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FORMING AND FORMATION OF PAPER

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ABSTRACT

Formation is a critical property for newsprint as well as printing and writing grades of paper. Measurements of the flow and fibre distribution properties in the forming section of an operating paper machine are related to the resulting paper structure. The 3-D M/K Analyzer is used to characterize the final paper structure in terms of the formation index and average floc size. A stochastic model is proposed to provide a basis for interpretation of the final paper formation.

INTRODUCTION

Formation is a critical property for newsprint as well as printing and writing grades of paper. It has been shown that formation, as characterized by the coefficient of variation of grammage, is affected by both statics and dynamics of the forming process (1, 2, 3, 4, 5).

From previous studies it turns out that beside the furnish characteristics and operating conditions, the next most important factor in the forming process is the hydrodynamics of the drainage process.

Although the flow of pulp suspension in closed conduits and the table activity on the forming section of Fourdrinier paper machines has been the subject of many recent studies (3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14), "open flow" of pulp suspension, specially on the forming table of Fourdrinier papermachines, and its relation to the forming process still suffers from lack of a reliable physical model.

On the other hand, about *80%* of existing papermachines used for newsprint manufacture are Fourdrinier, in which a significant portion of dewatering takes place while stock is carried by a high speed fabric.

Therefore, the present study is focused on the open flow of pulp suspension on the fabric of Fourdrinier paper machines, looking for:

1- Characterization of flow, flocculation, and formation in papermaking machines.

2- Effect of major process variables; e.g. consistency, jet speed, fabric speed, and pulp characteristics.

3- Modelling of the forming process in terms of major process variables.

This study will provide us with a better understanding of the forming process, which results in the possibility of:

1- Improved control of Fourdrinier papermaking machines.

2- Improved quality of paper products.

3- Engineering of new paper products.

4- Modification of existing papermachines.

5- Improvement in the design of new papermachines.

THEORY

The great degree of variability and stochasticity associated with the forming process of paper has defeated any deterministic approaches so far.

On the other hand, statistical geometric models such as the one used by Dodson and coworkers (1, 2, 15, 16, 17) seem to provide a valuable tool for this type of process.

In statistical geometry, the spatial variation of the density of a network measured by a sampling zone of size x mm, *Var(x)*, is related to the point variance, *Var(0)*, as (18):

$$Var(x) = \rho(x)\ Var(0) \qquad (1)$$

where ρ is the between zone variance, calculated using:

$$\rho(x) = \int_0^{D(x)} \alpha(r)\ b(r)\ dr \qquad (2)$$

here $\alpha(r)$ is the autocorrelation function of two points which are distance r apart, and $b(r)$ is the probability density function of finding two points chosen randomly and independently in a zone with a separation of r.

This approach is equivalently valid for isotropic pulp suspensions (1).

Flocculation Index

The flow of a flocculated pulp suspension could be looked at in projection as a flow of disc type objects of different sizes. If this model suspension is scanned by a laser beam, whose diameter is much smaller than the diameter of the model objects, then it will result in the measurement of random chords of disc shaped flocs.

For a disc of diameter D the probability density function for chords of length x is given by:

$$p(x) = \frac{1}{D} \qquad 0 \le x \le D \qquad (3)$$

with mean $D/2$.

Now, we know that for a 1-D random array of line segments of length λ, the autocorrelation function is given by (18):

$$\alpha_{Random,1}(r) = \begin{Bmatrix} 1 - r/\lambda & 0 \le r < x \\ 0 & x \le r \end{Bmatrix} \qquad (4)$$

The area under the above autocorrelation function is:

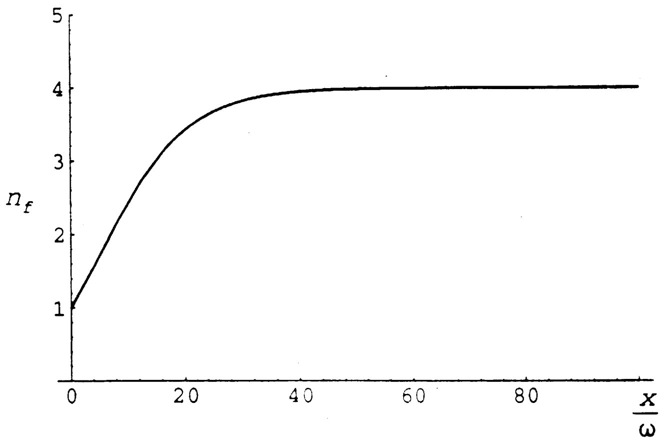

Figure 1: Formation number increases monotonically with the size of sampling zone and reaches a plateau after about *20* ϖ.

$$Area[\alpha_{Random,1}] = \int_0^{\lambda} \alpha_{Random,1}(r)\ dr = \lambda/2 \qquad (5)$$

Equivalently, this is the so called "integral length" of the stochastic process (19).

For a 1-D array of random line segments of different sizes uniformly distributed over $0 \leq \lambda \leq D$ (such as the chords of discs in our model suspension), the average area is:

$$E[Area] = \frac{1}{D}\int_0^{D} \frac{\lambda}{2}\ d\lambda = \frac{D}{2} \qquad (6)$$

Assuming that all flocs in the suspension are of the same size and putting equations (4),(5),(6) together, one can see that the observed net autocorrelation function is estimated by:

$$\overline{\alpha_{Random,1}}(r) = 1 - \frac{2r}{D} \quad (7)$$

Thus, the length, $d_{1/2}$, associated with half decay of the average autocorrelation function is:

$$\overline{\alpha_{Random,1}}(d_{1/2}) = \frac{1}{2} \qquad hence: \qquad d_{1/2} = \frac{D}{4} \quad (8)$$

As we see, $d_{1/2}$ is proportional to the floc size. This parameter is used as a measure of the state of flocculation in this study and is called the *flocculation index.*

Note that other averaging processes are possible. However, the above analysis is simple with minimal assumptions. Also, we would get the same result as (8) if we use for λ the value of the mean chord length for the discs of diameter *D*. A more refined analysis using a distribution of disc diameters will be reported elsewhere.

