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RESPONSE OF PULP FIBRES TO MECHANICAL TREATMENT DURING MC FLUIDIZATION

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ABSTRACT

Medium consistency (MC) unit operations are becoming increasingly widespread in pulping and bleaching processes. Many MC devices, notably MC pumps, mixers and screens, rely on creation of a fluid-like state in the pulp suspension. This fluidization requires the dissipation of considerable energy and exposes the pulp fibres to mechanical treatment. The treatment alters pulp physical properties.

The changes in properties of a never-dried semi-bleached softwood kraft pulp with mechanical treatment were determined in a batch operated concentric-cylinder device. A fluid-like state was created in medium and low consistency pulp suspensions with treatment energy varying up to 10 MJ/kg pulp. The treatment energies encompassed the range used in mill and batch laboratory operations and the extensive exposure given during batch MC fluidization studies. MC treatment was found to beat, curl and microcompress the pulp fibres. The implications of MC treatment in mill devices are discussed.

INTRODUCTION

Medium consistency (MC) pulp suspensions have mass concentrations (C_m) in the range of 8 to 20%. Recent developments have enabled unit operations traditionally performed at low consistencies (0–8% C_m) to be carried out in the MC range. This technology has been quickly embraced in bleaching and pulping operations as it reduces the volume of suspension flows resulting in reduced equipment size and savings in capital cost (1). Many MC unit operations, notably pumping (2), mixing (1) and screening (3), rely on creation of a fluid-like state in the pulp suspension. As MC pulp fibre suspensions have complex rheology and display solid-like characteristics, the attainment of this state occurs only under specific conditions. In particular, sufficient shear must be imposed in the suspension to initiate movement and then to maintain small-scale fibre motion (4, 5). Continued maintenance of the fluid-like state requires expenditure of considerable energy and exposes the pulp fibres to mechanical treatment. This energy is ultimately dissipated as heat while the mechanical action alters the physical properties of the fibres. The changes in pulp properties that occur with MC treatment are of concern to pulp producers and pulp users, particularly as MC unit operations become more widespread.

Recent laboratory work has investigated the fluid-like behaviour of MC pulp suspensions in a batch operated concentric cylinder device (5). As part of this study the changes in pulp properties occurring during this treatment were measured. The treatment energies not only encompassed those typically found in mill devices (for example, 0.1–2 MJ/kg pulp in beating and refining) and MC laboratory mixers (6), but were extended to the very high values (0.3–14 MJ/kg pulp) encountered in the fluidization study (5). The results offer insight into the changes in pulp properties likely to occur in the commercial devices in addition to the effect that prolonged exposure could have on them.

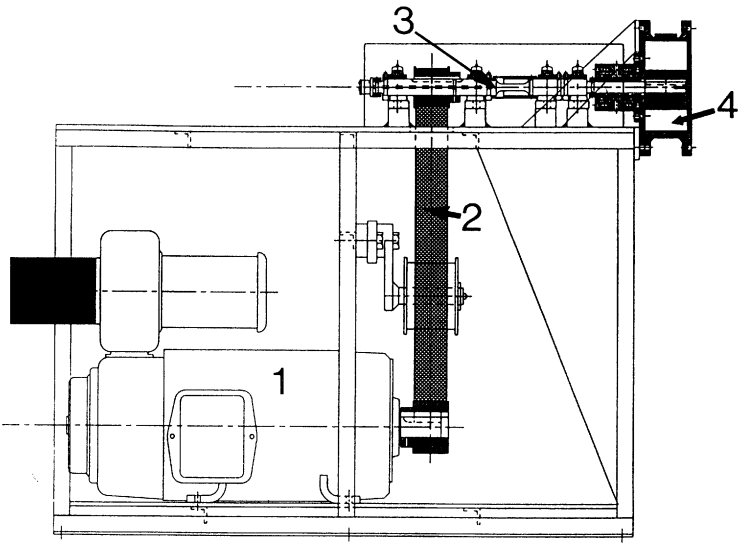


Fig 1– Side view of the pulp fluidizer. Shown in the drawing are the (1) 22.4 kW DC motor, (2) toothed drive belt, (3) fluidizer shaft and (4) fluidizer chamber.

