

THE PREPARATION OF LUMEN-LOADED PULP

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ABSTRACT

A lumen-loaded pulp is one containing filler which is confined to the lumen surfaces of the fibres. Prerequisites for obtaining such a pulp are filler particles which are small enough to pass through the pit apertures and chemical conditions favourable to a good bond between the particles and the lumen surface.

The first stage in the preparation of lumen-loaded pulp is agitation of the fibres in a concentrated suspension of filler. At high levels of agitation, entry of the filler particles into the lumens appears to be very rapid and the rate of the uptake of particles by the lumen surface is predictable from a Langmuir-type, adsorption-desorption mechanism. At prolonged times of agitation, a plateau level of loading is achieved which approximates to single particle coverage of those sites on the lumen surface capable of holding particles in the applied turbulent field. The second stage in the preparation is that of a wash which removes all filler particles not bound to lumen surfaces.

If subsequent to washing, the loaded fibres are subjected to high turbulence in water, some filler is lost relatively rapidly but the residual filler is much more resistant to removal. The more weakly-held filler can be kept to a minimum by the use of high levels of shear throughout preparation.

INTRODUCTION

A lumen-loaded pulp is one containing filler which is essentially all confined to the lumens and bound to the lumen surfaces. Such a pulp has two main advantages over a conventional mixture of fibres and filler. Firstly, the retention of filler during papermaking is higher. Within the lumen, the filler is protected from the full intensity of the shear forces of papermaking which dislodge filler from the outer surfaces of fibres, the location of conventionally-added filler. Secondly, the strength of the final sheet is higher. Filler within the lumens does not interfere with inter-fibre bonding as does filler on the outer fibre surfaces. General outlines of the preparation and properties of lumen-loaded fibres have been published (1, 2) and the essential features of this work have been confirmed by other workers (3).

The process of lumen-loading has been considered sufficiently interesting at our Institute to warrant commercial development and this is now at the pilot plant stage. In support of the engineering development, laboratory work has continued with emphasis being given to the basic mechanisms involved in the process. This is in order that commercial optimization might be made based upon a sound understanding of such process variables as pulp type, pulp consistency, filler type, filler concentration, energy input and time of impregnation. In addition, laboratory work has been concerned with the problem that, although the filler in a lumen-loaded pulp is much more resistant to dislodgement than in a conventionally-loaded pulp, there is some loss of filler when the pulp is subjected to severe turbulence. This phenomenon is clearly a reversal of the loading process and should be explained by the same mechanism. Thus the loading and 'unloading' processes are most appropriately considered together. The present paper gives our current interpretation of the mechanism behind these processes.

RESULTS AND DISCUSSION

The Basic Technique

The method of preparing lumen-loaded fibres on a laboratory scale consists of two stages. The first or impregnation stage is the vigorous agitation of fibres in a concentrated

suspension of filler. It is during this action that particles of filler enter the lumens via the pit apertures and become attached to the lumen surfaces. The second stage of the process is a washing step in which all filler free in the lumen and external to the lumen is removed. The level of turbulence applied in washing is less than that applied in the impregnation but it is sufficient to shear filler particles off the exterior surfaces. The particles attached to the lumen surface remain largely in place because they are protected from the full intensity of the shear forces by the cell walls.

Two standard pieces of equipment have been adopted for the two stages of the laboratory procedure. Impregnation is carried out in a British disintegrator - a stirred baffled vessel designed to slurry pulp without any cutting or beating action. Following impregnation, the charge of filler and fibre is transferred to a single unit of a Bauer-McNett classifier in which water is passed through the stirred suspension. A screen permits the passage of the excess filler while retaining the fibres. An unfortunate side effect of this procedure is the loss of pulp fines with the surplus filler. The quantities involved in each stage of the procedure are given in the Experimental section.

Filler/Fibre Compatability

A first requirement for obtaining lumen-loaded fibres is that the filler particles must be able to pass through the pit apertures. This subject has been discussed in our first paper (1). In the present paper we deal with pulps prepared from softwoods and a commercial grade of titanium dioxide filler. For these combinations, there is no such size problem.

