Monitoring flocculation on the paper machine

Otto J. Kallmes, Paul Kallmes, and Bradley S. Bishop

ABSTRACT: A 1.5-cm wide model Plexiglas headbox receiving a continuous flow of stock from commercial headboxes has been equipped with light source/photodetector systems to measure its point-to-point uniformity both in an undistributed quiescent state and after redispersion through a 90° elbow. The two floc indices measured are compared directly to the formation index determined by the same system on the sheet produced from the furnish. In this way, it is possible to ascertain whether it is the nature of the stock or the conditions on the paper machine which are responsible for a given change in a sheet's formation. In addition, the effect of chemical additives on the floc indices is readily determined both on-line and in the laboratory. A limited amount of data supporting this concept is presented.

KEYWORDS: Flocculation, measurement, monitoring, paper machines.

The floc structure of a sheet of paper generally reflects the flocculated state of the fiber suspension from which it was formed. That is, at commercially used consistencies, the fibers in papermaking suspensions do not float about freely, but rather are in contact with many other fibers, much like the passengers of a rush-hour subway. In fact, Kerekes *(1)* has defined a "crowding factor," i.e., the number of fibers present within a sphere whose diameter equals the fiber length. This crowding of the fibers results in a three-dimensional network of suspended fibers of considerable strength, and with a high degree of point-to-point mass nonuniformity.

All of this, and the fiber and network parameters which define the size and strength of the flocs in a suspension are well known and widely appreciated. What has not existed up to this point in time, however, is a practical, easy-to-comprehend means of directly relating the flocculated state of the fiber suspension in a headbox to the flocs of the sheet formed from it on the paper machine. As a result, the age-old argument between pulp and paper mills goes on unabated, i.e., whether a given loss in formation quality was due to poor pulp quality (as the papermakers often claim) or problems on the paper machine (as "suggested" by the pulp mill operators).

Basic principles of the flocculation monitor

Over the past two decades, we have designed and built a number of paper formation analyzers. Among these is an on-line formation tester which employs a white light to illuminate a small area of a moving sheet, and which continuously views a 1-mm diameter area of it by means of a photodetector located opposite the light source. That is, the formation of the sheet is measured in transmission.

Every 8 or so seconds, 10,000 readings are taken, and a histogram of the optically sensed point-to-point mass variation is stored in memory. The ratio of its peak height (the number of data points in the class with the most points) divided by the number of classes containing at least 100 data points is defined as the formation index. The more uniform a sheet, i.e., the greater the peak height and the fewer the number of classes of its histogram, the higher the formation index, and vice versa (see **Fig. 1**).

It recently occurred to us that it should be possible to view headbox stock in exactly the same manner by

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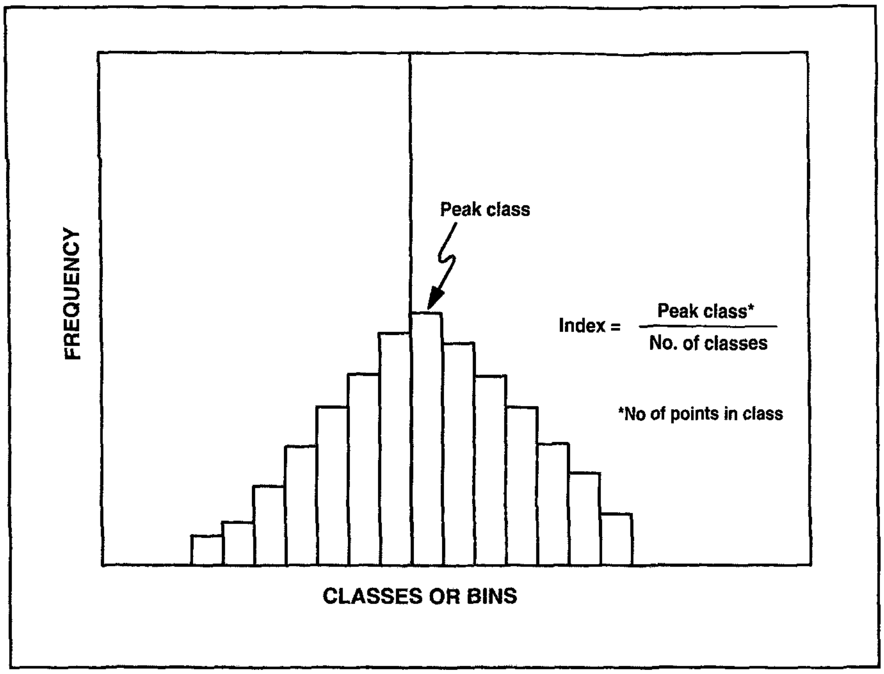
1. Definition of indices



bleeding a small flow of it through a narrow transparent flow channel. In fact, there are a number of commercial stock consistency meters on the market which operate in exactly this manner, i.e., they continuously measure the light transmission of a bleed flow of headbox stock passing through a narrow transparent tube.