Formation Scale

Formation as measured by the variance of local grammage, depends on the mean grammage in a qualitatively similar form for both random handsheets and commercial papers. The ratio of the variance of local grammage for a commercial sheet to the corresponding variance of a random sheet from the same furnish is therefore an intrinsic and dimensionless index of formation (2). For a square inspection zone of size *x*:

$$n_f(x) = \frac{Var(x)}{Var_{Random}(x)} \quad (9)$$

This ratio at the scale $x \approx \lambda$ has an approximate statistical geometric interpretation as the number of fibres in an incipient floc, and for commercial papers it is found that:

$$\frac{n_f(x)}{n_f(1)} \approx x \qquad \textit{when:} \qquad 1 \le x \le 4mm \qquad \textbf{(10)}$$

So:

$$\frac{1}{n_f(1)} \frac{dn_f}{dx} \approx 1 \qquad at \qquad x \approx 1mm \qquad \textbf{(11)}$$

The random variance used in (6) can now be evaluated from the autocorrelation function of local grammage in random paper, $\alpha_{Random}(r)$ as follows:

$$Var_{Random}(r) = Var(0) \int_0^{\sqrt{2}x} \alpha_{Random}(r)\; b(r)\; dr \qquad \textbf{(12)}$$

Here $b(r)$ is a known probability density function for the distribution of pairs of points separated by distance r, chosen independently and at random in the zone.

We estimate $n_f(x)$ by a simple family of exponential autocorrelation functions $\alpha(r,d)$ given by:

$$\alpha(r,d) = e^{-r/d} \qquad \textbf{(13)}$$

where d is a characteristic length.

This choice is made because the actual $\alpha_{Random}(r)$ for random paper made from fibres of width ω somewhat resembles $\alpha(r,k\omega)$, where k is found to be about 1.

We approximate $b(r)$ by a triangular probability density function to obtain a simple closed expression, a full analysis with the precise $b(r)$ and numerical integration will be discussed elsewhere. Here we use:

$$b_{\Delta}(r) = \begin{cases} \dfrac{4r}{x^2} & 0 \le r < \dfrac{x}{2} \\ \dfrac{4}{x}\left(1-\dfrac{r}{x}\right) & \dfrac{x}{2} \le r \le x \\ 0 & otherwise \end{cases} \tag{14}$$

Based on the above simplifications an estimate of $n_f(x)$ is obtained:

$$n_f^d(x) \approx \frac{\int_0^x \alpha(r,d)\; b_{\Delta}(r)\; dr}{\int_0^x \alpha(r,k\omega)\; b_{\Delta}(r)\; dr} \tag{15}$$

The numerator turns out after a page of calculus to be:

$$\int_0^x \alpha(r,d)\; b_{\Delta}(r)\; dr = \frac{4d^2}{x^2}\left(1+ e^{-x/d} - 2\; e^{-x/2d}\right) \tag{16}$$

Hence:

$$n_f^d(x) \approx \frac{d^2}{k^2\omega^2}\;\frac{1 + e^{-x/d} - 2\; e^{-x/2d}}{1 + e^{-x/k\omega} - 2\; e^{-x/2k\omega}} \tag{17}$$

For a zone size of 1mm and $\omega \ll x$, then $2 \le nf\,d(1) \le 7$ implies $1.4 \le d/\varpi \le 2.6$ if k is assumed to be 1. In particular for $d \approx 4\omega$, we have $n_f^{2w} \approx 4$.

Equation (17) is plotted in Figure 1. We observe that $n_f{}^d(x) \to 1$ as $x \to 0$ and $n_f{}^d(x) \to d^2/k^2\omega^2$ as $x \to \infty$.

Now, the rate of change of formation number, $n_f^d(x)$, can be approximated by:

$$\frac{dn_f^d}{dx} \approx \frac{d}{\omega^2}\left(e^{-x/2d} - e^{-x/d}\right) \qquad (18)$$

which is positive, and of order 1.

Typically, if $\omega = 0.04$mm and $d = 4\,\omega = 0.16$mm , then at $x = 1$mm the rate of change of formation number is *0.64*, comparable to that which is observed for commercial papers.

Flocculation Number

Consider the case where a pulp suspension is scanned by a small laser beam, such that the real time observation can be replaced by a random line process. For this case $\alpha_{Random}(r)$ can be approximated by:

$$\alpha_{Random}(r) = e^{-r/\omega} \qquad (19)$$

In reality, fibres in a suspension are not fully dispersed. Instead, they flocculate and form fibre clumps known as flocs. Also, the number of fibres per floc is not the same for all fibre clumps. The average number of fibres in a floc or *flocculation number* (n_{floc}), is a measure of the state of flocculation in the suspension.

Results of our experiments showed that the autocorrelation function for suspensions can be approximated by:

$$\alpha(r) \approx e^{-r/d} \qquad (20)$$

Analogous to the integral length of turbulence (19), one can define the integral length of flocculation, *L*. If the autocorrelation function is approximated by equation (20), it is easy to show that:

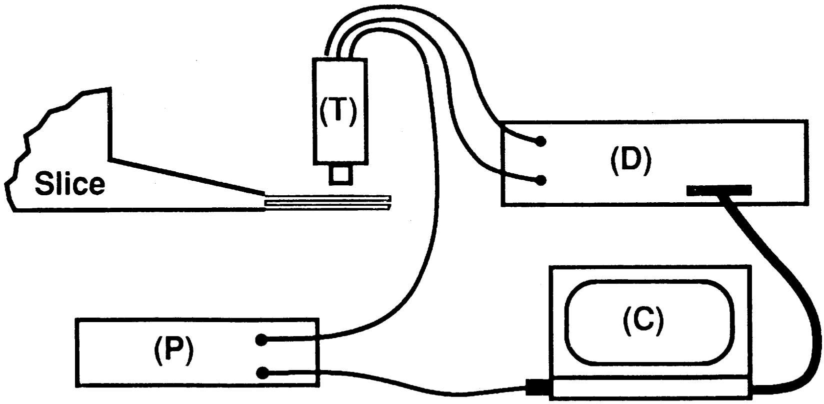

Figure 2: Schematic diagram of experimental set-up for online measurements (T: Transducer, D: Data Acquisition, P: Processor, and C: Computer).

$$L = \int_0^\infty \alpha(r)\, dr = d \tag{21}$$

Thus, the characteristic length (d) in this case is same as the integral length (L) and we can re-write equation (20) as:

$$\alpha(r) \approx e^{-r/L} \tag{22}$$

Now, assuming that a flocculated suspension could be modeled by a fully dispersed suspension of clumps of fibres, then we estimate the autocorrelation function by:

$$\alpha(r) \approx e^{-r/n_{floc}\omega} \tag{23}$$

From equations (22) and (23), the flocculation number is estimated by:

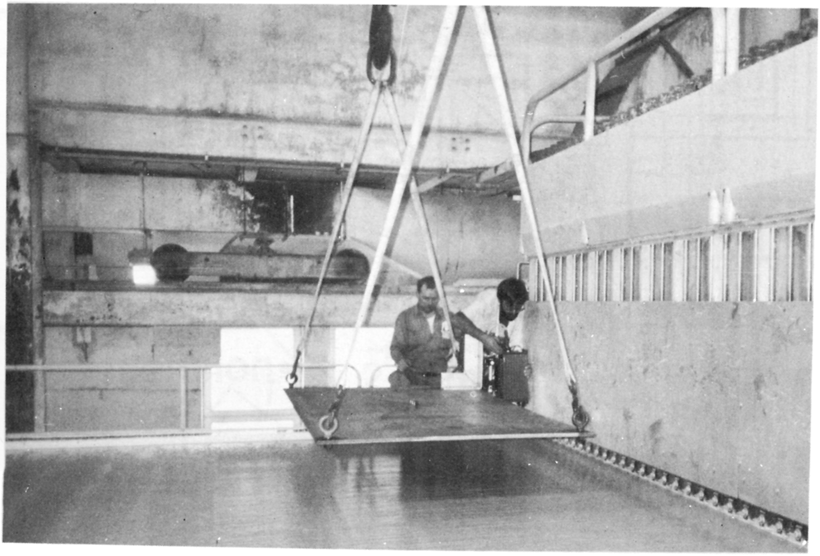

Figure 3: Laser sensor hanging from the wet end crane above the forming fabric (Ramin Farnood is adjusting the sensor).

$$n_{floc} \approx \frac{L}{\omega} \tag{24}$$

The integral length L in the autocorrelation function is related to the flocculation index $d_{1/2}$:

$$\alpha(d_{1/2}) = 0.5 = e^{-d_{1/2}/L} \tag{25}$$

Then:

$$L = \frac{d_{1/2}}{\ln(2)} \tag{26}$$

Putting the last two equations together:

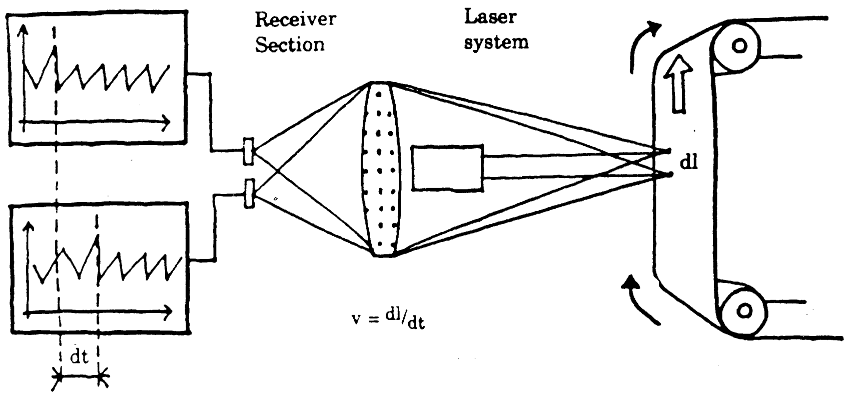

Figure 4: Two-spot correlation principle.

$$n_{floc} \approx \frac{d_{1/2}}{\ln(2)\ \omega} \qquad (27)$$

Typically, for the case when ω = *.02*mm and flocculation index $d_{1/2}$*=0.16*mm the flocculation number is *12*.

Note that the measured variance, σ^2, of the back-scattered signal obtained from most instruments is only a measure of the point variance of the process. It does not contain information on the scale of the stochastic structure. The autocorrelation $\alpha(r)$ is the ratio of covariance between measurements at separation *r* to this variance, σ^2.

EXPERIMENTAL APPROACH

The on-line measurements of speed and flocculation are performed using a Dantec SensorLine 7510, modified to get raw back-scattered signals. The specifications of this system are listed in Table 1.

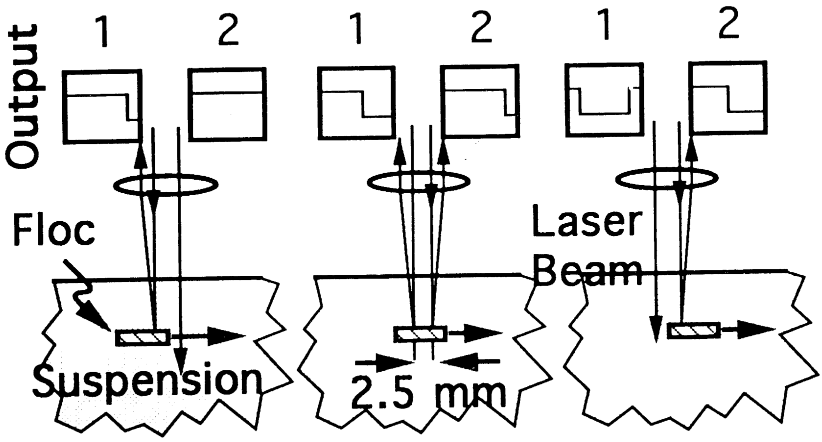

Figure 5: Principle of laser measurement.

Figure 2 is a schematic diagram of the experimental set-up. The transducer (T) is installed on a bracket which is attached to a *2.5*m by *1.2*m steel plate. The plate is positioned at an appropriate distance from the forming fabric using the wet end crane (Figure 3). The transducer is connected to a Dantec Processor (P) for speed measurements and to a data acquisition system (D) for flocculation measurements.

The principle for the speed measurement is shown in Figure 4. The system directs two parallel laser beams to the surface of a moving target. The back-scattered beams are collected and focused onto individual detectors. If the system is aligned with the direction of movement, the two signals will be identical except for a time delay between them. This time delay and the spacing between the two spots are used for calculation of speed.

Flocculation measurements are based on the analysis of back scattered signal (Figure 5). Raw back-scattered signals are transferred through BNC connectors to a computer driven HP data acquisition system (D) where data are digitized and analysed with a sampling frequency of 51.2 kHz, and the results are stored on the computer (C).

Each peak in the recorded signal corresponds to a moving object, presumably a floc. The higher the degree of flocculation, the larger the floc and the broader the peak. This produces a long correlation length and a slowly decaying autocorrelation function. Thus, the length scale corresponding to *50%* decay in the autocorrelation of the back-scattered signal is used as a flocculation index (Figure 6).