EXPERIMENTAL

The laboratory pulp fluidizer (Figure 1) is a concentric-cylinder device powered by a 22.4 kW variable speed DC motor that permits a rotor attached to the fluidizer shaft to reach speeds of 524 rad/s. The pulp suspension is contained in a chamber formed between the rotor and a housing which provides the outer cylinder surface. The rotor has lugs that protrude into the pulp suspension to prevent slippage at the rotor/suspension interface, while the housing is baffled to prevent slip at the outer wall. A clear Lexan plate encloses the fluidizer chamber. Two rotor/housing combinations were used in the work reported here: a wide-gap (50 mm) and a narrow-gap (5 mm) configuration. They are illustrated in Figure 2 with dimensional details given in Table 1.

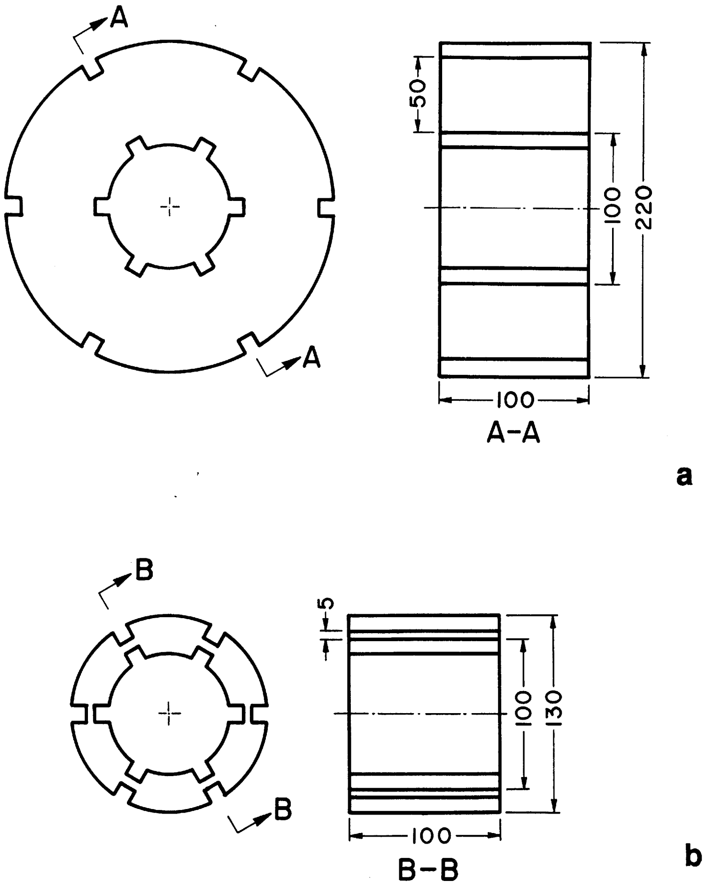


Fig 2– Pulp fluidizer rotor and housing configurations used in tests. Dimensions are given in millimetres. (a) Wide-gap configuration, (b) narrow-gap configuration.

Chamber Component	Units	Wide-Gap	Narrow-Gap
Housing			
diameter	mm	220	130
depth	mm	100	100
number of baffles		6	6
baffle dimensions	mm	10×10	10×10
Rotor			
diameter	mm	100	100
depth	mm	100	100
number of lugs		6	6
lug dimensions	mm	10×10	10×10
Gap width	mm	50	5
Volume of chamber	m^3	3.16×10^{-3}	7.1×10^{-4}

Table 1– Comparison of wide and narrow-gap chamber dimensions.

A measured weight of pulp was packed into the fluidizer chamber and the front cover secured. The rotor speed was then accelerated at 52.4 rad/s^2 to 524 rad/s. The maximum speed was held for different lengths of time to vary the treatment of the pulp suspension. Deceleration was at 52.4 rad/s^2. Torque and rotational speed were measured during the test and allowed computation of the treatment energy.

The pulp used in these tests was a commercial semi-bleached softwood kraft pulp from western Canada that had never been dried. It was treated at 9.7% C_m in the wide-gap configuration (Series A) and at 9.2% C_m in the narrow-gap configuration (Series B). A low consistency 6.4% C_m suspension was also treated in the wide-gap configuration (Series C). Energy exposure was varied up to 10 MJ/kg pulp. The standard procedures of the CPPA (Technical Section) were followed when evaluating pulp properties.