A second requirement is that the chemistry of the impregnation system should be favourable to the formation of a bond between the filler particles and the lumen surface. This subject too has been discussed extensively in an earlier report (4) and will be considered only briefly here. For many filler/fibre systems, it appears that, in common with the mode of bonding of filler particles to the outer surfaces of fibres, a potential bond between the filler and the lumen surface is composed of two components. Over one component (the van der Waals forces), we have little control but, fortunately, these

forces always attract a particle to a surface. The other component is an electrostatic force which may be attractive or repulsive. A strong bond is associated with having the charges on the filler and on the lumen surface of high magnitude but of opposite sign. In this way, the electrostatic force acts in concert with the van der Waals forces. For a number of commercial grades of titanium dioxide, it was shown how a strong bond could be promoted by the judicious use of alum and the adjustment of pH (4).

The Mechanism of Loading

Fig. 1 gives the level of lumen-loading achieved as a function of filler concentration and impregnation time. The pulp is an unbleached kraft prepared from black spruce and the filler is a commercial titanium dioxide. The pH of impregnation is 4.0 and for the particular filler, this is sufficient chemical adjustment to ensure a good filler to fibre bond (4).

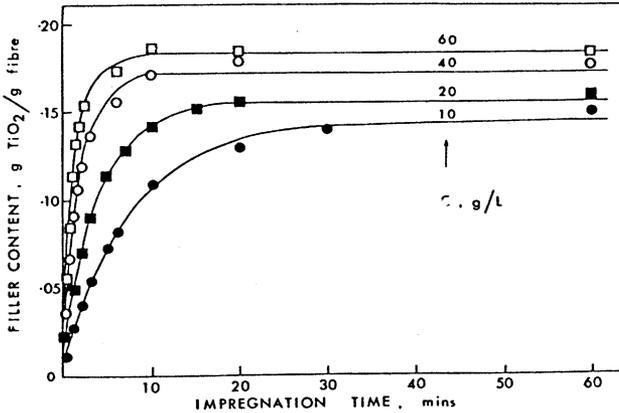


Fig 1—The effect of titanium dioxide concentration and time of impregnation upon the level of loading of an unbleached kraft pulp. The pH of impregnation was 4.0 and the disintegrator speed was 3000 rpm. The curves drawn to each set of data are the best fits to Equation 3.

In order to explain such data, we have adopted an approach originally used by Langmuir to explain gas adsorption isotherms (5) and used more recently to explain the adsorption of small particles onto solid surfaces (6). A system having similarities to ours is the adsorption of polystyrene particles onto dispersed nylon fibres (7, 8). The following assumptions are made:

- i) The filler concentration within the lumens reaches the concentration of the external suspension in an effectively instantaneous manner. As we have previously postulated this could be due to a pumping action induced by the alternate collapse and reopening of the lumens in the turbulent field (1).
- ii) There is a maximum level of loading at prolonged times which approximates to a 'monolayer' of filler particles on the lumen surface. This is not a close-packed monolayer in the classical sense but is full coverage of those sites able to hold particles in the applied turbulent field.
- iii) There is an elementary process for the adsorption of particles onto the lumen surface, the rate of which depends upon the frequency of collision of particles with the surface, which, in turn, depends upon the concentration of filler in suspension. The rate also depends upon the number of sites available for adsorption at a particular time since only collisions with unoccupied sites are effective.
- iv) There is an elementary process of desorption which, at a given degree of turbulence, depends only upon the amount of filler adsorbed at a particular time.

Using these concepts, the overall rate at which loading occurs at any instant may be expressed as the difference in the rates of the two elementary processes:

$$dm_s/dt = kC (M - m_s) - k_s m_s \quad (1)$$

where k and k_s are the rate constants of the elementary processes of adsorption and desorption, m_s and M are the weights of filler (per unit weight of fibre) taken up at a given time and infinite time, and C is the concentration (g/L) of filler

in suspension. If it is now taken into account that the concentration of filler is normally so high as to be unchanged during impregnation, Equation 1 may be integrated to yield the level of loading at a particular time (t):

$$m_s = \frac{kCM}{k_s + kC} (1 - e^{-(k_s + kC)t}) \quad (2)$$

This suggests that the filler level should rise exponentially to a plateau value at prolonged times.