Velocity	0.2 - 35 m/s
Laser class	IIIB
power	10 mW
wave length	810 - 850 nm
beam diameter	80 μm
Accuracy	< 0.5% of reading

Table 1: Technical specifications of Laser sensor (20).

Samples of pulp as well as wound paper were taken for off-line fibre and paper analysis. Paper formation was measured using a 3D M/K Analyser, which gives a formation index as well as an average floc size and the total floc area.

As seen in Figure 7, good formation corresponds to low flocculation index, indicating that flocculation index may be a valid measure of the state of flocculation in the suspension.

RESULTS AND DISCUSSION

On-line measurements were performed on four Fourdrinier papermachines for different operating conditions. Table 2 lists operating parameters of these machines.

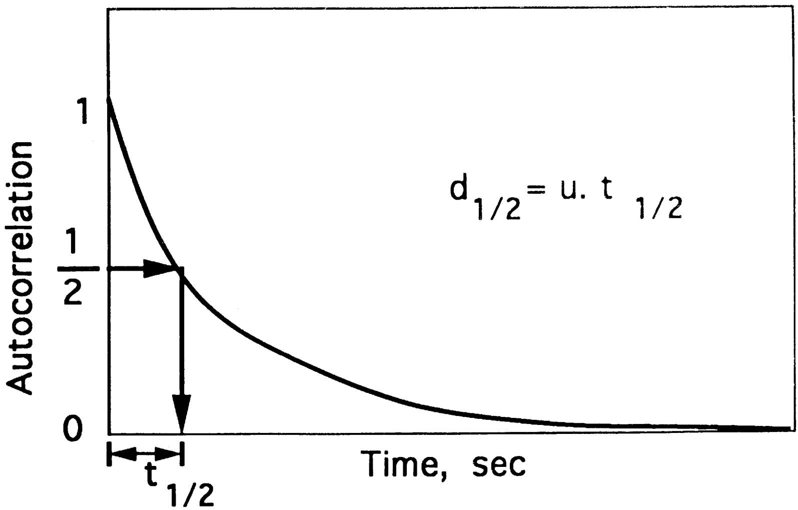

Figure 6: Flocculation index is defined as the corresponding length of *50%* decay in the autocorrelation function.

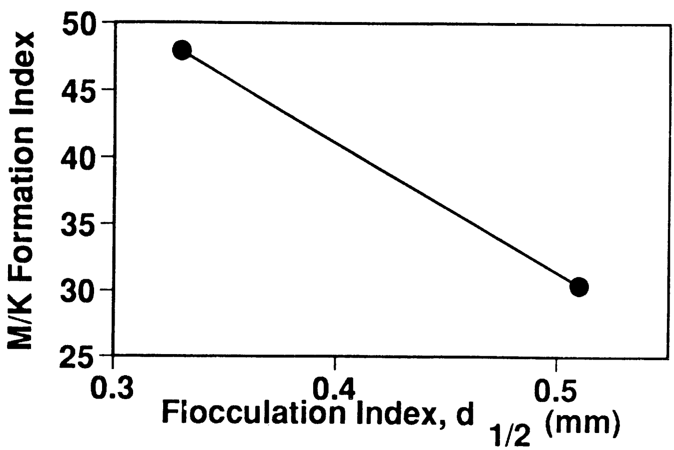

Figure 7: An increase in flocculation index resulted in a decrease in formation index (worse formation).

Paper Machine	Speed (m/min)	Consistency %	Grammage (gsm)	Drag(-) or Rush(+)%
B-PM#1	1000	0.77	49	-2
B-PM#2	880	0.77	45	-5
C-PM#1	280	1.03	86, 91	+1.5, +1, -3
C-PM#7	490	0.61	49	-1, -3, -5

Table 2: Operating conditions of Fourdrinier papermachines used in this study.

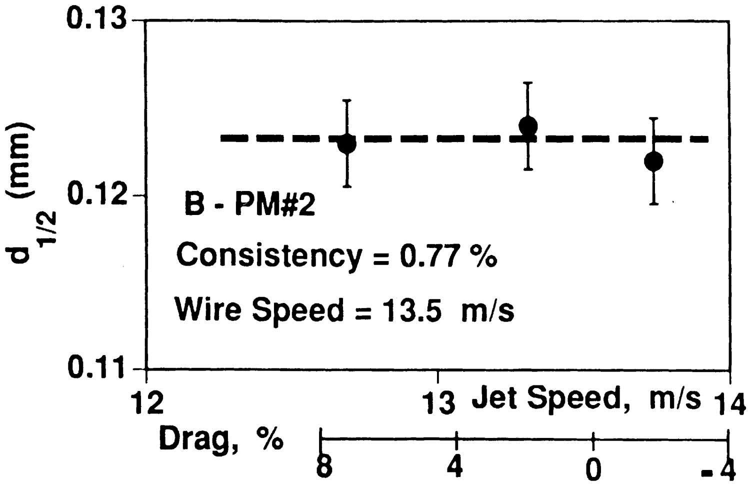

Figure 8: Flocculation index is not sensitive to the speed of the jet leaving the slice.

The results discussed in this article are primarily of qualitative interest, aimed at improving our basic understanding of the formation process and providing analytic tools for its study. The series of mill trials is continuing.

State of Flocculation at the Jet

Measurements of flocculation index at the jet coming out of the slice for different jet velocities in the range *3%* rush down to *6%* drag showed no statistically significant change in the state of flocculation (Figure 8). In other words, the state of flocculation at the jet is not sensitive to the jet speed. So any changes in the sheet formation are not simply a direct function of jet speed. However, the authors believe that jet speed affects the formation through changing the drainage profile characteristics along the forming fabric.

MD Velocity and Flocculation Index Profiles

Measurements along the machine showed a decrease in the jet to wire ratio in MD (Figure 9). This is consistent with the results of Loewen et al. (21).