SAMPLE IDENTIFICATION	Control	A_1	A_2	A_3
TEST CONDITIONS				
Mass concentration, C_m,%		9.7	9.7	9.7
Time at maximum speed, s		5	20	40
Maximum temperature, ^{0}C		20.6	35.1	35.1
Maximum shear rate, s^{-1}		516	515	504
Peak power input, W/m^3		2.90×10^6	5.42×10^6	5.56×10^6
Energy input, J		9.47×10^4	4.01×10^5	7.44×10^5
Treatment energy, MJ/kg pulp		0.32	1.31	2.39
PULP PROPERTIES				
CSF, ml	680	615	499	451
Sheet bulk, cm^3/g	1.85	1.71	1.61	1.59
Burst index, kPa·m^2/g	4.07	5.25	6.47	6.52
Tear index, mN·m^2/g	22.0	18.8	17.3	17.2
Breaking length, km	4.67	6.28	7.39	7.28
Stretch, %	3.30	3.72	4.49	4.81
Air resistance Gurley, s/100 ml	<2	5.3	14.8	21.4
Opacity, %	79.2	77.2	75.4	73.8
Scattering coefficient (681 nm), cm^2/g	298	271	244	235
Weighted fibre length, mm	2.11	2.04	2.36	2.08
Zero-span breaking length, km	17.1	17.2	17.4	17.6

Table 2 – Pulp properties after treatment at medium consistency (9.7% C_m) in the wide-gap configuration of the fluidizer.

DISCUSSION

The effect of MC mechanical treatment on pulp properties is shown by the data given in Tables 2 to 4. For comparison, the properties of the pulp following a standard PFI mill beating run are given in Table 5. The Canadian standard freeness, sheet bulk, tensile breaking length and tear index for each test series is plotted in Figures 3 to 6 as a function of treatment energy. From these results it appears that two distinct treatments are experienced by the fibres during MC fluidization. The first is primarily a beating action at treatment energies below 2 MJ/kg pulp. Here, consistent with beating, the pulp freeness, sheet bulk and tear index drop with increasing energy input, while the breaking length increases. When the pulp consistency was lowered to 6.4%, the changes in pulp properties were less dramatic at the same treatment energy.

When the pulp was treated in the narrow-gap configuration the intense power input resulted in high treatment energies and rapid beating. The freeness dropped rapidly and levelled out above 4 MJ/kg pulp. The sheet bulk and tear index initially decreased and the tensile strength increased. However, as treatment was continued beyond 4–5 MJ/kg pulp the sheet bulk and tear index increased while the tensile strength decreased. This suggested that a transition had occurred from beating to severe curling and axial compression of the fibres.

The induction of curl and microcompressions in fibres treated in the narrow-gap configuration of the fluidizer is indicated by the data in Table 3 and photomicrographs of treated fibres. The increase in sheet bulk and tear index, and the decrease in tensile strength, are consistent with the induction of curl and microcompressions in the fibres generally observed in pulps treated at high consistencies (7). The increase in dry-sheet stretch is indicative of microcompressions in the fibres, while the increase in opacity, light scattering coefficient and porosity is consistent with an increase in sheet bulk resulting from curl and kinks in the fibres. The water retention value increased with treatment up to 3.3 MJ/kg pulp and then decreased with continued treatment. This is consistent with previous observations made on pulps treated mechanically at high consistencies (8), and has been attributed to the closure of pores in the fibre wall (9). The

SAMPLE IDENTIFICATION	Control	B_1	B_2	B_3
TEST CONDITIONS				
Mass concentration, C_m,%		9.2	9.2	9.2
Time at maximum speed, s		5	15	35
Maximum temperature, ^{0}C		46.5	72.9	115
Maximum shear rate, s^{-1}		4460	4510	4560
Peak power input, W/m^3		2.46×10^7	2.52×10^7	2.53×10^7
Energy input, J		2.09×10^5	3.75×10^5	7.09×10^5
Treatment energy, MJ/kg pulp		3.31	5.87	10.6
PULP PROPERTIES				
CSF, ml	680	386	335	345
Sheet bulk, cm^3/g	1.85	1.53	1.55	1.70
Burst index, kPa·m^2/g	4.07	6.79	6.54	4.48
Tear index, mN·m^2/g	22.0	15.9	17.9	26.2
Breaking length, km	4.67	7.26	6.47	4.07
Stretch, %	3.30	4.57	4.91	5.86
Air resistance Gurley, s/100 ml	<2	41.5	44.8	11.5
Opacity, %	79.2	73.1	73.1	80.5
Scattering coefficient (681 nm), cm^2/g	298	226	227	276
Weighted fibre length, mm	2.11	2.04	2.05	1.92
Zero-span breaking length, km	17.1	18.2	17.8	14.7
Water retention value, kg/kg	1.32	1.44	1.38	1.20
Curl index, fraction	0.134	0.162	0.174	0.194
Elastic modulus, km	596	669	600	465

Table 3– Pulp properties after treatment at medium consistency (9.2% C_m) in the narrow-gap configuration of the fluidizer.

