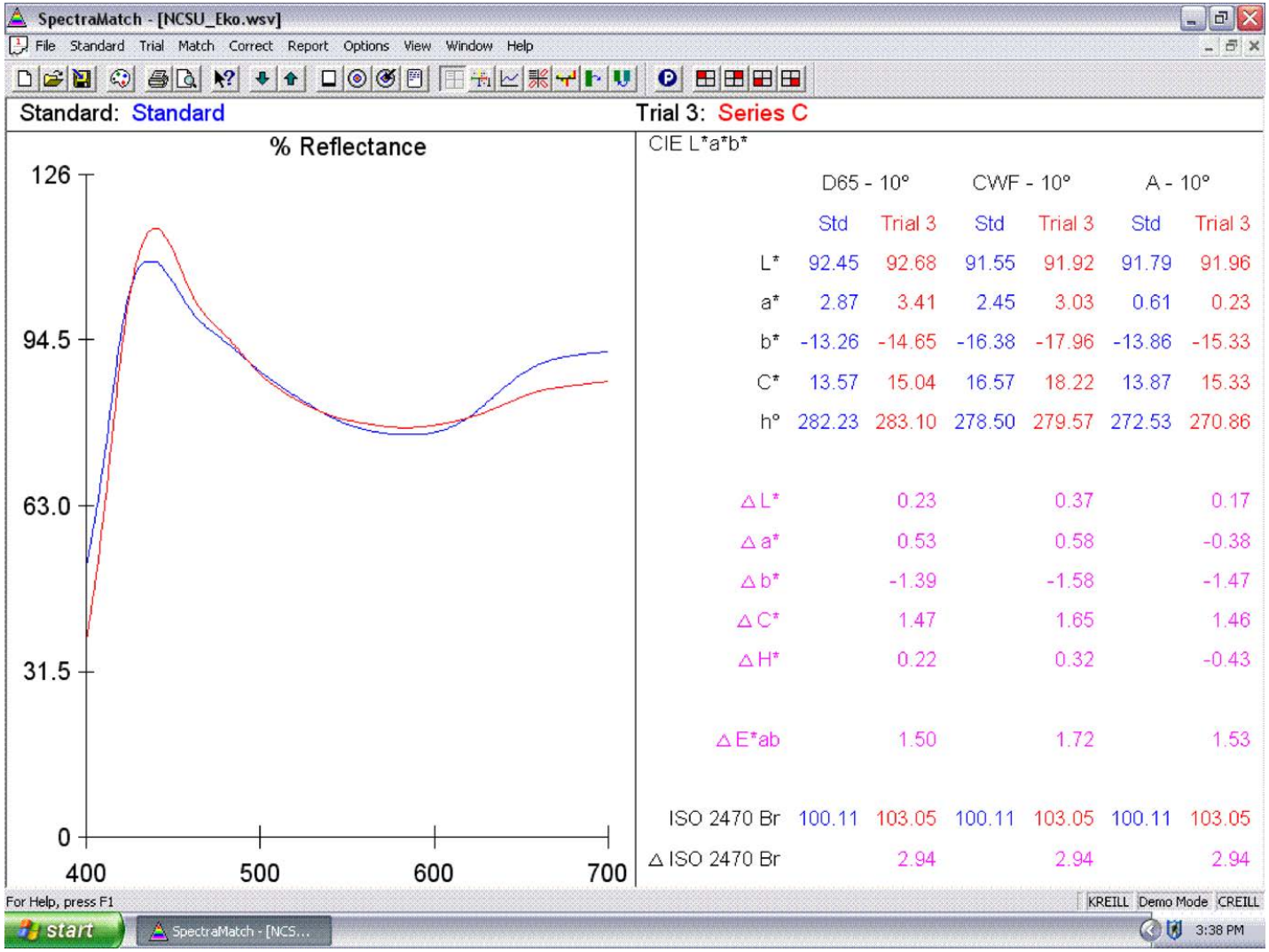
Additives & Color Matching – Bleached Paper

- Bleached paper to have a bluish-white color similar commercial copy paper commercially available in Malaysia
- Shade matching tests at Shanghai R&D centre of Clariant Chemicals (China) Ltd. using samples of the pilot-scale bleached EFB pulp from NCSU and the commercial paper sample
- Three bench-scale shade matching and OBA trials were carried out at NCSU based on Clariant tests
- NCSU bench-scale Trial 3 conditions were used for the pilot-scale additives, tinting pigments and OBA usage

