

Local grammage distribution and formation of paper by light transmission image analysis

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ABSTRACT: *A method based on light transmission coupled with computer-based image analysis has been developed for determining the distribution of local grammage and hence the formation of paper. This technique is fast, inexpensive, and accurate. The method, tested over the range of 20 to 75 g/m² basis weight, for various finishes and formations, has a resolution of at least 0.1 mm, with an accuracy better than 0.5 g/m². A data processing procedure was developed to convert local opacity to local basis weight. A frequential analysis based upon a Fast Fourier transform treatment of the data can extract the contour map of the flocs in the paper, providing a visual representation of flocs not previously available. Further processing of the power spectrum data gives a single number as a new floc formation index (FFI) describing paper formation. The FFI criterion discriminates much more sensitively between different qualities of formation than does the standard formation number, while not having the disadvantage of the multiple indices of second-order statistics.*

KEYWORDS: *Basis weight, computers, flocs, formation, image analysis, optical properties, paper, radiography, test methods, transmittance, weight.*

The formation of paper, in spite of its great importance for paper quality and paper machine control, remains a particularly difficult paper property to determine. Key paper quality aspects include

strength and printing properties. For paper machine control, the ideal would be complete assessment of paper formation on-line (1). With the current state of development of quantitative methods, it remains common practice for experienced papermakers to assess visually the quality of sheet formation. Although visual inspection has its role, the importance of formation for paper quality requires methods which are objective, quantitative, fast, and convenient to use.

The determination of paper formation is required by those concerned with the production of paper, with its end use, and in laboratories for research on paper. Our laboratory carries out research on new technologies of drying and calendering paper. The drying research focuses on potential high-intensity techniques, including drying paper in high-temperature superheated steam. As there can be important interaction in such new drying processes between sheet formation, drying process conditions, and properties of the dry paper, current approaches to quantify sheet formation were re-examined. Likewise a fundamental understanding of the calendering of paper, a structured material with floc and inter-floc regions, requires knowledge of paper structure.

The initial results are now reported to the extent to which ac-

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cepted limitations of light transmission methods for paper formation can be reduced by the use of better equipment and more effective data processing.

Current status

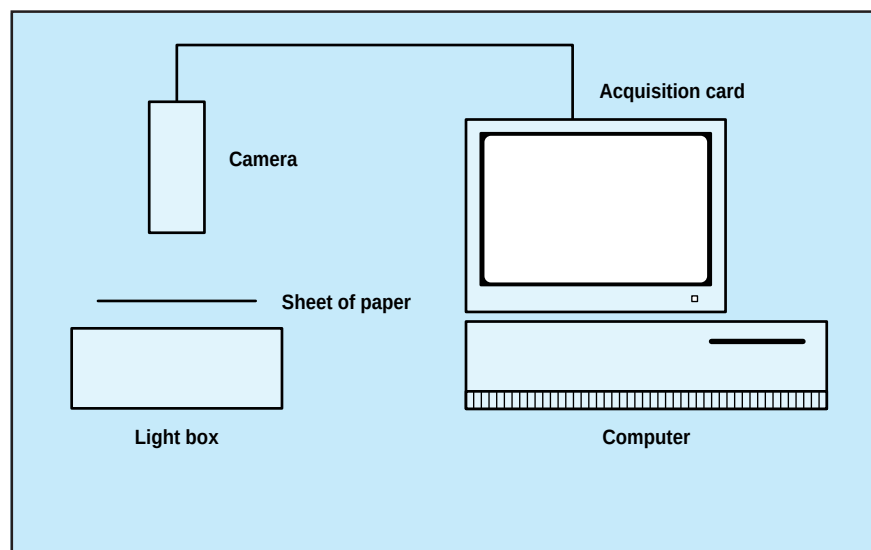
Quantifying sheet formation and floc structure

The various proposed "formation indexes" constitute attempts to provide quantitative definitions of paper formation. These formation indices are quantitative representations of local grammage, histograms, or maps of local grammage. The most commonly used formation index derives from the histogram of local grammage, and is the standard deviation of local grammage divided by mean grammage (2, 3), generally referred to as "formation number." A limitation of this index is that it may have the same value for formations of quite different floc structure. A more informative index is Dodson's formation number (4, 5), a quantitative relation between a particular sheet and a sheet of ideal formation paper.