SAMPLE IDENTIFICATION	Control	C_1	C_2	C_3
TEST CONDITIONS				
Mass concentration, C_m,%		6.4	6.4	6.4
Time at maximum speed, s		5	15	30
Maximum temperature, ^{0}C		25.8	34.5	47.2
Maximum shear rate, s^{-1}		511	486	492
Peak power input, W/m^3		5.56×10^6	5.55×10^6	5.67×10^6
Energy input, J		1.67×10^5	3.42×10^5	5.86×10^5
Treatment energy, MJ/kg pulp		0.82	1.66	2.78
PULP PROPERTIES				
CSF, ml	680	600	551	494
Sheet bulk, cm^3/g	1.85	1.73	1.66	1.64
Burst index, $kPa\cdot m^2/g$	4.07	5.22	5.76	6.25
Tear index, $mN\cdot m^2/g$	22.0	20.6	19.2	17.4
Breaking length, km	4.67	5.77	6.41	7.09
Stretch, %	3.30	4.57	4.91	5.66
Air resistance Gurley, s/100 ml	<2	7.2	12.8	18.4
Opacity, %	79.2	77.8	76.5	75.5
Scattering coefficient (681 nm), cm^2/g	298	273	259	252
Weighted fibre length, mm	2.11	2.16	1.83	1.88
Zero-span breaking length, km	17.1	17.4	17.7	17.4

Table 4 – Pulp properties after treatment at low consistency (6.4% C_m) in the wide-gap configuration of the fluidizer.

PFI REVOLUTIONS	0	300	600	2000	4000	8000
PULP PROPERTIES						
CSF, ml	683	673	662	591	496	320
Sheet bulk, cm^3/g	1.87	1.64	1.60	1.49	1.45	1.40
Burst index, $kPa \cdot m^2/g$	4.06	5.61	6.25	7.82	8.54	9.06
Tear index, $mN \cdot m^2/g$	21.1	16.1	14.6	11.0	10.4	10.1
Breaking length, km	4.77	6.54	8.01	9.45	10.6	11.0
Stretch, %	3.36	3.14	3.48	3.46	3.38	3.58
Air resistance Gurley, s/100 ml	2.7	4.8	6.9	14.9	37.4	149
Opacity, %	80.6	76.8	75.2	70.1	67.1	66.8
Scattering coefficient (681nm), cm^2/g	303	250	235	195	172	164
Weighted fibre length, mm	2.02	2.42	2.27	1.91	2.08	2.04
Zero-span breaking length, km	16.3	17.6	17.7	18.8	19.3	20.0

Table 5– Pulp properties after treatment in the PFI mill.

sheet elastic modulus first increased, as expected for beating, then decreased because of the increased occurrence of microcompressions. These observations are supported by measurement of the fibre curl index which increased with treatment as shown in Table 3. The fibres started out "moderately curly" and were "very curly" after prolonged treatment in the fluidizer.

The transition from beating to severe curling is further supported when the end points of the tensile stress–strain curves are plotted as shown in Figure 7. Here, when the treatment energy is below approximately 3 MJ/kg pulp (tests made in the wide-gap configuration) there is an increase in breaking length with increasing stretch which is indicative of beating and mild curling. When the treatment is continued above 3 MJ/kg pulp (tests conducted in the narrow-gap configuration) there is a decrease in breaking length with increasing stretch indicative of severe curling (7).