For the purpose of characterizing the structure of the flocs passing through a headbox, we built the small Plexiglas model headbox shown in **Fig. 2**. Its open width is 1.3 cm (or 1/2 in.), a gap large enough for the undisturbed or "inherent" flocs of most stocks to pass through in "plug" flow, yet narrow enough for the passage of a small diameter light beam.

The reason the flocs passing through the Plexiglas model headbox are representative of the flocs flowing through a commercial air-padded headbox from which the sample flow is taken is as follows. When redispersive energy or turbulence is no longer introduced into a fiber suspension at a consistency above 0.2% or so, it reforms into a flocculated structure in a fraction of a second. This reflocculation phenomenon is clearly evident in Fig. 2. That is, when the stock flow traveling at a high velocity from the entrance "manifold tube" (with its fibers well dispersed due to the turbulence generated in a small diameter tube) passes into the bottom left-hand corner of the headbox, its speed is greatly reduced, the intensity of the turbulence is largely diminished, and reflocculation occurs in a matter of milliseconds.

As most flocs at consistencies of 0.2–1% are less than about 1 1/2 cm in cross section, the flocs pass through the 1/2-in. wide Plexiglass headbox essentially undisturbed. To characterize their homogeneity, or lack thereof, a white light and photodetector are located on opposite sides of the flow near its top. That is, its uniformity is measured in transmission. The same algorithm as used by the on-line dry paper formation tester is employed. However, we call the index determined from the histogram measured on a pulp flow the "floc index" rather than the formation index. This floc index also rises and falls as the suspension becomes more or less homogeneous.

The stock flow passing through commercial air-padded headboxes is accelerated to the speed of the forming section at their slice. This acceleration generates some shear and turbulence, resulting in a reduction in the size and intensity of its flocs.

Because of the extremely high rate at which stocks reflocculate following the decay of fiber dispersive energy, a variety of shear- and/or turbulence-inducing devices are employed in the forming section of all paper machines. Otherwise, as Farnwood *et al.* *(2)* have shown using a back-scattered signal from a pulsed laser light, reflocculation on a 3000 ft/min forming section is essentially completed within the first 0.1 s after the stock leaves a slice. To simulate the redispersive power of the devices on a fourdrinier table, a 90°, 1/2 in. x 1/2 in. elbow was installed right after the exit or "slice" of the Plexiglas headbox. This elbow has a second white light/photodetector sensing system across it.

So the flocculation monitor provides measurements of the uniformity of three streams; i.e., that of:

1. The headbox stock in its quiescent state, i.e., its "inherent" flocs
2. The same stock dispersed in a fixed manner, i.e., its "dispersed" flocs
3. The resultant sheet.

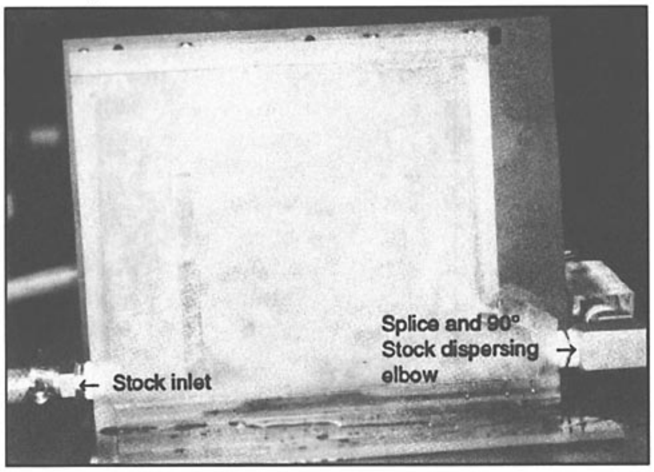
On the readout of the instrument, these three flows are indicated as (1) FlOC, (2) DISP, and (3) FORMATION.