Additives & Color Matching – Bleached Paper

Furnish Tested			
80% bleached EFB pulp + 20% GCC			
Order of Addition			
Furnish→GCC→Cationic Starch→Leucophor AP→Tinting Pigments→AKD→Percol 182→ handsheet→size press			
Addition Rates for Good Match			
	Trial 1	**Trial 2**	**Trial 3**
Cationic starch	10 kg / OD mt	10 kg / OD mt	10 kg / OD mt
Leucophor AP	8 kg / OD mt	32 kg /OD mt	16 kg / OD mt
Cartaren Violet BN paste	138 g / OD mt	552 g / OD mt	179.4 g / OD mt
Cartaren Blue AN F-CN	41 g / OD mt	164 g / OD mt	53.3 g / OD mt
AKD	10 kg / OD mt	10 kg / OD mt	10 kg / OD mt
Percol 182	450 g / OD mt	450 g / OD mt	450 g / OD mt

Additives & Color Matching – Bleached Paper



CIE L*a*b*

	D65 - 10°		CWF - 10°		A - 10°	
	Std	Trial 3	Std	Trial 3	Std	Trial 3
L*	92.45	92.68	91.55	91.92	91.79	91.96
a*	2.87	3.41	2.45	3.03	0.61	0.23
b*	-13.26	-14.65	-16.38	-17.96	-13.86	-15.33
C*	13.57	15.04	16.57	18.22	13.87	15.33
h°	282.23	283.10	278.50	279.57	272.53	270.86
Δ L*		0.23		0.37		0.17
Δ a*		0.53		0.58		-0.38
Δ b*		-1.39		-1.58		-1.47
Δ C*		1.47		1.65		1.46
Δ H*		0.22		0.32		-0.43
Δ E*ab		1.50		1.72		1.53
ISO 2470 Br	100.11	103.05	100.11	103.05	100.11	103.05
Δ ISO 2470 Br		2.94		2.94		2.94

SpectraMatch – Standard vs. NCSU bench-scale Trial 3

Pilot Paper Machine

Pilot Paper Machine

Operating parameters	Basis weight range	33 – 325 g/m^2
	Speed range	9 – 45 m/min
	Production rate	23 – 46 kg/hour (machine dried)
	Deckle width	14 – 15 in.
	Reel width	9 – 12 in.
Wet end	Headbox	Atmospheric
	Former	Fourdrinier type
	Wet end shake	Included for good formation
	Table rolls	
	Vacuum flat boxes	4
	Dandy roll	Included
	White water system	Complete recirculation loop
	Additives system	High-shear makedown tanks, continuous metering to multiple points in wet end
Press section	1st press	Forward type, felted
	2nd press	Reversing type, felted
	3rd press	Smoothing type, unfelted
Dry end	1st dryer section	8 steam heated cylinders
	Size press	Metering type, inclined, flooded-nip
	2nd dryer section	5 steam heated cylinders
	Scanner	Measurex 2002 with basis weight and moisture control
	Calendar stack	2 hard nips, 1 soft nip

Pilot Paper Machine

Previous experience with nonwood fiber pulps showed that many have poor machine runnability. Problems may include:

- poor drainage on the wire
- fines and parenchyma in the slurry mesh into the forming wire, making it difficult to get the sheet to release from the wire
- poor wet web strength, making it difficult for the sheet to successfully cross the 15 cm open draw between the couch roll and the first press
- severe sticking to the first press roll (high adhesion due to fines and parenchyma)
- severe sticking to the first three dryer cylinders
- high linting in the dryers
- excessive adhesion to the size press rolls once starch is applied

Pilot Paper Machine

Precautions taken to avoid these problems as much as possible:

- couch roll vacuum level reduced to a minimum - to promote sheet release

- first press roll and first three dryer cylinders were buffed with a rubbing compound and treated with three layers of a polymeric release agent - to prevent sheet sticking

Agenda

- Introduction
- Experimental
- **Results**
  - The Goal
  - Papermaking Trial 1
  - Papermaking Trial 2
  - Papermaking Trial 3
  - Papermaking Trial 4
  - Papermaking Trial 5
  - Offline Size Press Trial
  - Unbleached EFB Paper Properties
  - Bleached EFB Paper Properties
- Summary & Conclusions

The Goal

Papermaking Goal:

- Produce 30 kg each of five paper grades

	Trial	Basis Weight	Furnish	Surface Sizing
Unbleached paper	1	70 g/m^2	100% EFB pulp	Yes
	2	40 g/m^2	80% EFB pulp, 20% softwood kraft brownstock	No
Bleached paper	3	80 g/m^2	85% EFB pulp, 15% GCC filler	Yes
	4	60 g/m^2	85% EFB pulp, 15% GCC filler	Yes
	5	60 g/m^2	70% EFB pulp, 15% softwood kraft, 15% GCC filler	Yes