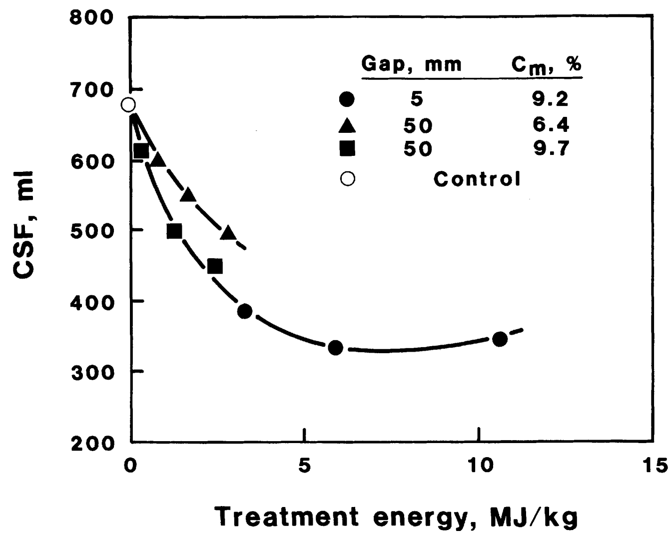


Fig 3– Canadian standard freeness vs. energy input for semi-bleached kraft pulp treated in the fluidizer.

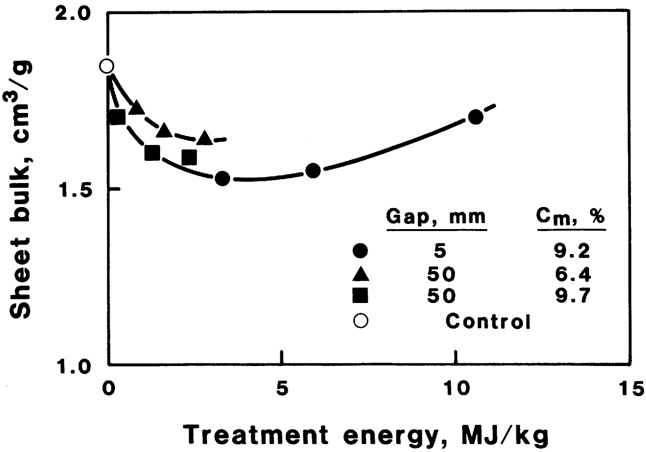


Fig 4– Sheet bulk vs. energy input for semi-bleached kraft pulp treated in the fluidizer.

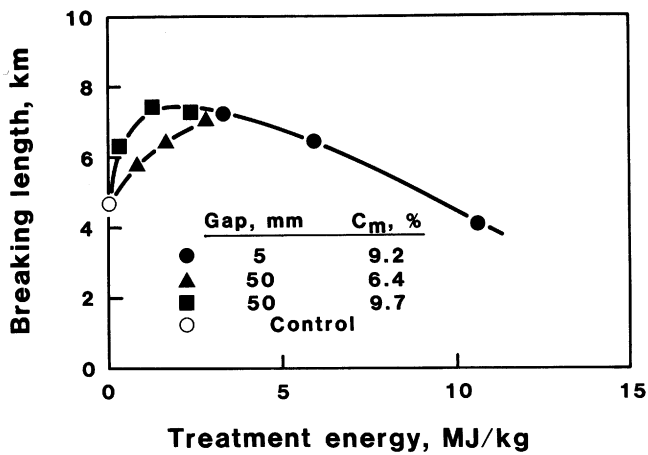


Fig 5– Tensile breaking length vs. energy input for semi-bleached kraft pulp treated in the fluidizer.

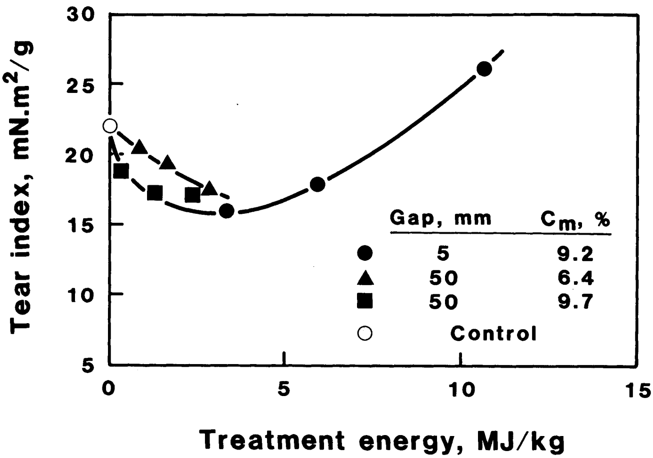


Fig 6– Tear index vs. energy input for semi-bleached kraft pulp treated in the fluidizer.