The ratio of 2:1, i.e., the ratio of the:

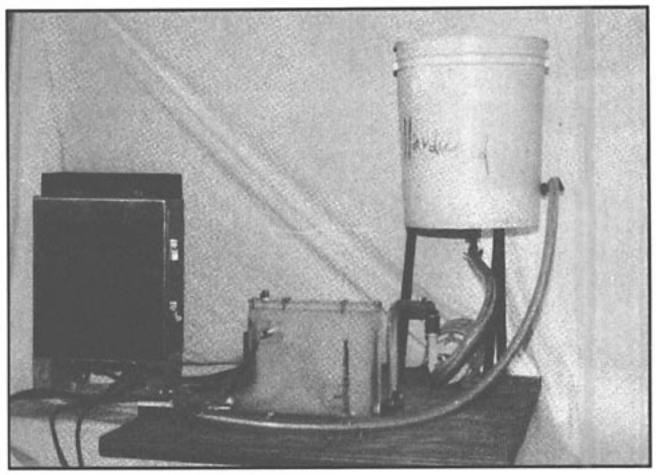
$$\frac{\textbf{Floc index of the dispersed suspension}}{\textbf{Floc index of the quiescent suspension}} = \textbf{Stock mobility}$$

provides a measure of how well the headbox stock responds to fiber dispersive forces. Kerekes *(3)* has called this characteristic of a fiber suspension its "mobility." The shorter and more flexible the fibers, i.e., the greater their degree of refining, and

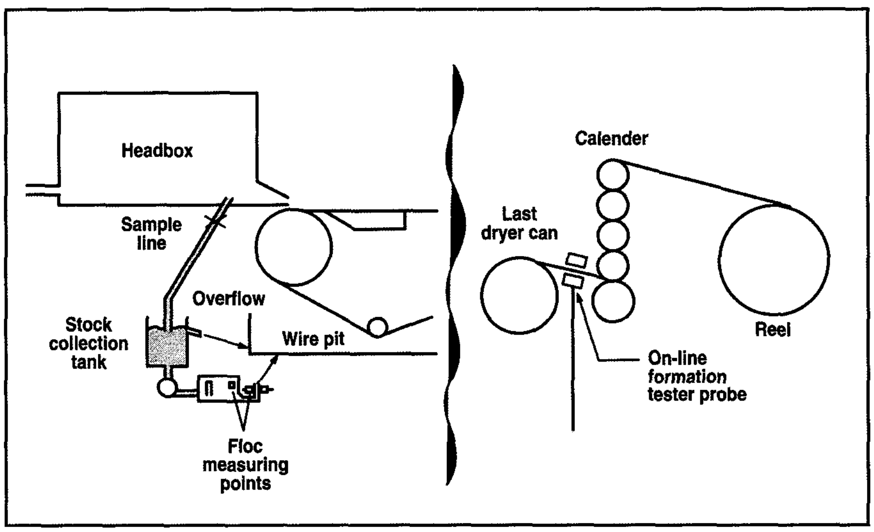
2. Plexiglas model headbox



3. Prototype flocculation monitor



4. Location of flocculation monitor elements on a paper machine



the lower the consistency of the suspension they form, the greater their "mobility" should be. As shown below, we have found this to be the case in practice.

The ratio of 3:2, i.e., the ratio of the:

$$\frac{\text{Formation index of the dry sheet}}{\text{Floc index of the dispersed suspension}} = \text{Forming efficiency}$$

provides a measure of how well the wet end of a paper machine keeps the stock dispersed in forming a sheet. In effect, this ratio is a "forming efficiency." Its numerical values must be determined empirically, and its meaning is as follows:

> When the forming efficiency rises due to an increase in the formation index or a decrease in the floc index, it says that the wet end of the machine is doing a better job of forming the sheet. If it drops due to a decrease in the formation index only, a less favorable forming condition is indicated. If the dispersed floc index decreases, the forming efficiency may rise or fall depending on how well the machine compensates for the loss in pulp quality or its mobility.