Referring now to the experimental data in Fig. 1, there appears to be an appreciable degree of loading at zero time (m_w). This, as we will describe later, is an additional quantity deposited after the impregnation stage. Thus Equation 2 may be modified to the following form to describe the pick-up of filler during impregnation:

$$m - m_w = \frac{B_1}{B_2} (1 - e^{-B_2 t}) \quad (3)$$

where m is total filler content, $B_1 = kCM$ and $B_2 = k_s + kC$. The best fits of this equation to each of the kinetic experiments are shown in Fig. 1 where it is seen that an excellent fit has been obtained for each of the four cases. In Fig. 2, the best-fit values of the constants are plotted against the concentration of filler. Both B_1 and B_2 are proportional to C , as expected from theory, but B_2 shows no significant intercept at $C = 0$ and hence k_s is effectively zero. From the slopes of these plots, the values of the elementary constants are $k = 0.12 \text{ (g/L)}^{-1} \text{ min}^{-1}$ and $M = 0.14 \text{ g/g}$. As kC is much greater than k_s the desorption process is negligible compared with the adsorption process as a rate-determining step and the equilibrium level of $m - m_w$ is M irrespective of filler concentration. These conclusions, of course, only apply within the framework of the assumption that the concentration of filler is so high as to be effectively unchanged during impregnation.

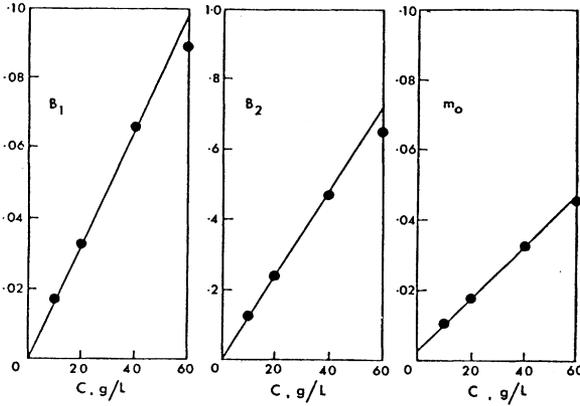


Fig 2—The values of the constants obtained from the best fits in the previous figures are plotted as a function of the concentration of filler in suspension.

What is the additional quantity m_w ? This we feel is a quantity of filler loaded at the cessation of the agitation of the impregnation and transfer of the fibre/filler charge to the washing stage. Here the filler in suspension within the lumens becomes attached to weak bonding sites unavailable at the high turbulence level of impregnation. Many of the particles on these sites are able to withstand the lower level of shear in the washing stage. In support of this hypothesis are the facts that m_w is of the order of the amount of filler in suspension within the lumen (Item 5 in the Appendix) and that m_w varies directly as the concentration of filler in suspension (Fig. 2). That the quantity of particles m_w is weakly-held is apparent from the kinetics of 'unloading' which will now be considered.

The Mechanism of Unloading

As stated in the Introduction, the fact that some filler is lost from the lumens, when washed lumen-loaded fibres are subjected to severe agitation, has been a matter of some concern. The amount lost and its typical dependence on time and degree of agitation is shown in Fig. 3.

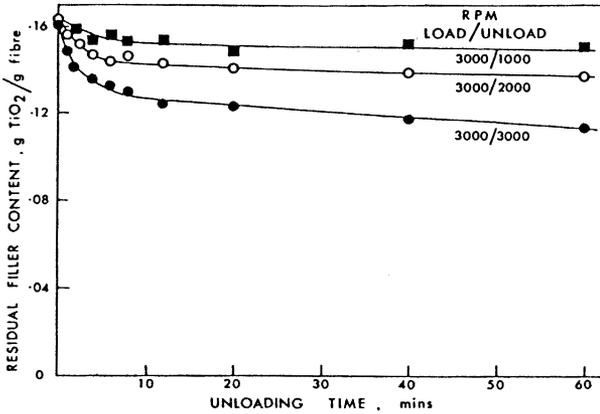


Fig 3—The loss of filler from a washed loaded pulp is shown as a function of the time and rpm of unloading in the disintegrator. The curves are the best fits to Equation 6. The unbleached kraft pulp was previously loaded at 20 g/L titanium dioxide, pH 4.0 and 3000 rpm for 20 min.

If the level of turbulence to which washed lumen-loaded fibres are exposed is of the order of that used to fill the lumens, then the theory, that we have already proposed for impregnation, would predict that the elementary process for desorption operates and that Equation 1 reduced to the following form describes the rate of loss:

$$dm_s/dt = -k_s m_s \quad (4)$$

This equation upon integration yields:

$$m_s = m_{s0} e^{-k_s t} \quad (5)$$

where m_{s0} is the initial amount of filler and m_s is now that remaining at time t . Thus, with time, the filler content should decrease exponentially to zero.

