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Prepared contribution

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I WOULD like to mention briefly in this session a piece of work that will be published fully in *Pulp & Paper Magazine of Canada.* It is relevant to the whole question of the relationship between paper structure and its mechanical properties and has a bearing on the paper by Henderson *et al.* on high consistency refining.

An examination has been made of the literature on the effect of consistency at which stock preparation is carried out on the stress/strain properties of standard sheets. A completely consistent picture emerges. The higher the consistency, for a given production of tensile strength, the higher is the stretch-to-break. This applies for all pulps, all beaters and refiners, as well as over the entire consistency range used from 1.6 per cent in the Valley beater to 40 per cent in high consistency refining.

The effect can be explained by a single hitherto unconsidered action of the beater. It is suggested that fibres during stock treatment are subjected to forces of axial compression and that the forces are larger the higher the consistency, since they depend on the interaction of fibres. They are sufficient to cause an appreciable shortening of intact fibres and it is this shortening, which can be recovered during straining of the dry sheet, that increases the stretch-to-break.

The hypothesis is strongly supported by microscopical observations. Irrespective of the means of treatment, fibres treated at high consistency show a high content of compressional dislocations of the cell wall similar to those of axially compressed wood. Dislocations are less frequent, the lower the beating consistency. Conclusive evidence has been obtained by measurement of the lengths of the same individual fibres before and after high consistency treatment. An average shortening of several per cent has been observed on intact fibres. The implications of these findings for pulp evaluation, beater characterisation, theories of paper properties and the design of stock treatment equipment are considerable.

Discussion

Dr J. S. Barton—You will be interested to know that Dr J. d'A. Clark admitted to me before coming here that he should add this additional factor to his list, based on our work.

Mr H. P. Dahm—At the Norwegian Pulp and Paper Research Institute, we have studied high consistency refining in the PFI laboratory beater. By and large, the results obtained are similar to what has been reported here, though they do differ on a few points.

Most of you are familiar with the PFI mill and know that it has a roll and a housing that both rotate in the same direction, the roll having the greater peripheral speed. Centrifugal forces press the pulp against the wall of the housing and the pulp is carried (it does not flow) into the gap between them. It is possible to measure the distance between the roll and the housing during beating and, since the roll rests directly in the pulp layer, the distance gives some information about the nature of this layer.

In Fig. Q, the distance (mm) between roll and housing is plotted against the number of revolutions of the roll for the same amount of pulp (30 g oven-dry) being beaten at different consistencies. There is a very pronounced increase in gap as consistency rises to 40 per cent. At 50 per cent, marked shortening of the fibres takes place during beating and the gap is rapidly reduced. You can see also that the gap actually increases during beating at 40 per cent consistency. This and other observations have led us to believe that, in high consistency refining (HCR), the fibres form rolls or balls that may increase in diameter during beating. A result of this is that HCR pulp needs more disintegration after beating to loosen up the fibre bundles formed.

In contrast to what has been found elsewhere, our results indicate that more fines may be formed during high consistency refining than from beating at low consistencies, but that these fines differ considerably from the usual fines. Thus, beating at 40 per cent consistency gave five times as much colloidal material as beating at 10 per cent consistency, which indicates that fibrillation is taking place. Fines production will probably depend strongly on other factors—for instance, beating load—and this may explain the difference in observations on this point. We have also found (as mentioned earlier by Page) that it is possible to obtain the HCR effect without producing fines (in fact, even without beating) by granulating the pulp with a kitchen mixer. This gives results very similar to high consistency refining. Thus, wet elongation is increased by about 100 per cent.

We think that the HCR effect is a composite effect of kinking, curling and twisting the fibres and of fibrillation, but that the kinking, curling, etc. as such is sufficient to give much of the beneficial effect.

You may have noticed that I have not mentioned axial compression as one of the HCR effects. This does not mean that we think compression is unimportant, but it is probably in addition to the effect of the changes in fibre shape and flexibility, the latter effects being the most important.