Papermaking Trial 1

Unbleached paper: 70 gsm, 100% EFB pulp, surface sizing

- Sheet enmeshed in forming wire
  - could not make it leave the wire and thread into the press section
- Increased basis weight and reduced couch vacuum
  - sheet still stuck on wire
- Trial halted to avoid wasting EFB pulp

Papermaking Trial 2

Unbleached paper: 40 gsm, 80% EFB pulp, 20% softwood kraft brownstock, no surface sizing

- Started running 70 gsm sheet

- Adding 20% highly-refined softwood kraft
  - allowed sheet to leave wire and thread into the first press section
  - sheet stuck to first press roll – could not get the sheet to release.

- By-passed first press and fed sheet into second press, a reversing press, so that the wire side of the sheet sees a smooth press roll
  - sheet released from second press, and it became possible to make paper.
  - behavior indicates that EFB fines and parenchyma cells made the sheet too sticky for traditional press rolls - wire side of sheet usually has lower content of these materials as they wash out of the bottom side of the sheet

Papermaking Trial 2

- Sheet tried to adhere to the first three dryer cylinders
  - turned down the temperature of the three cylinders
  - machine attendant continuously applied a thin film of release agent

- Sizing
  - ran sheet through to reel
  - started applying surface size gradually - sheet stuck in second dryer section
  - by-passed size press

- Did not attempt 40 gsm sheet due to problems with heavier sheet

- Produced un-sized 70 gsm sheet

Papermaking Trial 2

70 gsm, 80% EFB pulp, 20% softwood kraft brownstock, no surface sizing

Papermaking Trial 3

Bleached paper: 80 gsm, 85% EFB pulp, 15% GCC, surface sized

Furnish: 80% EFB bleached pulp, 20% GCC	
Order of Addition: Fiber→GCC→Cationic Starch→Leucophor AP→Tinting Pigments→AKD→Percol 182	
Addition Rates:	
Cationic starch	10 kg / OD mt
Leucophor AP	16 kg / OD mt
Cartaren Violet BN paste	179.4 g / OD mt
Cartaren Blue AN F-CN	53.3 g / OD mt
AKD	10 kg / OD mt
Percol 182	450 g / OD mt
Note: 20% GCC filler was added to the furnish to account for wire losses.	

Papermaking Trial 3

- Machine started up with a line speed of 14 metres/minute

- Sheet released from forming wire with no problems

- Sheet stuck to first press roll
  - machine stopped
  - polymer tape applied to first press roll
  - stopped sheet sticking
  - imparted heavy mark on the sheet

- Sheet released from second press roll

- Sheet stuck to smoothing press
  - by-passed press

Papermaking Trial 3

- 1st dryer section
  - if steam cylinder temperature > 88 ^{0}C, sheet would pick and stick to cylinder causing a sheet break
  - temperature of all of steam cylinders turned down to the temperature that prevented sticking

- Size press
  - by-passed as sheet to wet

- 2nd dryer section
  - would be used to complete drying
  - weak sheet and long draw between 1st and 2nd dryer sections caused sheet breaks

- Trial terminated without making any paper

Papermaking Trial 4

Bleached paper: 60 gsm, 85% EFB pulp, 15% GCC, surface sized

- Not attempted as 80 gsm trial with same furnish failed

Papermaking Trial 5

Bleached paper: 60 gsm, 70% EFB pulp, 15% bleached softwood kraft pulp, 15% GCC, surface sized

- Added refined bleached softwood kraft pulp to the furnish
- Additional quantities of additives were mixed in to account for the increased amount of fiber to maintain the additives loadings
- Significantly less sticking on the first press roll
-
- Less sticking in 1st first dryer section but still needed cylinder temperatures lower than 88 ^{0}C.
- By-passed size press
- Sheet strong enough to run from 1st to 2nd dryer groups
- Produced about 25 OD kg of paper on the reel

Papermaking Trial 5

65 gsm, 70% EFB pulp, 15% bleached softwood, 15% GCC, no surface sizing

Off-Line Size Press Trial

- One reel of fully-dried paper from Trial 5 mounted on unwind stand of the inclined, flooded-nip size press.
  - Ethylated starch prepared at 10% solids for surface application
  - 2nd heated very slightly, to dry the starch applied to the sheet.

- Multiple attempts were made to surface size the sheet
  - entering the flooded nip of the size, the sheet would pick up so much sizing that it would stick to the size press rolls or break immediately.