As shown in Fig. 3, the kinetics of unloading do not fit this simple treatment. The kinetics do, however, fit the concept that there are effectively two types of particles unloading simultaneously — one type held strongly and lost slowly and one type held weakly and lost at an early stage, i.e.,

$$m = m_{s0} e^{-k_s t} + m_{w0} e^{-k_w t} \quad (6)$$

where m_{w0} is the initial quantity of weak particles and k_w is the rate constant for their loss.

Fig. 3 shows the fit of Equation 6 to the unloading kinetics of a pulp, the previous loading conditions of which corresponded to the 20 g/L curve in Figure 1. The fit to the unloading curve at 3000 rpm (which was also the loading condition) gives a value of m_{s0} of 0.13 g/g thus identifying the strongly-held filler with M obtained in the loading kinetics. The fit also gives a value of m_{w0} of 0.03 g/g thus identifying the weakly-held material with that deposited at the end of impregnation. The value of k_s is 0.002 min^{-1} and so low as to be understandably undetectable in the loading kinetics. The rate constant for the weakly-held material is two orders of magnitude higher (0.4 min^{-1}).

Differences Between Pulps

The two previous sections describe work carried out on our reference pulp: a never-dried unbleached kraft. As an example of a different pulp, Fig. 4 shows the kinetics of loading of a semi-bleached kraft pulp reslushed from dry lap. Both bleaching and drying have been reported as detrimental to the level of loading which may be achieved (1) and, as seen in the figure, this pulp loads to a lower level than our reference pulp. Table 1 shows a comparison of the kinetic constants for the two pulps. The difference in k is of such a magnitude as to have only a modest effect on the shape of the loading curve: the major difference is in the value for monolayer coverage.

One cause of the lower level of M for the semi-bleached kraft pulp is the loss of accessible lumen surface. It has been shown that collapse of the lumens occurs upon drying and that a fraction of the lumen surfaces fail to separate upon rewetting (9). Examination of the loaded fibres by light microscopy showed that, in comparison with the unbleached pulp, there were more sections of the fibres containing no filler (Fig. 5). However this appears to be only part of the difference between the two pulps. There were also sections of the semi-bleached pulp which were lightly loaded and this phenomenon is probably not due to lumen collapse.

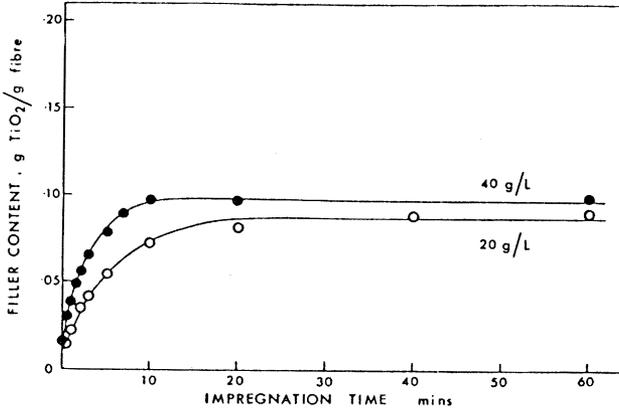


Fig 4—The kinetics of loading of a semi-bleached kraft pulp using the same impregnation conditions as for fig 1.

Constant	Never-dried Unbleached kraft	Dried Semi-bleached kraft
k, min^{-1}	.012	.008
$k_s, (\text{g/L})^{-1} \text{min}^{-1}$.0	.0
m_w (at 20 g/L), g/g	.02	.01
$M, \text{g/g}$.14	.08

Table 1. Constants calculated from kinetic data for two types of pulp.

An additional cause of the lower M value for this pulp we consider to be bleaching. A sample of unbleached lap pulp from the same mill showed a higher level of loading. A sample of our unbleached pulp showed a lower level of loading upon bleaching but without drying. These results are shown in Table 2. Our opinion as to why bleaching is detrimental will be described in a later section on monolayer coverage.