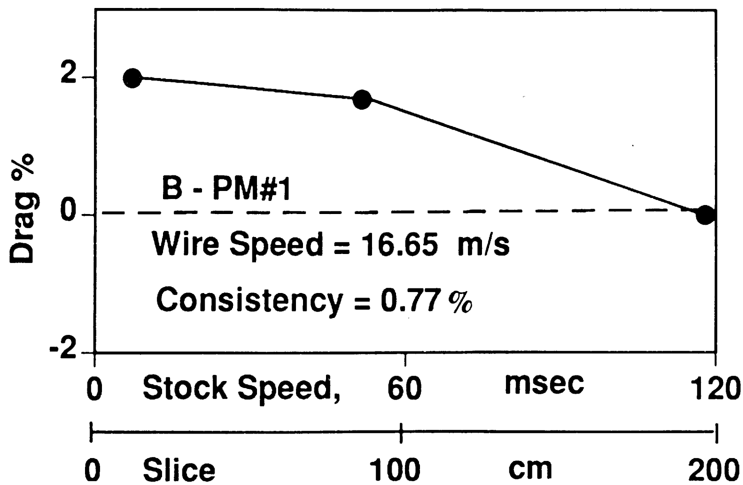

Figure 9: Stock speed approaches the fabric speed as it passes along the forming section.

Flocculation index also varies along the machine. Figure 10 shows that flocculation index increases sharply within the first *100* msec after stock leaves the slice and it remains almost constant all the way down to 6 metre mark. However , this plateau is not observed in all measurements. We believe that the initial increase in the flocculation index is because of a sudden decrease in the level of energy input to the suspension. This causes a more flocculated suspension, larger flocs, and a higher flocculation index corresponding to floc formation in decaying turbulence as observed by Kerekes et al. (11).

Since a larger floc is less stable and could be disintegrated more readily, it is possible to reach a level where average floc size and flocculation index remain constant. In this case, the rate of energy delivered to the suspension is presumably enough to break flocs with a rate equal to the rate of re-flocculation. Otherwise, the flocculation index will increase all along the forming table (this phenomenon is actually observed in some experiments).

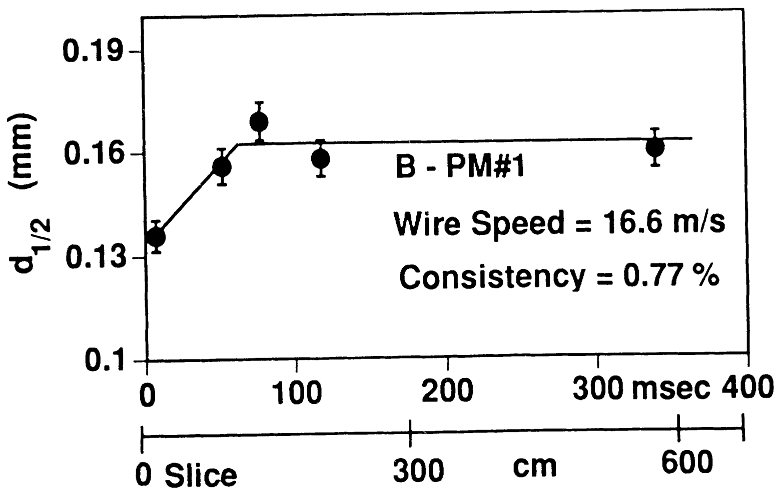

Figure 10: Flocculation index increases quickly after stock leaves the slice.

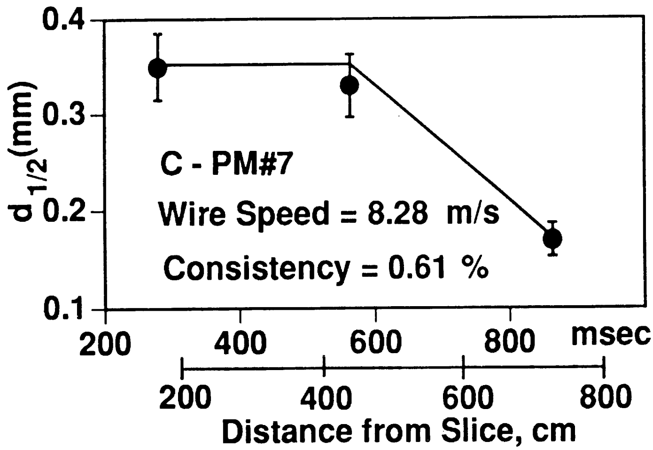

Figure 11: Flocculation index drops quickly after the dry line on the forming fabric.

At the end of the forming table, a sharp decrease in the flocculation index is observed (Figure 11). In this zone, there is no undrained suspension left. Thus, the laser beam hits the rough surface of a wet mat and the reflected signal resembles white noise. This causes a smaller correlation length corresponding to surface features as well as flocculation.

Velocity and Flocculation Variation Across a Foil

It is observed that there is a wave-like pattern when stock passes a foil (Figure 12). It is usually believed that this is due to the fabric bending when it passes an inclined foil. But, results of measurements performed across a foil showed a decrease in the speed along the foil equivalent to an increase in the drag from *2%* to about *4%* (Figure 13). Although this could be partly due to a change in the direction of the fabric (4), the authors believe this could also be due to pressure variation along a foil. Perhaps the high vacuum at the leading edge of a foil pulls down the free surface of the stock and decreases the flow

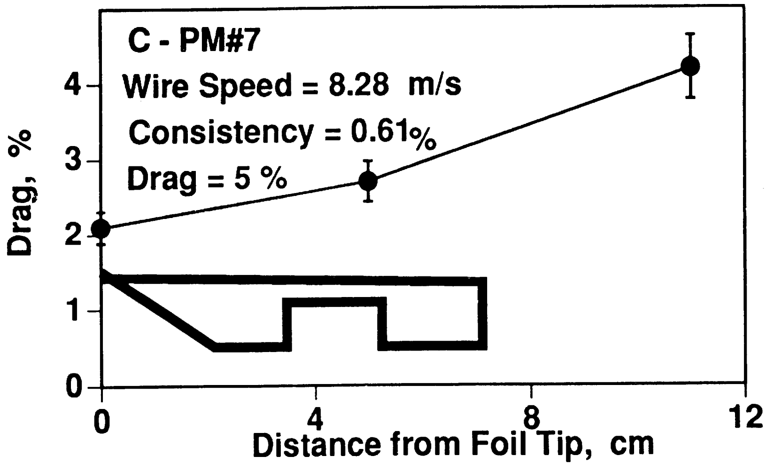

Figure 12: A wave-like pattern on the stock passing over foils.

area, resulting in an increase in the stock speed. Since the level of vacuum decreases along the foil and vanishes after the foil, the flow area increases and speed decreases correspondingly.

The periodic contraction and expansion flow in MD can be an effective mechanism for energy injection into the stock on the fabric.