As a quantitative index of floc structure, Jordan (6) defined specific perimeter as the ratio of the sum of floc perimeters for a sample to the size of the sample. In this method, flocs are defined as regions of heavier than median grammage and are detected by a simple thresholding of the image, based on a threshold equal to the mean grammage. This method is sensitive to paper structure and the graininess of the flocs. Kallmes (7) proposed a simple data processing based on an analysis close to that of Jordan.

Statistical analyses have been proposed to provide quantitative characterization of the floc structure. The simplest treatment is power and wavelength spectra, which provides a description of the various contributions to the variance of different frequency intervals. This method is related directly to floc size but, as it

1. Light transmission image analysis equipment



treats only periodic variations in the paper, this statistical method provides an incomplete description of floc structure and hence of paper quality (2, 8).

The approach chosen by Cresson *et al.* (8–10) is to describe formation with second-order statistics of the local grammage bi-dimensional map. Such statistics "compute the probability of occurrence of various predefined patterns in the image under study." Among various possibilities, they chose the "co-occurrence matrix," first applied for characterizing paper formation by Yuhara *et al.* (11–12). This method provides five indices which are indirectly related to the floc size, frequency, distribution, and formation quality.

Thus current quantitative definitions of paper formation range from simple representations such as standard deviation of local grammage, which do not reflect the true nature of floc structure, to the very complex method of second-order statistics, which provides results that are difficult to interpret. Floc and floc size are concepts that are not strictly defined. The many authors who have tried to translate the very subjective perception of flocs by using elaborate data processing, and the absence yet of a widely accepted treatment demonstrates the importance of ob-

taining an appropriate representation of the floc structure.

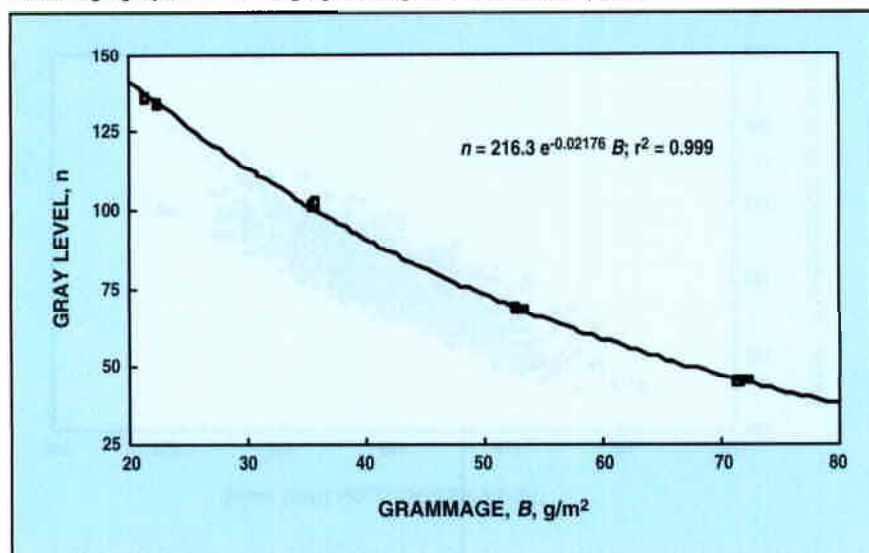
Local grammage by radiation absorption

The above formation indices are based on the local basis weight of the sheet, which is then subjected to data processing of various degrees of complexity. Methods of determining the histogram of local grammage, or the map of local grammage (for second-order statistics) are therefore of interest. The less detailed form of this information is the histogram of grammage, i.e., the frequency distribution curve of local grammage. The form containing much more information is the local grammage map, the grammage as a function of x and y , the coordinates in the plane of the sheet. The grammage histogram can be obtained from the grammage map as the latter provides the most complete information.

The distribution of local grammage is usually determined from the absorption of radiation, generally β -rays, sometimes X-rays. Radiation transmission is then related to local basis weight, requiring a calibration curve.

Two methods based on β -ray absorption are β -radiography and β -ray direct transmission. For β -radio-

2. Average gray level—average grammage relation for kraft paper



graphy, the paper sample is sandwiched between a β -ray source and a photographic film. Image analysis and calibration of the resultant developed film provides a real size map of local grammage of the paper. Soft X-ray radiography (i.e., of energy less than 10 keV) uses the same principles as β -radiography. The β -ray transmission method measures directly the β -ray absorbance of an elementary part (aperture size) of a sheet but, since every measurement gives only a point, many measurements must be done to produce a map.