Thus, pulps treated in the fluidizer experience a combination of beating and curling. When the treatment energy is below 3 MJ/kg pulp the treatment is primarily beating with mild curling, however when the treatment is extensive the curling becomes severe. The tear index vs. tensile strength plots for the tests are given in Figure 8 and support this statement. At a given tensile strength, all the samples treated in the pulp fluidizer generally have a higher tear index than those treated in the PFI mill. This can be attributed to microcompressions induced in the fluidizer-treated fibres which are known to enhance the tear index (7, 10). For example, although sample B_2 (9.2% C_m pulp treated in the narrow-gap configuration) and the PFI pulp beaten for 300 revolutions have similar tensile strengths, sample B_2 is considerably more extensible than the PFI beaten pulp. The presence of microcompressions in the fluidizer-treated pulp is confirmed by the photomicrographs in Figure 9.

The treatment in the fluidizer did not reduce fibre length. The pulp strength (as indicated by the zero-span breaking length) was only reduced in the case of extensive treatment.

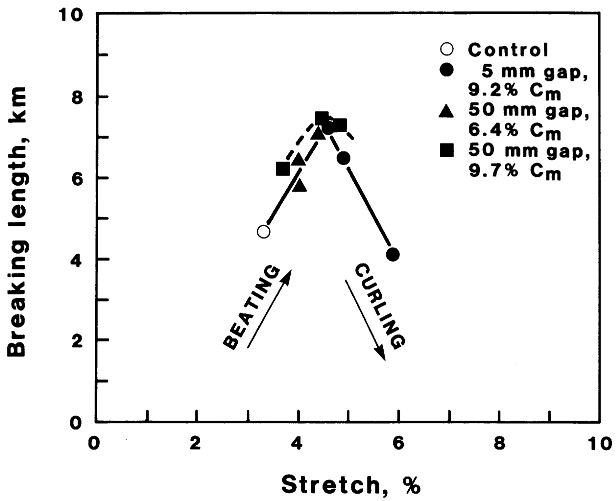


Fig 7– End points of tensile stress–strain curves for semi-bleached kraft pulp treated in the pulp fluidizer.

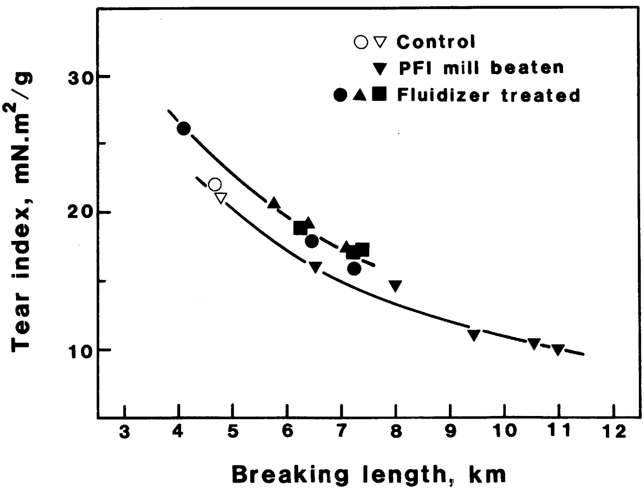
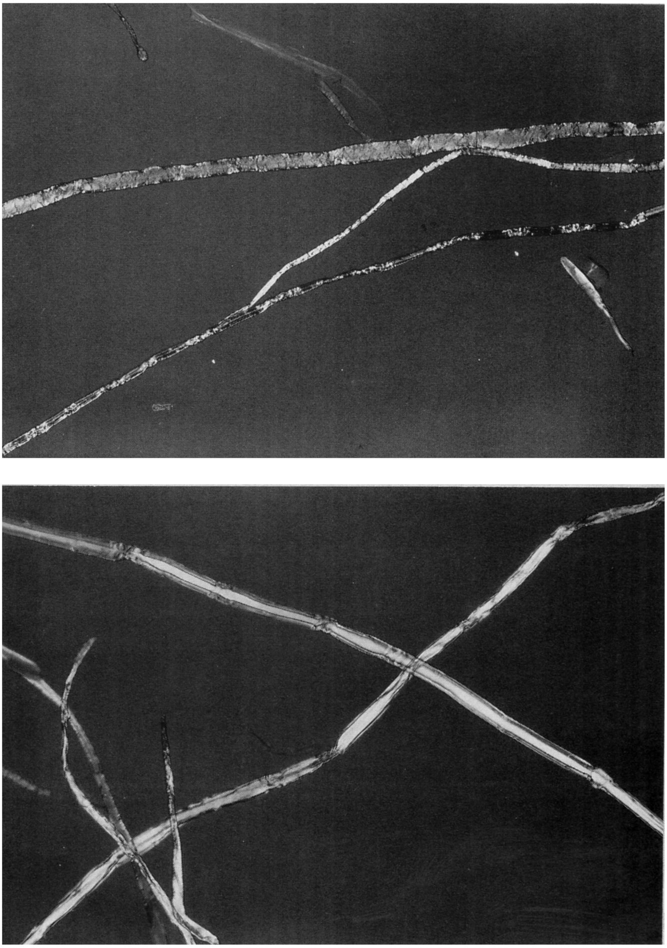