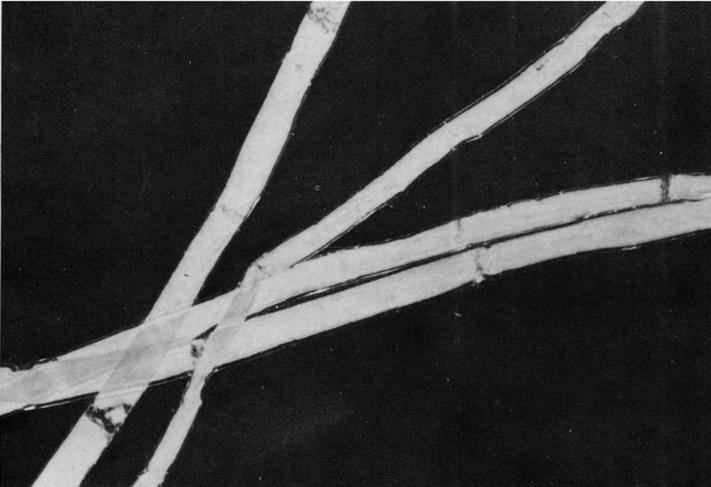
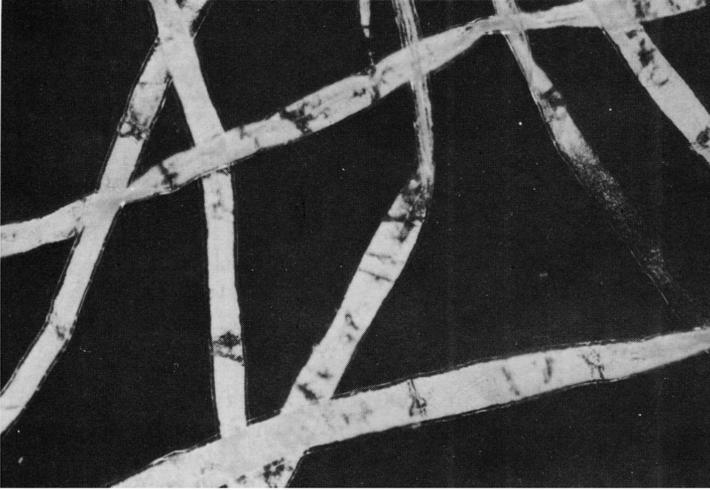


Fig 5—Optical micrographs of lumen-loaded fibres showed that in those prepared from a dried semi-bleached kraft pulp (upper figure) there were more sections of fibres containing little or no filler than in those prepared from a never-dried unbleached kraft (lower figure).

Pulp	Filler content, m, g/g	
	Unbleached	Bleached
Laboratory pulp, never-dried	0.156	0.108
Commercial pulp, dry lap	0.116	0.083

Table 2. Filler contents of different kraft pulps loaded under a given set of conditions.

The Effects of Turbulence During Impregnation

The stirrer speed of 3000 rpm is near the upper limit that may be applied in a disintegrator without the contents leaving the vessel. Lowering the speed has a pronounced effect on the kinetics of loading. The level of loading is reduced at short times but raised at prolonged times (Fig. 6). The occurrence of a common cross-over point at 20 mins. for all speeds down to 1000 rpm led to a fallacious interpretation in our early evaluation of the effect of rpm which was done at a fixed impregnation time of 20 mins. (1).

Lower levels of turbulence during impregnation result in filler which is less-strongly held within the lumen. Thus Fig. 7 shows the unloading curves of pulps impregnated to the cross-over point at 20 mins. at two different stirrer speeds. When impregnation is carried out at 1000 rpm, a plateau level of loading of the order of 0.25 g/g may be obtained in 3 hours. If, however, a pulp loaded to such an extent is subjected to an unloading treatment at 3000 rpm almost half the filler is dislodged as the weakly-held fraction.

In terms of the mechanism we have proposed, the adoption of low rpm during impregnation should permit the deposition of particles in more shear-sensitive sites. Thus the result of greater deposition but of generally more weakly-held particles is explicable in a qualitative way. However, the kinetics of loading no longer fit the simple exponential equation which fits the data at high rpm. It is possible that additional processes considered negligible at high rpm now become important, for example, the passage of filler through the pits could be rate determining.