The detailed comparisons and analyses of these measurement methods (2,13–20) may be summarized as follows: both β and X-ray radiography are of high accuracy because of the close correlation between radiation absorption and fiber mass, and are of high resolution, as good as 0.1 mm. Radiography is however very slow (up to several hours), is relatively expensive and requires the care needed with radiation hazards. Alternatively, direct measurement of β -rays is also accurate, but has much lower resolution as the aperture size cannot be below 1 mm. It is likewise a slow method and requires the care common to the use of radiation. X-ray radiography provides a very uneven picture

because of the heel effect, a geometrical effect caused by the angle of the target and the imaging area. The data processing of the X-ray radiographic image required to remove the strong effects of such shading naturally reduces the accuracy of the method. The β -ray technique does not suffer from this problem, and is usually considered as the best method of obtaining the local grammage map of paper.

Whatever the measurement method, the sample size and the resolution are important inter-related variables. Desirable sample size is indicated by the scale of the grammage changes to be measured, but may be limited by the measurement method. The resolution is dictated by the capability of the measurement technique. The size of the radiation source limits the maximum sample size. The minimum sample size is given by statistics: the sample must be representative of the floc structure of the sheet. The poorer the formation, the larger the required sample size. For a uniform formation handsheet, a sample size as small as 1 cm² may be quite representative. For paper machine formed sheets, the minimum sample size will be a multiple of the size of the largest flocs, with floc size for such sheets in the range of 1 to 5

mm, this value being only an order of magnitude because of the lack of a mathematical definition of the floc. As for resolution, if the measurement technique gives too coarse a resolution there will be insufficient precision in determination of local grammage, with failure to detect some local nonuniformities or flocs. At the extreme of too high resolution, i.e., below 100 μ m, fibers begin to appear and the treatment of the sheet as a continuous medium is violated. Generally used values are 50–100 mm for sample size, with available resolutions of 0.1–1 mm except not less than 1 mm with β -ray direct transmission as noted above.

Because all methods except β -ray direct transmission require acquisition of an image, there is a link between sample size and resolution because the image is acquired on a grid. Modern image analysis methods typically provide 512 x 512 or 480 x 640 grids. Thus a 0.1-mm resolution with a 480 x 640-grid of square pixels corresponds to a 48 x 64-mm sample size.

Historical use of light transmission

The most accurate and used method of obtaining the local basis weight map of paper is then β -radiography. Nevertheless, its disadvantages as to equipment, cost, and extensive experimental time required provided an incentive for reevaluation of the light transmission image analysis method. Specifically, the availability now of more powerful computers adapted for image analysis data processing, and the possibility of incorporation of more refined mathematical treatment, provided two incentives for re-examining light transmission as a method of determining local grammage and floc structure of the paper.

β -ray and X-ray radiography methods have a higher correlation with mass than does light transmission. Limitations in the use of visible light transmission derive from its

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high sensitivity to sheet structure (wire mark), to heavy calendering, fillers, and coatings (2,13–20). More sophisticated data processing may alleviate some of these problems.

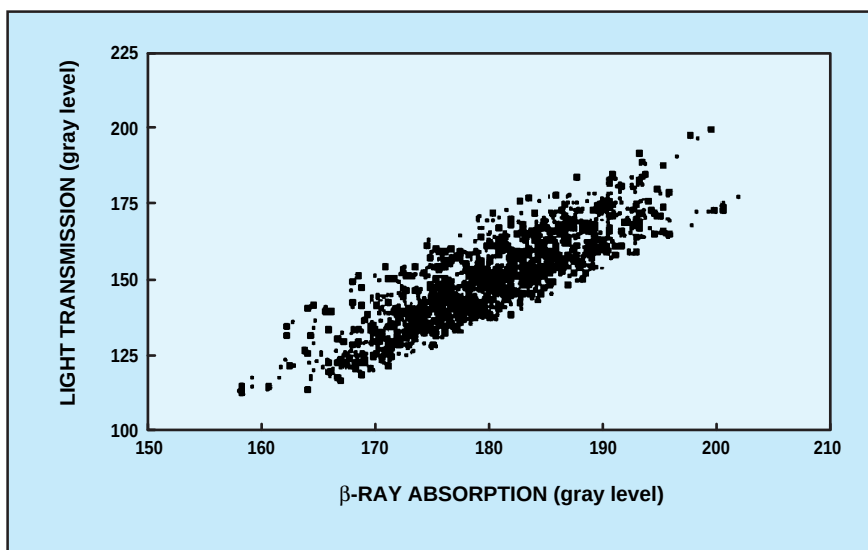
Thus determination of paper formation with the old technique of light transmission was tested with currently available video and computer hardware coupled with new data processing. The objective is to obtain formation information of four levels of complexity which, in order of increasing difficulty are: grammage histogram, grammage map, flocs map, and a new formation index.