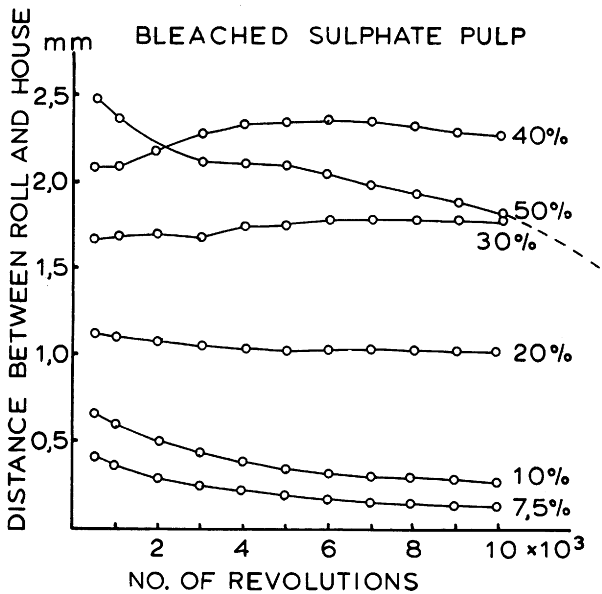

Fig. Q

Mrs R. Marton—High consistency refining is certainly one of the most important developments in recent years and deserves a lot of research. Why was most of the work carried out at the 30 per cent consistency level? Was it because the pulp came from the screwpress at 30 per cent? We have investigated the effect of refining at various levels of consistency on paper properties. Unbleached kraft pulp was beaten in a PFI mill at consistencies of 5, 10, 20 and 30 per cent, always using the same number of revolutions, to determine the variation in strength. It can be seen from Fig. R that for equal beating power input the freeness falls more slowly when the consistency increases. This is a well-known phenomenon that can be easily understood, since the fibres are not cut, but rub one against the other, so becoming fibrillated and activated.

When the strength properties of these pulps (Fig. S) are measured, it is seen that 30 per cent consistency is not necessarily the optimum for strength development. There is a marked increase in breaking length as the consistency increases to 10 per cent, then the slope of the curve reverses suddenly for each level of beating. These measurements were followed up by microscopic

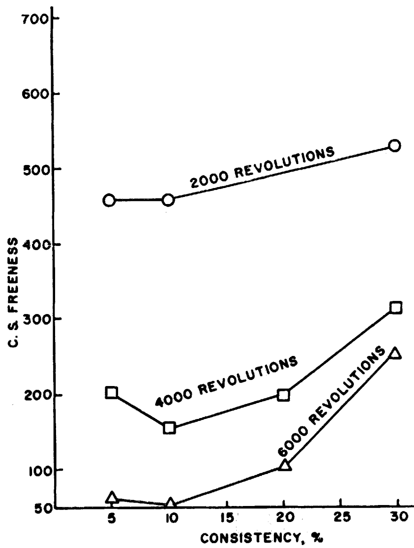

Fig. R—Changes in freeness on refining unbleached kraft pulp in PFI mill at various consistencies (freeness of original pulp was 680 CSF)

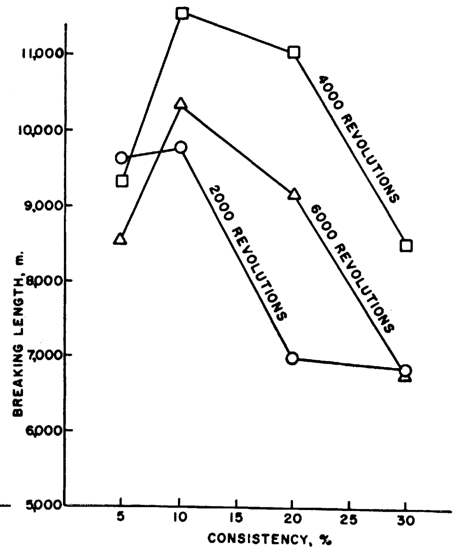

Fig. S—Changes in breaking length on refining unbleached kraft pulp in PFI mill at various consistencies (breaking length of original pulp was 5 400 m)