Fig 8– Tear index vs. tensile strength.



a

b

Fig 9– Photomicrographs of fibres confirm the presence of microcompressions in the fluidizer treated pulp. (a) Sample B_2, 9.2% C_m kraft pulp treated in the narrow-gap configuration of the fluidizer at 5.87 MJ/kg pulp. (b) Kraft pulp beaten for 300 revolutions in the PFI mill. These samples have similar tensile strengths. Sample B_2 is considerably more microcompressed and therefore has higher stretch and tear index than the PFI beaten sample.

CONCLUDING REMARKS

MC treatment of a semi-bleached softwood kraft pulp in the laboratory fluidizer beats, curls and microcompresses the pulp fibres. The extent of this treatment depends on the treatment energy and the consistency of the pulp suspension. The treatment appears similar to that experienced by LC (low consistency) pulps in some conventional bleach plants (11).

In the laboratory, bleaching studies employ MC mixers of similar design to that of the pulp fluidizer (12, 13). During MC bleaching, the energy imparted in mixing can reach 0.2 MJ/kg pulp (12) or more and the pulp fibres will experience only a modest decrease in freeness and bulk. However, tear and tensile properties change more rapidly with treatment. An exposure of 0.2 MJ/kg pulp can be expected to reduce tear and increase the breaking length by 10–20%.

In the mill, the extent of treatment is expected to depend on many factors including the geometry and flow pattern produced in the device, the energy expended in treatment, and the type and consistency of the pulp. Energy expenditure in MC mixing is typically 0.01–0.05 MJ/kg pulp (6) while a typical MC pump imparts approximately 0.01–0.02 MJ/kg pulp (14). Since a typical bleach plant may expose pulp to several "fluidizing" MC devices, the cumulative energy could easily be in the range of 0.05–0.15 MJ/kg pulp. The effect of mechanical treatment on pulp properties has been found to be additive (11) and changes in pulp properties similar to those described above are expected.

When MC treatment is severe ($>$ 3 MJ/kg pulp at 10% C_m) dramatic reduction in freeness is expected. The tear will begin to increase and the breaking length decrease as treatment is continued and as the fibres become more curled and microcompressed. It is extremely unlikely that pulp would be exposed to a treatment this severe in the mill. However, prolonged treatments in laboratory batch operations are possible, as was in the case of the batch fluidization studies (5). Here, dramatic changes in pulp properties can be expected.

ACKNOWLEDGEMENTS

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Transcription of Discussion

RESPONSE OF PULP FIBRES TO MECHANICAL TREATMENT DURING MC FLUIDIZATION

C. P. J. Bennington and R. S. Seth

Dr. A.H. Nissan, Westvaco

Dr. Seth, thank you very much, I think what you have done is very important. These mixers are being used more and more and I agree with all your findings; but I would like to make one point. I think part of the curling effect is due to the geometry that you have used, namely you rotated the inner rotors. I believe had you rotated the outer rotors at the same energy input you may not have had as much curling - because when you rotate the inner rotor you get Taylor vortices which give you twisting of the fibres and therefore, they would be conducive to curling. If you rotate the outer rotor the system is stable. You can go straight to turbulence but you will not go through Taylor-type vortices. The reason I am mentioning this is that it may be that commercial mixers may not have this curling effect at the same energy input if they avoid, in their design, secondary motions and vortices. Whereas if they don't, then they will have trouble.
In this respect, let me ask a question; in the very last slide where you compared commercial mixers with your instrument did you go high enough in energy input to produce the reversal in beating?