- Internal AKD sizing likely had not been effective
  - water drop test on the base sheet confirmed practically no resistance to penetration
  - low temperatures (max. 88 ^{0}C) required for the 1st and 2nd dryer sections to prevent sticking did not allow the AKD size to cure.

Unbleached EFB Paper Properties

- 70 gsm unbleached EFB paper compared to commercially available 80 gsm bleached paper from Malaysia.
- Commercial paper had better breaking length and TEA
- EFB paper has better tear index
- Both have similar burst index.
- Unbleached EFB paper (not surface sized) exhibits properties similar paper produced using a high content of nonwood pulp such as cereal straw or sugarcane bagasse

Unbleached EFB Paper Selected Properties

		Unbleached EFB Paper		Commercial Paper	
Basis Weight	g/m^2	66.8		78.3	
Apparent density	g/cm^3	0.566		0.725	
		MD	CD	MD	CD
Breaking Length	km	4.56	2.51	6.69	2.77
Tensile Stretch	%	2.52	3.7	1.67	2.81
TEA	J/m^2	51.9	45.5	57.03	43.82
Tearing Index	$mN*m^2/g$	8.59	9.75	8.27	8.31
		WS	FS	WS	FS
Burst Index	$kPa*m^2/g$	2.34	2.11	2.43	2.49

MD - machine direction , CD - cross direction, WS - wire side, FS - felt side

See paper for additional properties.

Bleached EFB Paper Properties

- 64 gsm and 74 gsm bleached EFB papers with the properties of commercially available 80 gsm bleached paper from Malaysia
- Due to the failure of the AKD size to cure properly, results should be interpreted with caution.
- 64 gsm bleached EFB paper generally exhibits lower physical properties than those of the 80 gsm paper.
- 74 gsm bleached EFB paper exhibits physical properties more similar to those of the 80 gsm paper, in particular the TEA.
- Brightness of both bleached EFB papers was higher than commercial paper, and the opacity of the three samples was similar.

Bleached EFB Paper Selected Properties

		Bleached EFB Pilot Machine Paper (Not Surface Sized, Not Calendared)				Commercial Paper (Surface Sized and Calendared)	
Breaker Stack		No Stack		Stack used after first dryer section			
Basis Weight	g/m^2	64.1		74.4		78.3	
Apparent density	g/cm^3	0.753		0.745		0.725	
		MD	CD	MD	CD	MD	CD
Breaking Length	km	4.23	2.05	5.23	2.62	6.69	2.77
Tensile Stretch	%	1.86	3.38	2.15	4.08	1.67	2.81
TEA	J/m^2	33.9	32.7	56.3	61.9	57.03	43.82
Tearing Index	$mN*m^2/g$	6.1	6.99	6.1	6.89	8.27	8.31
		WS	FS	WS	FS	WS	FS
Burst Index	$kPa*m^2/g$	1.32	1.39	1.6	1.82	2.43	2.49
Brightness	% ISO	90.7	90.6	90.7	90.7	87.1	86.6
TAPPI Opacity	%	90.6		91.9		93.6	93.5

NOTES: MD - machine direction, CD - cross direction, WS - wire side, FS - felt side

See paper for additional properties.

Agenda

- Introduction
- Experimental
- Results
- **Summary & Conclusions**

Summary & Conclusions

EFB pilot-scale papermaking was only partially successful. Trials showed:

1. EFB pulp appears to contain significant quantities of fines, and likely parenchyma, making the sheet have high adhesion as compared to wood pulp. For high EFB pulp content furnishes, this will impact paper machine design, and wire and felt selection.

2. It is doubtful that a 100% EFB sheet (with or without GCC filler) can run reliably at commercial scale without specialty additives and special wet-end and dry-end design. Recommend using a reinforcing fiber such as softwood kraft pulp.

3. The 80% EFB, 20% softwood kraft brownstock unbleached sheet was well-formed, and appeared to have acceptable strength and surface properties.

Summary & Conclusions

4. The 70% EFB, 15% BSK, 15% GCC bleached sheets were well-formed and appeared to have acceptable strength and surface properties. The sheets were bluish white and had high brightness, with no excessive shives, dirt or foreign bodies.

5. Low temperatures used to avoid sticking, prevented surface sizing the sheets as the internal AKD size had not cured properly.
   - paper machine design and wire and felt selection may resolve the sticking problems and allowing increased dryer temperatures and surface sizing
   - alternately increasing the amount of softwood kraft pulp may resolve the sticking problems

6. With a larger amount of EFB pulp that would allow more experimental time and perhaps a modified furnish with about 5 - 10% more softwood kraft pulp, paper grades with physical properties similar to the commercial paper likely could be produced.

Questions?

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