studies with polarised light, using cupriethylenediamine (cuene) treatment to accentuate the effect of refining damage. It was found that pulp refined at 5 per cent consistency is in general uniformly swollen by the cuene (Fig. T). At 10 per cent consistency, the fibres are much more activated, the outer layers of the wall are removed (Fig. U); the wall itself is more transparent than for the 5 per cent consistency beating, which explains why the strength continues to rise. At 20 per cent consistency, marked disintegration of the cell wall material is seen to occur (Fig. V). The fibres are extremely swollen, forming balloons

Fig. T—Kraft pulp refined in PFI mill at 5 per cent consistency for 4 000 rev: fibres treated with cupriethylenediamine [× 100]

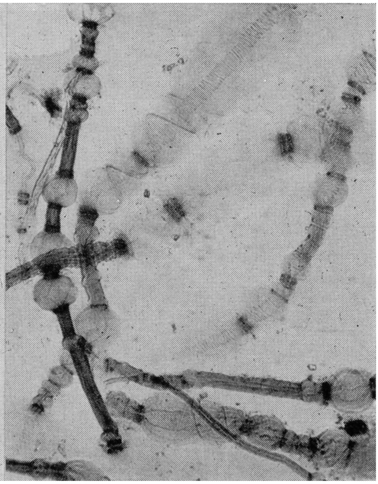

Fig. U—Kraft pulp refined in PFI mill at 10 per cent consistency for 4 000 rev: fibres treated with cupriethylenediamine [× 100]

Fig. V—Kraft pulp refined in PFI mill at 20 per cent consistency for 4 000 rev: fibres treated with cupriethylenediamine [× 100]

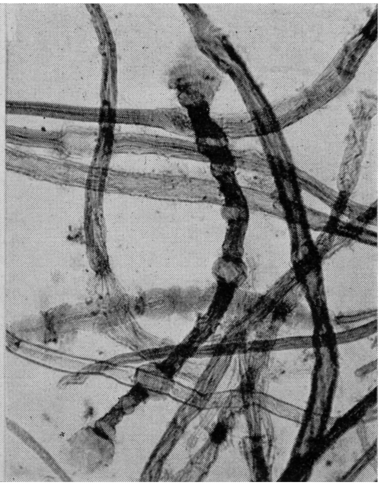

Fig. W—Kraft pulp refined in PFI mill at 30 per cent consistency for 4 000 rev: fibres treated with cupriethylenediamine [× 100] at many points and are almost dissolved in the cuene, which indicates that they are severely damaged: a fall in strength can therefore be expected. At 30 per cent consistency, the fibres seem to be less uniformly activated (Fig. W). Some of them are now swollen or even ballooned as if they were unaffected by the refining, whereas others are strongly beaten.

One point to be watched very carefully in high consistency refining is the formation of *fish eyes* (knots) during pressing of the pulp. They originate from the compressed flocs and are very difficult to disperse. Their amount in screw-pressing the pulp to 30 per cent consistency is quite appreciable and may show up as spots in the sheet of paper. When the pulp is refined at optimum consistency (which might be lower than 30 per cent), these flocs might be smaller and easier to disperse. Pulps other than that used for this work, also hardwood pulps, show a maximum in the curves of strength properties plotted against consistency: the location of these maxima depends on the yield of pulp and on the kind of wood used.

To some extent, these results obtained on laboratory equipment are supported by results from large industrial installations, which indicate that different grades of pulp may require different consistency levels for optimum results.

Mr G. F. Underhay—May I ask about the behaviour of sulphite pulp in contrast to sulphate pulp? I know that at one time sulphite pulp was not so well able to respond to HCR treatment as sulphate pulp. What is the present position?