Flocculation index decreased by about *30%* along the foil (Figure 14), showing the role of foil in the state of flocculation in the suspension on the fabric. The variation in the flocculation index could be a result of a higher degree of dispersion caused by the foil and/or due to a quick initial drainage which sucks through the pad smaller suspended entities leaving larger entities in the suspension and resulting in a higher reading for flocculation index.

Effect of Drag on the Formation

Few experiments were conducted to investigate the effect of drag on the sheet formation and forming process. The results of increasing

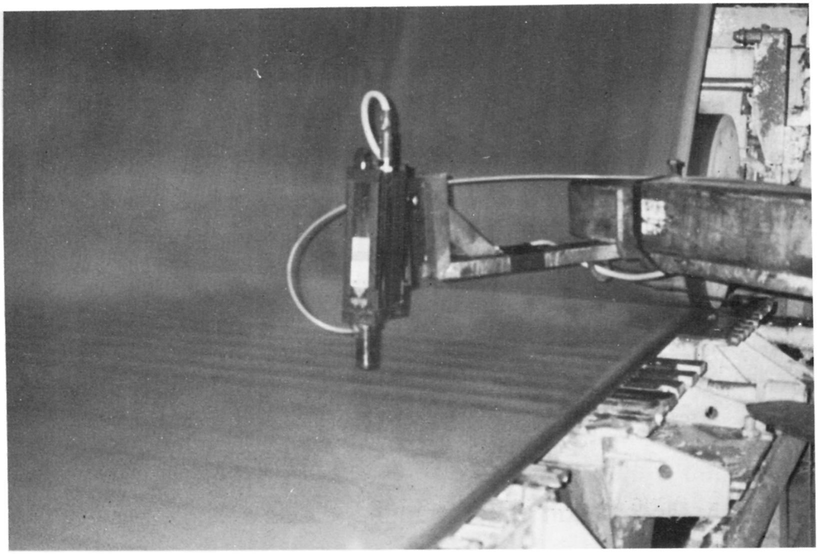

Figure 13: Drag changes across a single foil.

drag from *3%* to *5%* showed an increase of about *60%* in the flocculation index *460*cm downstream from the slice. A corresponding drop in the formation index of about 40% is observed (Figures 15,16). At the same time, the average back-scattered signal (which is a crude measure of local consistency) shows a 4-fold increase. This observation suggests that changes in the drag modify the sheet structure through changing the drainage mechanism along the forming fabric.

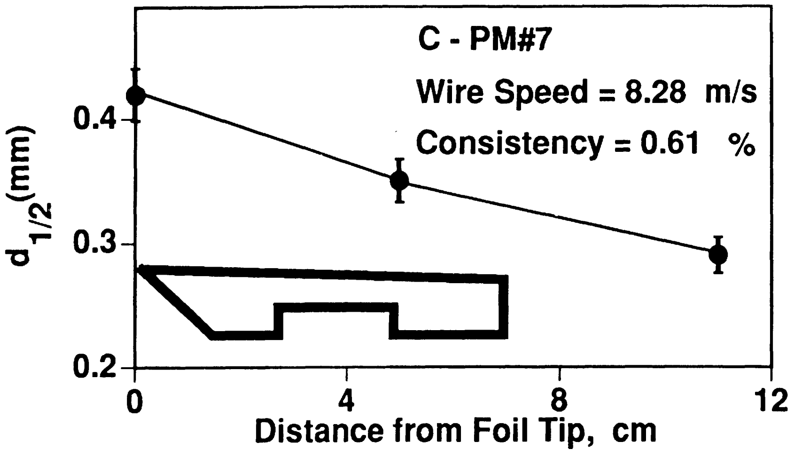

Figure 14: Flocculation index changes across a single foil.

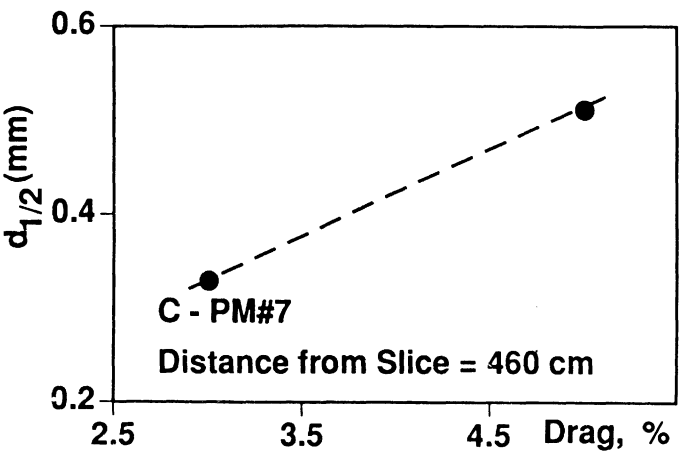

Figure 15: A change of drag from *3%* to *5%* causes a increase of about *50%* in the flocculation index.

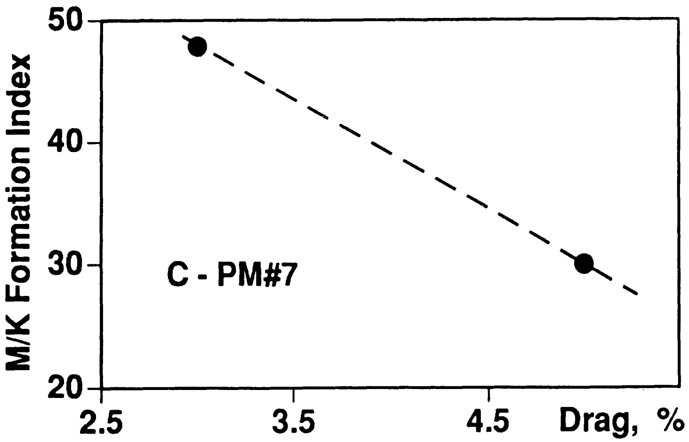

Figure 16: A change of drag from *3%* to *5%* causes a decrease of about *40%* in the formation index.

CONCLUSIONS

The state of flocculation in a suspension can be characterized using the flocculation index, $d_{1/2}$. For a model suspension of disc type flocs, this index is a linear function of the floc size. The integral length of flocculation is also proportional to the flocculation index. The integral length (and hence the flocculation index) is a measure of the floc size in a pulp suspension and is independent of the rms value which has been traditionally used to characterize the state of flocculation in a pulp suspension. Lower flocculation index on the forming table corresponded to better formation in the paper being made. Flocculation index is presumably a function of furnish characteristics (fibre length, flexibility, fines content) and papermachine configuration and operating conditions (fabric speed, jet speed, drainage mechanism).