R.S. Seth

No, but pretty close. The effects were similar to those and the fluidizer. My co-author has worked in the area of fluidization. Chad, would you like to respond?

C.P.J. Bennington

With respect to fibre curling, the energy input supplied in the industrial scale pump and valve just brought us to the point of the peaks shown in the figures in the test.

R.Seth

That is correct.

Prof. B. Steenberg, Royal Institute of Technology, Sweden

Mr. Chairman, may I remind you that all old pulp and papermill engineers always added the power input on all the refiners and pumps in the system to check that installed power was sufficient for refining. They had found that the refining action of energy put into a pump, an impellor or a refiner was pretty much the same. Here we have an impellor and, of course, it beats. But on the question of curling your temperature is quite high. As a matter of fact the maximum in one of your Tables was 115°C which I don't understand. All of the temperatures at high input are high. We know that at such high temperatures fibres become plasticised and when you cool them they may become curled and you have to take that latency out by special treatment. My question is - was your pulp treated for any latency?

R.S. Seth

No, all the pulps were disintegrated following the standard practice. The pulp was a low yield kraft. These pulps do not have latency as high yield or mechanical pulps have. We have seen this before in other work.

Prof. B. Steenberg

But don't you think that the high temperature around 100 degrees could change the form of the fibres?

R.S. Seth

Not for low yield pulps, I believe.

Prof. B. Steenberg

You believe, but have you measured it?

R.S. Seth

No, we haven't it wasn't necessary.

Prof. B. Steenberg

You could do the same experiment by putting in the same energy in three or four short treatments so you would not achieve temperatures over 100 degrees.

R.S. Seth

Yes, I agree with you. However, for low yield pulps curling is more a function of mechanical treatment than thermal energy. Therefore, I do not think that temperature comes into it.

Prof. B. Steenberg

You don't think so - but you haven't made the tests? That is my point!

R.S. Seth

Yes - that is correct, but we have done a lot of work on curl and we have seen that temperature is not important for lower yield pulps. That work was presented at the last Symposium.
We have worked with the industrial machine loop on mechanical pulps and we have noticed similar effects - in that case we removed the latency from the control sample as well as the treated sample, but this is not necessary for low yield kraft pulps.

Dr. W.J.M. Douglas, McGill University, Canada

Raj and Chad, you have shown very nicely that gap width is not important - I wonder if you checked the separation of variables between energy and time rate at which you are putting the energy in. Your paper mentions only one speed I wonder if you checked to see if you obtain the same curve if you change the rate at which you put the energy in? (See also comment by P. Whiting which follows).

R.S. Seth

We have not done that - but it would be easy to do because the fluidizer is a useful device to study how various fibres will respond to these kinds of treatments. So, instead of doing it on an industrial scale where you need half a ton of pulp, we can work with a few kilograms in the fluidiser and determine the response to the mechanical treatment.

C.P.J. Bennington

You have to achieve a certain level of power dissipation to create a fluid-like state in the suspension. Therefore there are limits to the rate at which energy can be applied to the system. We have to maintain power input at or above the fluidization level.

R.C. Williams, James River

Have you ever extended the energy input beyond your data to see if you can get beyond the original bulk in going through the system?

R.S. Seth

These energies we covered are already excessive - we don't expect to meet them in commercial devices or even sets of devices, six, seven or eight units in a mill. So we decided not to pursue that.

P. Whiting, Abitibi-Price

We have done some experiments using a mixer similar to yours on mechanical pulps - and looked at energy inputs at levels even below the fluidization point and found that at a constant amount of energy we got the same changes in pulp properties irrespective of whether or not the pulp was fluidized, which we found rather interesting.

R.S. Seth

You were putting in work so it is like a beating action.

P. Whiting

Yes, it didn't matter whether or not we were fluidizing, there didn't seem to be any difference in the qualities provided we kept the total amount of energy going in constant.

R.S. Seth

What pulps were they - chemical or mechanical?

P. Whiting

These were mechanical pulps.

R.S. Seth

It is possible that mechanical pulps may respond differently to chemical pulps?

P. Whiting

Possibly, but we were seeing similar effects to those you have seen.

C.P.J. Bennington

For the softwood kraft pulp we were using, if the power input is below that required to achieve fluidization, we don't achieve complete suspension throughout the chamber. Again it is necessary to be above the fluidization level to ensure that every fibre is treated.