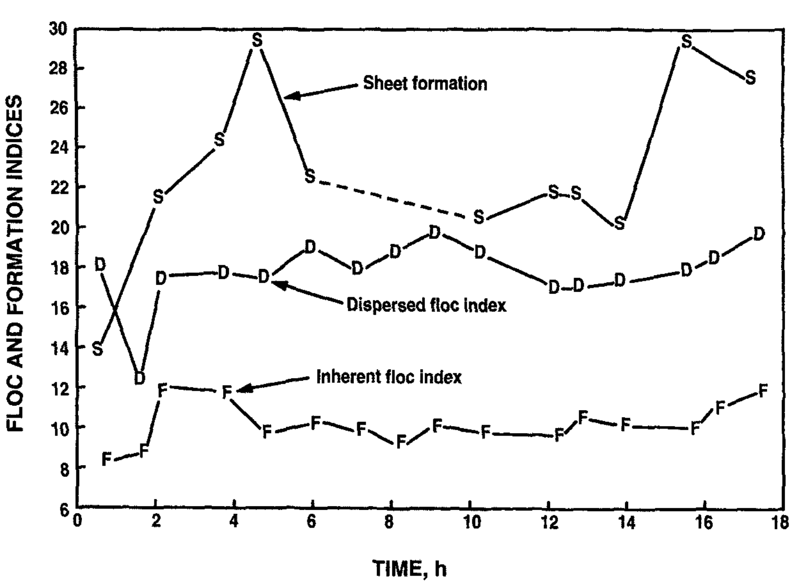
Initial mill trials

Several mill trials of the wet end portion of the flocculation monitor have now been carried out, i.e., headbox stock has been passed through the Plexiglas headbox to provide readings of the (1) FLOC and (2) DISPersed flows. The sheet (3) FORMATION has been measured simultaneously in only the first trial because of the lengthy time required to install its probe at the dry end of the paper machine. In the third trial at Simpson Paper Co., the sheet formation was measured by a bench top formation tester.

As shown in **Figs. 3 and 4**, the portion of the flocculation monitor at the wet end comprises a small stock tank, a centrifugal pulp, and the Plexiglas model headbox with its redispersing elbow after its "slice." The flow rate of the stock into the headbox was held constant at about 2.5 gal/min, which gives a velocity of 4.2 ft/s through the "manifold" tube, a residence time of 3 s in the headbox, and a velocity of 3.3 ft/s through the dispersed stock sensing channel.

Incidentally, in one set of laboratory trials, the flow rate at a typical bleached fine paper stock was varied over a fourfold range, from about half to double the value indicated above. Both the FLOC and DISPersed indices held remarkably constant. The importance of this find-

5. Floc, dispersed, and formation indices measured during an 18-h period on the 65-g/m² (40 lb) sheet.



ing is the demonstration that (1) the FLOC index represents the state of the stock in the flocculated state, and (2) the DISPersed index that after the maximum amount of redispersion attainable on a commercial paper machine; it is difficult to visualize a much more intense shear force on a paper machine than that generated by a narrow 90° elbow.

Stock from a sample line in the overflow from the manifold of the headbox of the paper machines examined was fed continuously into the stock tank above the model headbox. The discharge from the model headbox was also fed to this tank whose overflow, in turn, went into the wire pit. It took less than a minute for a complete change over of the stock in the tank.

Trial I

The initial trial of the flocculation monitor was carried out on a small paper machine producing 65 and 80 g/m² (40 and 50 lb) kraft specialty papers at 690 ft/min from a bleached 60:40 softwood:hardwood kraft furnish with a headbox freeness of 280 mL CSF. The headbox consistency was 0.4–0.45% and the pH in the low 4s.

Over the four hours of the trial, the FLOC index of the quiescent headbox flow varied randomly between 6.1 and 7.7. The FLOC index on the DISPersed stock index varied correspondingly from 26.1 to 33.5, a somewhat larger spread. However, it should be noted that as this index rises, an absolute variation in it becomes less significant as the denominator comprising it becomes a smaller number.

In other words, the mobility of this stock was a surprising fourfold or more. In addition, it appears that the dispersed stock flow was close to optimum dispersion as its index was almost as high as the value of 35 obtained on white water.

The formation index of the 80-g/m² sheet formed was around 35; on the lighter 65-g/m² sheet it was only about 15–20. As both the FLOC and DISPersed indices held essentially constant throughout the trial, it is clear that the wet end of this machine produces a far better 80-g/m² than 65-g/m² sheet. That point was evident from a visual examination of the two grades as well. However, at the time the mill was not willing to alter the table configuration to improve the formation of the lighter sheet.

At the end of the 4-h trial, no fiber, fines, or dirt buildup was evident on the walls of the model headbox. We realize, of course, that over time, there have to be such buildups. On commercial versions of the monitor, cleaning procedures employed by consistency meters will be included, i.e., periodic automatic flushing cycles with either fresh water or mild cleaning solution.