Average numbers of fibres in a floc can be characterized using the flocculation number (n_{floc}). For a model suspension of flocculated fibres it is shown that the flocculation number is a multiple of flocculation index. Thus, in principle, either of them can be used to characterize the state of flocculation. Typically, $n_{floc} \approx 12$.

An approximate but convenient expression for the formation number is derived theoretically. According to this correlation, the formation number is strongly dependent on the correlation length, which in turn is a function of the state of flocculation in the suspension, as well as its evolution along the forming fabric and the drainage characteristics.

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REFERENCES

1- M.Deng and C.T.J.Dodson. Paper: An Engineered Stochastic Structure. University of Toronto, Internal Report 1993.

2- C.T.J.Dodson and C.Schaffnit. Flocculation Effects on Formation Statistics. Tappi J. 75(1) 1992, 167-174.

3- A.J.Kiviranta. Characterization and Optimization of Fourdrinier Table Activity on the Middle Ply Fourdrinier of a Folding Boxboard Machine. Paperi Ja Puu 74(8) 1992, 109-118.

4- A.J.Kiviranta and H.V.Paulapuro. The Role of Fourdrinier Table Activity in the Manufacture of Various Paper and Board Grades. Presented at the Nashville Conference, April 1992.

5- A.J.Kiviranta and H.V.Paulapuro. Characterization and Optimization of Fourdrinier Table Activity in Linerboard Manufacture. Paperi Ja Puu 74(9) 1992, 151-160.

6- P.Ahonen, A.Kiviranta and J.Kaipila. Effect of Fourdrinier Table Layout on the Wet-End Performance of a Fine Paper Machine. Paperi Ja Puu 74(10) 1992, 179-183.

7- M.J.Hourani. Fibre Flocculation in Pulp Suspension Flow. Part 1: Theoretical Model. Tappi J. 71(5) 1988, 115-118.

8- M.J.Hourani. Fibre Flocculation in Pulp Suspension Flow. Part 2: Experimental Results. Tappi J. 71(6) 1988, 186-189.

9- R.J.Kerekes. Pulp Floc Behaviour in Entry Flow Constrictions. Tappi J. 66(1) 1983, 88-91.

10- R.J.Kerekes and R.G.Garner. Measurement of Turbulence in Pulp Suspension by Laser Anemometry. Transactions of Technical Section JPPS 1982, TR53-TR60.

11- R.J.Kerekes, R.M.Soszynski and P.A.Tam Doo. The Flocculation of Pulp Fibres. Transactions of the 8th Fundamental Research Symposium. Oxford, England. Vol.1 1985, 265-310.

12- M.Steen. Fibre Flocculation in Turbulent Flow. Flocculation Control in the Paper Industry Conference. Luxemburg 1992.

13- U.Stelwagen, L.K.Cheng and R.C.van Essen. Flocculation Sensing with a 1-D Optical Reflection Sensor. Flocculation Control in the Paper Industry Conference. Luxemburg 1992.

14- D.G.Wagle, C.W. Lee and R.S.Brodkey. Further Comments on a Visual Study of Pulp Floc Dispersion Mechanisms. Tappi J. 71(8) 1988 137-141.

15- C.T.J.Dodson. A Universal Law of Formation. J.Pulp and Paper Sci. 15(4) 1990, J136-J137.

16- C.T.J.Dodson. The Statistical Evolution of Paper in Three Dimensions. Proceedings of TAPPI International Paper Physics Conference, Hawaii. 1991, 197-201.

17- C.T.J.Dodson and L.Serafino. Simulation and Analysis of Stochastic Flocculation and Dispersion. Internal Report Pulp & Paper Centre. University of Toronto 1992.

18- C.T.J.Dodson. Spatial Variability and the Theory of Sampling in Random Fibrous Networks. J. Roy. Statist. Soc. B33(1) 1971, 88-94.

19- H.Tenekes and J.L.Lumley. A First Course in Turbulence. The MIT Press 1974.

20- DANTEC Measurement Technology, Dantec SensorLine™ Surface Velocity Sensor 7510: How to Install and Use.

21- S.R.Loewen and A.Buttler. *Laserspeed™* Measurement of Forming Section Flow Properties. Pulp and Paper Canada. 93(12) 1992, 161-164.

Transcription of Discussion

FORMING AND FORMATION OF PAPER

R R Farnood, S R Loewen & C T J Dodson

Dr R Popil, MacMillan Bloedel Research, Canada

How would you extrapolate your results for formation improvement to a twin wire machine.

R Farnood

The approach would not be directly applicable for twin wire machines. However, I think there are other opportunities. Perhaps an estimate of shear in such a case will be good enough. At the same time, the results of this study would provide us with an insight into the dynamics of forming and establish a correlation between this and the formation of paper. Such a correlation could be quite helpful both for Fourdrinier and twin wire formers.

Prof C T J Dodson, University of Toronto, Canada

A point of additional information to what has been said. Of course one of our great interests is in extrapolating the theoretical and experimental work to gap formers and the preliminary information we have in cooperation with Ari Kiviranta of Valmet will be reported at CPPA in January. The preliminary results of 140 trials suggest that this methodology and the variables we are using, such as the formation number looked at in relation to flocculation states, does demonstrate why gap formers are better than fourdriniers in handling the process of forming. So there is some data on its way but not quite ready yet.

Dr W Sampson, UMIST, UK

You showed towards the end a graph of the velocity gradient decreasing then it increased before it levelled off - do you have an explanation for this?

R Farnood

Can I have a look at the slides again. As I mentioned the velocity gradient profile (Figure 1) is the result of two measurements, stock height profile (Figure 2) and stock slip velocity profile (Figure 3). The lower level of shear after the second foil group corresponds to a lower velocity at that point. The reason for this observation is that the distance between these two foil groups is very small and some of my measurements show that the velocity is affected by the presence of foils, and I could not escape from this effect.