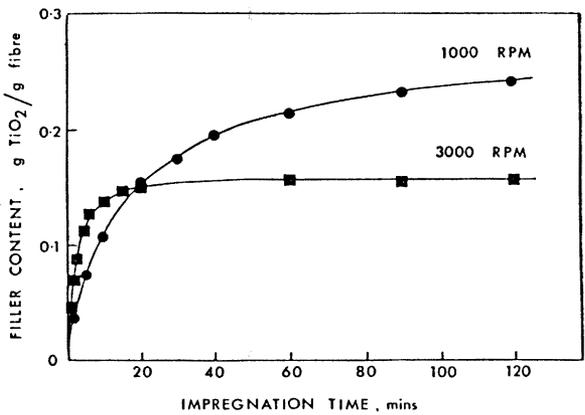


Fig 6—A comparison of the rates of lumen-loading of the unbleached kraft pulp at two different levels of turbulence during impregnation. Other conditions are identical (pulp consistency 1%, filler concentration 20 g/L and pH 4.0).

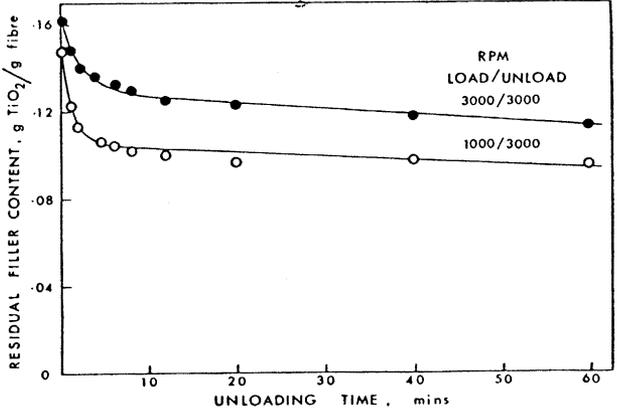


Fig 7—The rates of loss of filler from pulps previously loaded at 1000 and 3000 rpm for 20 min. (the cross-over point in the previous figure). Unloading was carried out at 3000 rpm. The curves drawn are the best fits to Equation 6.

Monolayer Coverage

The term 'monolayer' has been retained from the early work of Langmuir although it is obvious that M is not such a fixed quantity as occurs in studies of inter-facial adsorption. However, microscopy does reveal that the general appearance of a loaded surface is that of coverage by single particles. Small aggregates do occur but these are compensated for by empty spaces even at high loadings. Thus a monolayer is a good description of the average state of coverage at high levels of loading.

From the dimensions of fibres and filler particles it is possible to calculate a theoretical value of M corresponding to a true monolayer of close-packed single particles. Such a calculation leading to a value of 0.18 g/g is shown in the Appendix. There are, of course, variations in both filler and fibre dimensions from one source to another and these could readily lead to M being half or double this quantity. Nevertheless, the theoretical value of M is of the order of those calculated from experimental data.

We have shown that values of M calculated from experimental data may be changed by such parameters as bleaching and changing the level of turbulence applied during impregnation. These effects can be understood if M is regarded as a function of the actual surface area of the lumen multiplied by a factor relating to the efficiency of coverage. This factor could be the fraction of the surface area able to hold particles capable of withstanding a given rate of shear. Lowering the rpm would then increase the factor by bringing the weaker sites into play. Bleaching on the other hand, could lower the factor by generally lowering bond strength. Along with lignin and hemicellulose, bleaching reduces the acidic group contents of pulps and these are the sources of electrostatic charge on the fibre surfaces. The acidic group contents of the unbleached and semi-bleached pulps in this study were 81 and 40 meq/kg respectively.

FINAL REMARKS

In this paper we have described our current interpretation of the mechanism of lumen-loading. While we are by no means certain that we are correct in all details, the mechanism does provide a model by which we have been able to understand the role of many of the variables in this new process. The mechanism indicates that the bond between filler and lumen surface is vitally important to all aspects of the process. By increasing its strength, we should be able to obtain fibres which contain filler which is not only present to a high level but is also highly resistant to dislodgement. This is particularly desirable in bleached pulps which are the most likely candidates for commercial application of the process. Work in progress indicates that the response of bleached pulps can be upgraded by the adsorption of ionic polymers prior to lumen-loading. Amongst other roles the ionic polymers compensate for the loss of surface charge which occurs upon bleaching.

EXPERIMENTAL

Materials

The unbleached kraft pulp was prepared from black spruce to a yield of 48% in the Institute's pilot digesters. The pulp was pressed to 35% solids and maintained in this condition until use. The semi-bleached kraft pulp, also from black spruce, was obtained from a mill in dry lap form. The pulp was reslushed in the British disintegrator just before use. The titanium dioxide pigment was of the rutile type and was supplied by NL Chem Canada Inc. under the name Titanox RA-50.