Secondly, may I query your statement about getting away with using more mechanical pulp? We should approach this matter the other way round by telling our customers of the difficulties in putting 100 per cent groundwood into newsprint and similar papers. We should emphasise that, by doing this, the customer gets a better quality sheet with improved opacity and printability. Incidentally, we shall reduce some of our problems at the same time, including effluent disposal.

Thirdly, may I say, especially as my old friend Jim Clark is not here, that I very much prefer to see strength development curves plotted against energy consumption than against freeness. Freeness is of no direct importance to the finished sheet of paper and we pander far too much to papermachines in endeavouring to produce a range of freeness that suits them. Wet ends can now be made very flexible with the many devices for controlling drainage, therefore freeness should surely be put much further into the background than it is.

Dr Barton—We were concerned about freeness and I referred to it therefore in the way I did; perhaps we should have taken another variable, another parameter. We will certainly try that. We had quite a conversation with Dr Clark on this subject, as you can imagine.

On groundwood, this was an unfortunate piece of phraseology, because we are certainly anxious to use all the groundwood that we can, not only for economy, but for the very desirable qualities it has for many grades of paper. In newsprint, we have been able to reduce the chemical pulp requirement dramatically by HCR treatment.

It is certainly true that sulphite and sulphate pulps respond differently to beating. The only way we can explain it is that kraft is a harder beating pulp and so it takes this kind of treatment much better than does sulphite pulp. In air-dried handsheets, there is very little difference between the two pulps, but, as soon as they are dried under forced conditions, the strength improvement falls off in the sulphite pulp compared with the kraft pulp. We probably have some more work to do on the type of refiner plates we use and on the operating conditions used in treating sulphite pulp. In our own affairs, this is a very minor problem, as kraft pulp is what we are concerned with primarily. One trend we have certainly noted is that sulphite pulp cooked at a higher pH value responds more like kraft pulp.

The flocs mentioned by Mrs Marton and their effect on formation are certainly something to be careful about and it calls for more skill from the machine operators. As a compromise, we have to touch up the pulp with jordan treatment, thus we have to compromise on stretch to get formation.

I believe consistency was dealt with in West's first paper. A graph of consistency against stretch from his data would give a curve somewhat like that Page talked about. At about 25 per cent consistency, the stretch increase fell off and, because of the system geometry, we were unable to handle more than 40 per cent consistency, at which value we encountered feeding difficulties. Since the curve flattened off at this consistency, we decided to operate in this range. It was not accidental, but was probably fortuitous, since the work in Norway showed that, if 40 per cent consistency is exceeded, effects that are not at all advantageous intrude, so this seems to be the optimum range in which to operate.

Dr H. F. Rance—May I take a little further Page's comments in which he speculatively relates microcompression in the fibres from shrunken sheets to microcompression in fibres from HCR pulp. To carry the speculation a little further, I wonder what is the essential difference between high consistency refining at 40 per cent solids and planar compaction at 60 per cent water content. I honestly believe that we have microcompression of the same type in all these three phenomena and this may be the common ground of the high extensibility of paper resulting from these three different treatments.

Mr D. H. Page—That will be mentioned in my paper yet to be published.

Dr H. K. Corte—We experimented on high consistency refining 12 years ago, but we were using a fast-rotating peg mill, a production size instrument. Contrary to what we have heard here, we observed no increase in stretch at the same strength. Stretch at break increased with tensile strength as one would expect, but the property that was improved was tearing strength, as well as the folding endurance. When we looked at the fibres, we saw that they were hardly shortened at all, but were curled and they tended to be twisted into knots. Consequently, they compacted much less easily than fibres refined in a hollander or in a conical refiner. The marked effect of note was the preservation of the fibre length and a corresponding increase in tearing strength.

Dr N. Hartler—In an article some years ago,* we reported the very marked influence of mechanical treatment at high consistency upon the floating tendency of rayon pulp sheets—that is, the ability of such a sheet to be 'filled' with mercerisation lye without air inclusion. At that time, we were unable to explain the findings. The HCR results now presented seem to indicate that such a sheet would swell more readily on mercerisation, thereby reducing the chances of air inclusion.