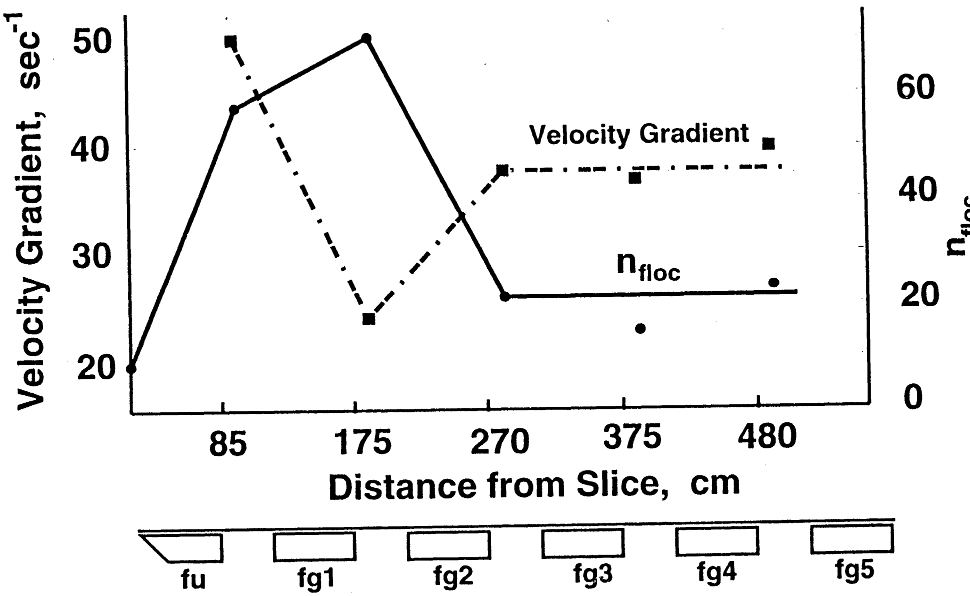

Figure 1. Machine direction profile of flocculation number and velocity gradient for Test B.

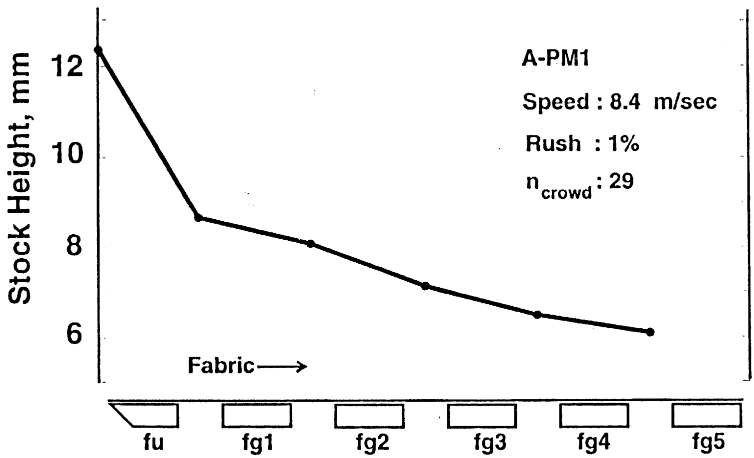

Figure 2. Machine direction profile of stock height as measured by gamma gauge for Test B.

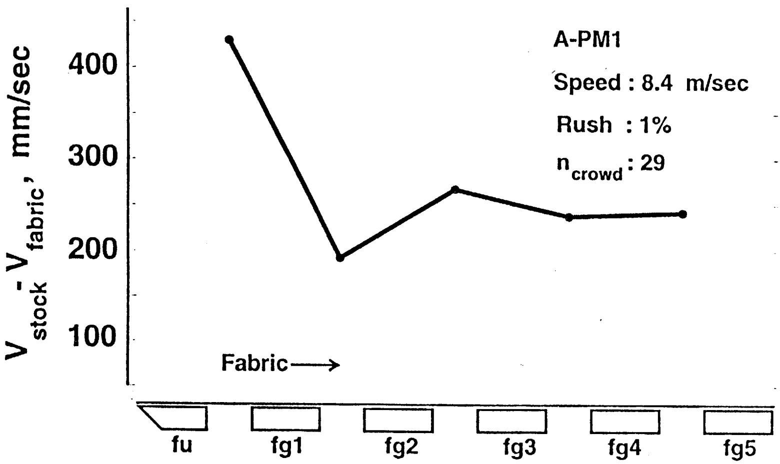

Figure 3. Machine direction stock slip velocity profile as measured by Dantec Laser sensor for Test B.

Dr L Wagberg, SCA Research AB, Sweden

When measuring flocculation from the autocorrelation function of the signal from the reflected laser light on a moving wire the detached flocculation has to be largely influenced by the waves on the wire. How did you separate the influence from the waves, the distribution of waves and the flocs in the furnish?

R Farnood

As you mentioned, there will be reflectance from the stock surface as well as the floc surface. However, intensity of reflectance from the stock surface is much less than the intensity of reflectance from the floc surfaces. Thus, the dominant feature which determines the shape and magnitude of the autocorrelation function is the backscattered signal from the flocs rather than waves.

Dr K Ebeling, Kymmene Corp, Finland

Is it possible with the theoretical work you have done to say which of the shearing forces is more significant for the formation, ie so called hydrodynamic shear that you have between various layers of the stock or the grooming type of shear which is introduced by the velocity difference between the fabric and the still not yet drained layer of stock. Is there a critical consistency about which you need to utilise the grooming type shear in order to get better formation?

R Farnood

Our study on measuring shear is at its earliest stages. I did not try to look into your suggestion, but I believe the method used here is capable of detecting the shear along the forming fabric and is a very promising way of looking into hydrodynamics of forming tables. So it is quite possible that using this method would answer your question in the near future. However, I do not have the answer right now.

Dr F El Hosseiny, Weyerhaeuser Paper Company, USA

You have considered the effect of velocity gradient on flocculation this would characterise the laminar flow but we also have a very important flow component which is coming from the turbulence and activities that are introduced to the forming section for the purpose of improving sheet formation. Do you have any feel as to what is the relative importance of these two components of flow ie which component is more important for flocculation or breaking up flocculations.

R Farnood

The gradient of velocity on the fabric is estimated using a simple linear model. The actual hydrodynamics is much more complicated than this linear model due to the drainage and pressure pulses which stock experiences as it passes over a foil. So, there are many irregular types of internal flows in the stock itself. The effect of these internal flows in the stock would be a flattening of the velocity profile so that we shall probably get a higher local shear at the bottom layer of the stock compared to the top layer. In other words, the flocculation number gives some information from near the surface but the velocity gradient approach will give us some information from the bottom of the suspension.