Lumen-Loading Procedure

15 g (dry weight) of pulp was fiberized in 1250 mL of deionized water by a 5 min. treatment in a British disintegrator. Separately, the appropriate amount of filler was dispersed in 250 mL of deionized water using a Series 2000 Dispensator (Premier Mill Corp.). Both suspensions were adjusted to pH 4.0 by the addition of hydrochloric acid. The filler suspension was then added to the pulp and impregnation carried out in the disintegrator set to the required speed. Following

the impregnation, the mixture was poured into a prefilled Bauer-McNett unit (capacity 12L) through which water was already passing at 6 L/min. Washing was carried out until the effluent was visibly clear of filler (15-30 mins.). A 3 g sample of the washed pulp was oven-dried and its ash content determined. The quantity m was calculated from the ash content after correction for the ash content of the fibres.

Unloading Procedure

Unloadings were carried out at 0.7% pulp consistency which required that a separate loading was necessary to supply pulp for each unloading time point. The pulp was added to the disintegrator, diluted to 1500 mL and its pH adjusted to 4.0 with hydrochloric acid. After the required time of treatment the pulp was rewashed and the new ash content determined.

APPENDIX

Referred to in the text are a number of estimates of monolayer coverage, lumen volume, etc. The calculations are collected here. The symbols used and their values are:

d_L = diameter of lumen (18.4×10^{-6} m).

W = weight of fibre per unit length (0.145×10^{-3} g/m)

d = diameter of TiO_2 particle (0.2×10^{-6} m)

D = density of TiO_2 (rutile) (4.26×10^6 g/m³)

C = concentration of TiO_2 in suspension, g/L

The fibre dimensions are calculated from the literature values of black spruce wood (10). The approximations have been made that the weight of fibre per unit length drops to half on pulping to 50% yield while the lumen diameter is unchanged (11).

1. Specific surface area of lumens

$$\begin{aligned}
 &= \frac{\text{Area of lumen per metre of fibre}}{\text{Weight of fibre per metre}} \\
 &= \frac{\pi d_L}{W} = 0.40 \text{ m}^2/\text{g}
 \end{aligned}$$

2. Weight of particles/unit area of a monolayer

$$\begin{aligned}
 &= \frac{\text{Weight of a particle}}{\text{Area covered by a particle}} \\
 &= \frac{(4/3) \pi (d/2)^3 D}{d^2} = 0.446 \text{ g/m}^2
 \end{aligned}$$

3. Monolayer coverage

$$\begin{aligned}
 &= \text{Specific area of lumens} \times \text{particle weight/unit area} \\
 &= 0.40 \times 0.446 = 0.18 \text{ g/g}
 \end{aligned}$$

4. Lumen volume/unit weight of fibre

$$\begin{aligned}
 &= \frac{\text{Lumen volume per metre of fibre}}{\text{Weight of fibre per metre}} \\
 &= \frac{\pi (d_L/2)^2}{W} = 1.83 \times 10^{-6} \text{ m}^3/\text{g} \quad \text{or} \quad 0.0018 \text{ L/g}
 \end{aligned}$$

5. Weight of particles in suspension in the lumens

$$\begin{aligned}
 &= \text{Lumen volume/g} \times \text{filler concentration} \\
 &= 0.0018 C \text{ g} \\
 &= 0.036 \text{ g} \quad \text{when} \quad C = 20 \text{ g/L}
 \end{aligned}$$

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Transcription of Discussion

The Preparation of Lumen-loaded Pulp

by A.M. Scallan and S.R. Middleton

Professor J. Kline University of Michigan, Kalamazoo,
U.S.A.

At what pH were you loading the calcium carbonate and how were you making it stick?

Dr. A.M. Scallan We were using a pH of about 6 as obtained by just adding a small amount of alum to the water. We have not optimised the calcium carbonate system at all as we have done with the titanium dioxide.

Kline Not enough to dissolve the chalk?

Scallan No.

Kline What about the effect of refining on these loaded fibres?

Scallan These fibres can stand a certain amount of mechanical action in things like pumps and disintegrators. However, you cannot refine them, this will take the loading out of the fibre. Therefore in any industrial usage, the fibres would have to be refined before loading, or perhaps refined during loading, i.e. the refiner used to load the fibres.