Equipment

As shown in **Fig. 1**, a camera acquires the image of a sheet placed on a light box and transmits it to an Apple Macintosh IIx computer via an acquisition card. The GTFS Ultimage image analysis software drives the acquisition card and processes image analysis and file management. A standard CCD (charge coupled device) monochrome video camera is used. With the solid-state image sensor used, the image is acquired on a 640 x 480 grid with 256 gray levels (8 bits data). By comparison, although the data processing capability of the human brain is immeasurably greater than any computer, the fact that the human eye can discriminate only about 70 gray levels indicates the potential of computer-based light transmission image analysis.

The number of picture elements, or *pixels*, (307,200 for the above equipment) and the discrimination of opacity measurement (256 gray levels) provide a quantitative basis of comparison between this equipment and that used previously. The rapid improvement in quality and performances of equipment is apparent by noting that Sara (2) worked with no more than 2200 data points and 16 gray levels. Taylor and Dixon (21) used a digital system based on 64 gray levels. Gorres *et al.* (22) had a 16 gray level pixel depth

3. Correlation between local β -ray and local light transmission for a kraft handsheet



along with a 240 x 320 pixel grid. In 1991, l'Anson and Kropholler. (23) used a 512 x 512 grid with only 64 gray levels. In 1988, Cresson used 128 gray levels, before switching for his current work to 256 gray levels and 512 x 512 definition—equivalent to that used in the present study.

Image analysis requires a very large memory (a typical image is ca. 0.3 MB) and a high processor speed to treat the enormous quantity of data quickly and allow more sophisticated data processing. In 1984, the first Macintosh came with 128 KB of machine memory (RAM) and a 400 KB floppy drive. Today standard machines have 8 MB RAM and 80 or 160 MB hard drive. Our configuration is 20 MB RAM and 250 MB hard drive. Data processing speed underwent an even more impressive jump with today's equipment hundreds of times faster than a decade ago. The choice of Macintosh rather than PC equipment was based on the technical abilities of the two systems to handle gray level images and RAM management.

As the optical characteristics of our system make the smallest possible resolution (pixel size) 15 μ m, a sheet as small as 7.2 x 9.6 mm² could be examined. Since previous studies establish that a resolution of between 0.1 mm and 1.0 mm is sufficient, this

range of resolution has been generally used here. The optical capabilities of the present equipment permit a maximum pixel size of 0.35 mm, but data processing can emulate any larger magnification by local averaging, which is exactly what happens optically when magnification is reduced. This data processing technique of local averaging is valid only when transmitted light intensity is a linear function of gray level in the range of the sample.

Theoretical basis

The relationship between light transmission through paper and sheet properties may be expressed as follows (13):

$$T = b/[a \sinh(bSB) + b \cosh(bSB)] \quad (1)$$

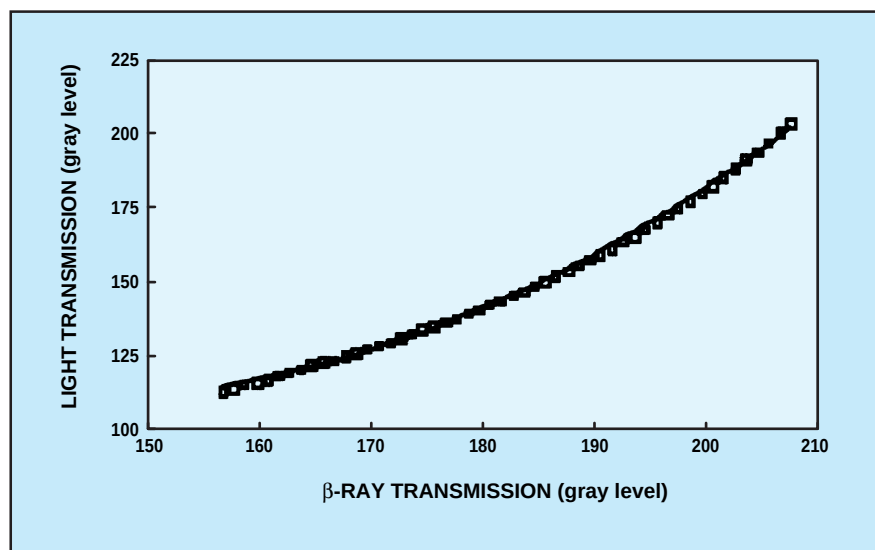
where T is the ratio of transmitted to incident light, S the scattering coefficient of the sheet (m²/g), B the grammage (g/m²), R_{∞} the light reflectivity of an infinitely thick sheet (adimensional), with a and b defined by:

$$a = 1/2[(1/R_{\infty}) + R_{\infty}]$$

$$b = 1/2 [(1/R_{\infty}) + R_{\infty}]$$

For materials that strongly scatter light, such as paper, Eq. 1 can be approximated as follows because the

4. Histogram correlation between β -ray and light transmission for a kraft handsheet



product (bSB) is much greater than 1:

$$T = 2b R_{\infty} e^{-bSB} \quad (2)$$

The shape of the light transmitted-grammage calibration curve is an invert exponential. One direct consequence is that the precision of grammage as determined from light transmission measurements is better in the low grammage-high light transmission-high gray level part of the curve. For paper with a relatively wide distribution of local grammage (high standard deviation for local grammage), it may be necessary to take images using more than one set of optical parameters (diaphragm aperture and/or magnification) in order to obtain sufficiently good quality results by separating the analysis into two or more ranges of local basis weight. The optical parameters are key elements in the light transmission technique (24).

Method

Once the image has been acquired as noted above, and has been coded in an 8-bits, 640 x 480 table, the first treatment is to remove the effect of nonuniform lighting. This standard image analysis correction is usually made by a pixel to pixel subtraction,

or division, or both, between the image and a map of the nonuniformity. As this technique supposes that the sample area is always the same, it is inappropriate to use when the optical parameters and sheet size are varied. Therefore we use a more elaborate frequential technique based on an Fast Fourier transform (FFT) treatment, filtering, and inverse FFT processing. The amplitude of the correction is directly related to sample size. For a sheet smaller than 10 x 10 mm, no correction is required. For a larger size, the correction with the light box used here can be up to 20 gray levels for a 70 x 80 mm sample size.

The data are then processed to transform the gray level map into the grammage map. The gray level map is not the exact representation of the transmitted light map. The difference is introduced by the camera and by the digitizing of the camera continuous signal to the 256 gray level scale. The gray level/light transmission curve therefore must be determined by test. Fortunately, this relationship was found to be strictly linear in a gray level-light transmission range experienced in the present study. The theoretical invert exponential curve, Eq. 2, should therefore not be affected, as was subsequently confirmed by calibra-

tion. The calibration data processing is based on comparisons between gray level and grammage maps provided by a reference technique. This processing may change with paper characteristics, according to its degree of "friendliness" or "unfriendliness" to the light transmission technique.

For each elementary area A of the paper (the resolution of the method), defined by its coordinates x and y and its local basis weight or grammage B , the gray level n , a function of the basis weight and other variables, can be expressed as follows:

$$n = f(B) + \xi(x, y) \quad (3)$$

The ξ function describes the bias factors occurring when light transmission through the sheet does not match the local grammage; as mentioned above, this may be due to wire mark, heavy calendering, fillers in or coatings on the paper. Previous studies (2, 3, 13) show that this error function is not significant for "light transmission friendly" paper, including newsprint and sheets without filler or coating. To evaluate quantitatively the error function, a local basis weight-gray level calibration is required. Comparison between light transmission gray level and β -radiographs for the same sample determines the gray level calibration curve as a function of basis weight. Comparison of the local values of light transmission and β -ray absorption provides the ξ error function and establishes the validity of the method. A global, simpler calibration can be made by comparing the average gray level of a gray level map to the average basis weight of the sample. This calibration requires samples with various basis weights.