Trial II

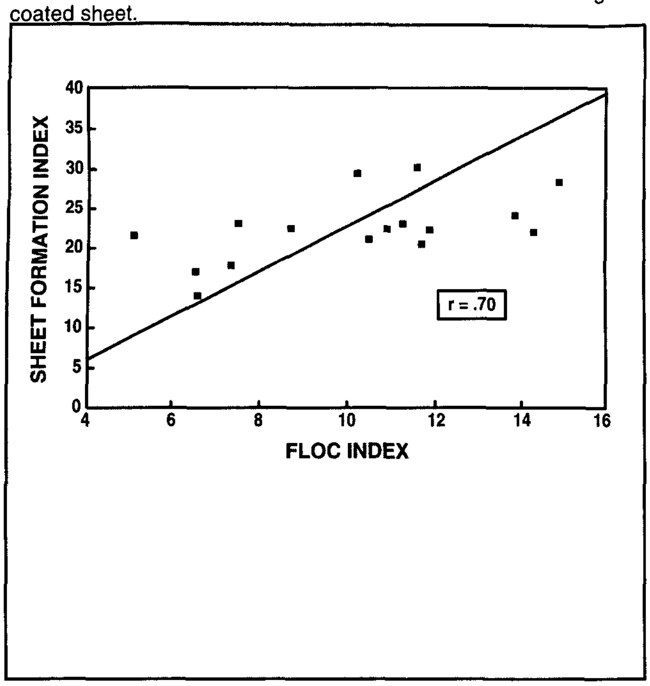
The second trial of the monitor was on a pulp machine producing a 700-g/m² sheet from an unrefined bleached southern pine kraft furnish at a headbox consistency of around 0.8%. The FLOC index varied a little around a value of 3, while the DISPersed Index was only slightly higher, around 4. In other words, this furnish, unrefined and run at twice the consistency of that used in Trial I, had a FLOC index half as large, and more significant, a mobility of one-third instead of fourfold. These results were completely inline with our expectations.

Trial III

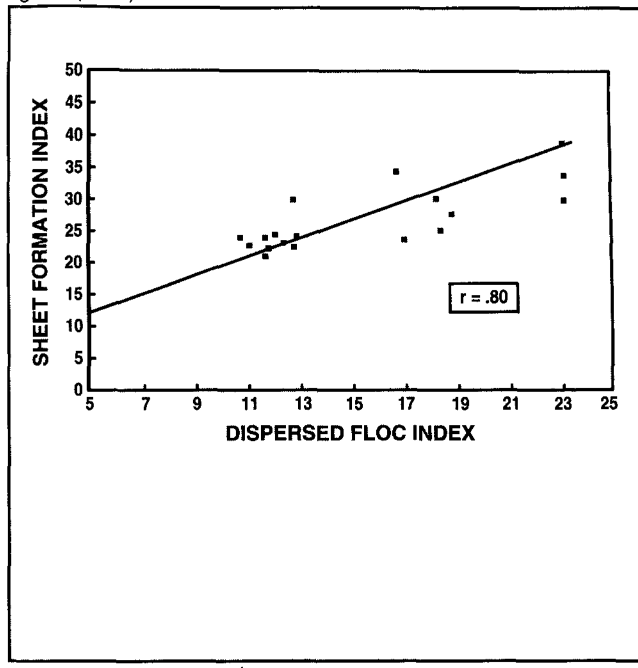
A 3-day trial was carried out on a pair of paper machines at Simpson Paper in West Linn, OR, producing lightweight coated grades at speeds up to 1500 ft/min. Both of these machines had two coaters. Thus, it was not possible to measure the formation of the base sheets they produce. As a result, the formation indices measured by a bench top formation tester reflected primarily the uniformity of the coatings rather than that of the base sheets (which, of course, should be related).

Even though the monitor provided in this case was strictly a prototype unit and not designed for continuous on-line operation, it performed surprisingly well. Although it did not

6. Sheet formation index as a function of floc index on 100-g/m² coated sheet.



7. Sheet formation index as a function of dispersed floc index on 72 g/m²- (45 lb) coated sheet.



have provisions for cleaning with water, the Plexiglass headbox remained totally clean during the trial period.

Figure 5 shows the FLOC, DISPersed Floc and sheet FORMATION indices over a typical 18-h period. Readings of the FLOC and DISP indices were taken at reel turnups by the machine operators when *single* coated paper samples were taken for testing. All readings of Fig. 5 reflect such single determinations.

Clearly, the FLOC and DISPersed readings generally rose and fell in concert. The same has been observed over many hours of laboratory testing of the monitor. However, as mentioned above, the stock mobility (i.e., their ratio) varied widely as a function of fiber stiffness and suspension consistency.

Figures 6 and 7 show the FORMATION index of a 106-g/m² sheet as a function of the FLOC and DISPersed indices. Given the relatively crude way in which the data had to be taken (all points represent single readings) the correlation coefficients of 0.70 and 0.80 are almost respectable. In fact these trials have given us the confidence to proceed with the next step, i.e., rebuild the unit for continuous operation and data collection.

Conclusion

In conclusion, we believe that in spite of the modest quality of the data obtained, there is clear evidence that the flocculation monitor can be built into a reliable, sensitive instrument providing direction as to the origin of variations in the uniformity of papers produced on commercial paper machines. **TJ**

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