In addition to this, is there any critical temperature during high consistency beating and is there any relationship between this and the second order transitions at high temperatures described during this symposium by Goring?

Dr Barton—We learned somewhat accidently of the importance of quenching the pulp with water immediately after refining. When this was omitted, we found that pulp strength fell somewhat after a few days. The fact that heating pulp slurries reduces strength has been observed by many others. This was something integral in the process that one had to take care of.

Dr H. G. Higgins—The PFI beater work in our laboratory by Watson & Phillips referred to by Page has been advanced considerably since the data mentioned were collated and results similar to those reported today were obtained for stretch and tearing strength, in the same consistency range.

It is suggested in the paper (page 878) that 'a pulp in the 25–40 per cent consistency range can therefore be characterised as a somewhat compressible, semi-solid substance, in contrast to the flowable dispersion of fibres in water at conventional refining consistencies of below 6 per cent'. This is in keeping with Watson & Phillips' concept of compression/decompression cycles

* *Tappi*, 1963, **46** (1), 50–52

during beating in the PFI mill. Results for 35–40 per cent consistency have been reported, but are there data for consistencies at 15–30 per cent?

Dr Barton—The effect of operating at lower consistencies is that more fibre cutting takes place; moreover, this type of refiner uses more power per ton. Unless there is some reason for doing so, it is rather impractical.

Dr S. Rydholm—In the graph shown by Dahm (Fig. Q) are the distances between the beating surfaces considered to be real measurements or just an expression of experimental conditions? What is the distance between the beating surfaces at, say, 6 per cent consistency?

Mr Dahm—The measurements are real, but I am afraid I cannot give any exact information about the distances at low consistencies.

Dr Hartler—In order to relate single fibre properties to sheet properties, we have been concerned with a somewhat similar approach to that presented

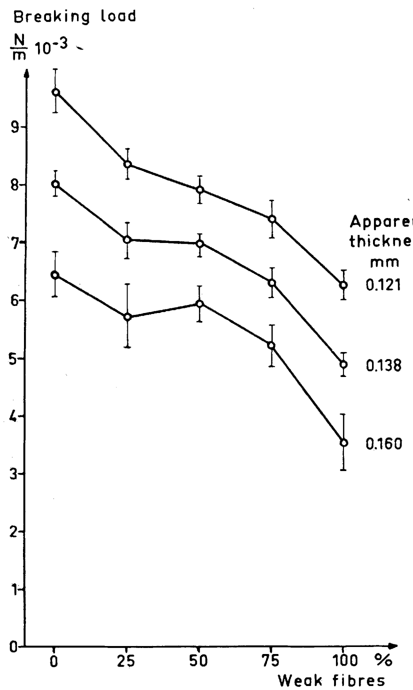

Fig. X

Fig. Y

by Houen. We have varied the fibre strength and followed its influence upon the sheet properties. Utmost care was taken to keep all other factors as constant as possible—in particular, the fibre length distribution and the sheet structure. Sulphite fibres were examined for their breaking strength, which was found to be 0.115 kgf. In order to reduce the strength, the fibres were hydrolysed with acid under conditions that removed no substantial amount of material, but it lowered the strength to 0.055 kgf. When preparing handsheets, no beating was carried out in order not to alter the fibre length distribution (beating would have lowered the fibre length more for the hydrolysed fibres than for the unhydrolysed). Sheet density was altered by means of varying pressures in the wet pressing. Fig. X shows the relationship between the breaking load of the paper and the corresponding proportion of weak fibres in the fibre blend for three different thicknesses of sheet. As is evident, the breaking load is lowered by the greater proportion of weaker fibres.

In Fig. Y, the same relationship is shown for the modulus of elasticity, which in this case is the initial slope of the stress/strain curve. A depreciation as a result of an addition of weaker fibres was experienced in this case, too. Furthermore, in the rupture zone, more broken fibres were found for papers made from weaker fibres. We do not wish at present to give any specific interpretation of the presented data, as the investigations will be extended.