Atalla Is there a possibility that the interior of the lumen has some chemical characteristic such that the pigment particles adhere to it more effectively than they might to the surface of the fibre?

Scallan We have found that pulps with large amounts of acidic groups such as high yield pulps are better for lumen loading than low yield pulps. Unbleached pulps will load to a higher level than bleached pulps.

Atalla What I had in mind was that for a particular type of fibre is the adhesion inside the lumen greater than it is on the exterior of the fibre?

Scallan We have no way of knowing this.

Atalla I was wondering whether you attempted to measure the relative adhesion?

Scallan It is not possible. There are two factors involved; the lumen surface is protected by the cell wall so we don't know how much of the better retention is due to a difference in bondability and how much is due to the protection by the cell wall. We always assume that the lumen surface is the same as the outside surface.

Dr. D. Reeve University of Toronto, Canada

Would you describe the sequence of events in the zero time experiment?

Scallan At the end of the turbulence of loading, the material which is inside the lumen but not bonded to the surface goes to the surface and is weakly held there. It is then slowly released upon subsequent agitation.

Reeve How long is the pulp fibre exposed to the suspension filler particles from initial mixing to the when you begin washing?

Scallan Less than a minute.

Dr. D.W. Clayton PPRIC, Pointe Claire, Canada

Referring to Prof Atalla's question, I recall a reference to the fact that the inside of the lumen is rich in xylan. If that is the case, then the glucuronoxylans will give you a negative charge.

Scallan In other studies, we have found that the acidic groups are present on the residual hemicelluloses and lignin, not on the cellulose itself. If the lumen surface is rich in xylan therefore, it is probable that the lumen surface has a high concentration of acid groups and hence, as you say, a high negative charge.

P.F. Lee Mead Central Research, U.S.A.

How much power per tonne of fibre is necessary to successfully load? What power/tonne did you use as a design criteria for your pilot plant?

Scallan We are talking about far less power than in beating.

Lee What is the horse power of the agitator in that pilot plant?

Scallan Off hand, I do not know.

Prof E.L. Back STFI, Stockholm, Sweden

I assume that the penetration of the particles takes place through the simple pores of the tracheids to the parenchyma cells, not through the bordered pores. These are very large for the pines, about 10 microns by 20 microns in size, but rather smaller for the spruces. In our spruces, they are only of the order of 3 microns in diameter. I was therefore surprised to see good results with black spruce while it was difficult to load the hardwood tracheids where the size is 1 - 2 microns for birch and 8 - 10 microns for aspen.

Scallan Yes, pines load better than spruces, but I should point out that we have loaded cotton fibres and they have no pits at all. In cotton, the filler must work its way in through the cut ends of the fibres and it is surprising that distribution is quite uniform.

R.C. Williams James River, Richmond, U.S.A.

How much latex were you able to add in your experiments?

Scallan We did not measure it.

Williams Does it behave like clay?

Scallan No, latex particles, having a spherical shape behave more like titanium dioxide. An interesting application of latex is to load a film-forming latex with titanium dioxide. After heating the loaded fibres, the film locks in the titanium dioxide. However, we have not done a lot of work on this.

I. Fineman STFI, Stockholm, Sweden

You showed a graph of scattering co-efficient against ash content for titanium dioxide loaded fibres. Titanium dioxide has a high refractive index compared to cellulose fibre. If you have a filler such as clay with about the same refractive index as fibre, would you have the same scattering co-efficient for lumen loaded as for normally loaded sheets? Is the pore size of the lumen large enough to obtain this effect?

Scallan Clay has an effect on a paper sheet even though its refractive index is similar to that of cellulose. This is because of its surface area contribution to light-scattering co-efficient. Lumen-loaded sheets should show the same response as normally loaded sheets.

Dr. J. Mardon Omni Continental, New Westminster, Canada

What is the ratio of filler retained in the lumen to that removed during washing? Secondly, what is the concentration of the washed off filler? If this concentration is low, how will you handle large quantities of dilute suspensions?

Scallan During impregnation, the ratio of filler to fibre is 2:1. If loading is to 10% filler on fibre, this means there is a ratio of 9:1 unused to used filler. However, the unused filler is reclaimed by sedimentation and is recycled to the impregnation stage.