Grammage maps, formation indices

Kraft handsheets

Experiments using light transmission image analysis to determine the

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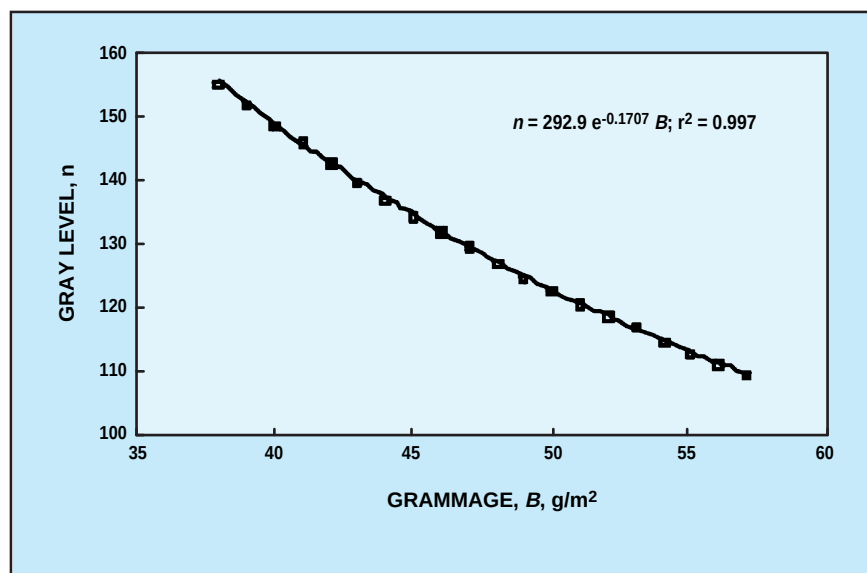
grammage map for kraft handsheets were carried out as a preliminary test to evaluate the equipment and data processing performance. Sheets of 155-mm diameter, having mean basis weights from 21 to 72 g/m², were analyzed. As expected, the calibration curve (average gray level—average grammage relation, **Fig. 2**) is an invert exponential. This curve shows an average response of 0.79 g/m² per gray level. Since the equipment behaved as expected for average values, the correlation between local light transmission and local β -ray absorption was determined. Comparison of these results is **Fig. 3**, presented as gray level vs. β -ray absorption (gray levels of the β -radiograph). This local comparison has been processed with a resolution of 0.5 mm. As the data scatter is the same in **Fig. 3** as for equivalent comparisons carried out by other authors (13,16), the procedures used here are confirmed.

Since a local β -ray map and a local light transmission map cannot have a perfect correspondence of local area, a correlation test should be made between the two histograms. From the cumulative histograms of β -ray transmission and light transmission, one may extract the β -ray transmission—light transmission curve. This is **Fig. 4**. The slightly round shape of the curve is due to the respective sensitivity of light transmission and β -rays to basis weight (13): the shape of this curve is close to a power function. As the results clearly show the high performance of the method, it was then possible to test a type of paper which could cause more difficulties with the light transmission technique (larger ξ) and to investigate the potential for using the data obtained by this technique to quantify floc structure.

TMP machine made paper

Experiments with machine made TMP paper were carried out in order to evaluate formation and to determine the ability of the proposed light transmission image analysis

5. Histogram based gray level—grammage relation for a TMP machine-formed sheet. Resolution 1 mm.



I. Measurements of formation by various methods for TMP machine-formed paper

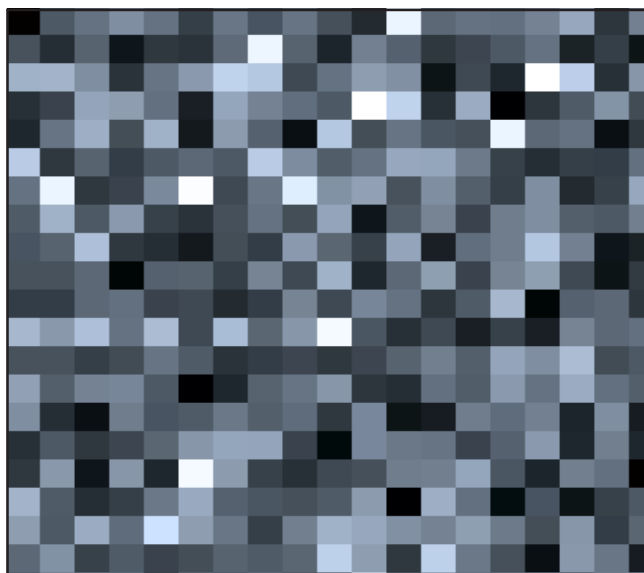
Paper type	Mean grammage, g/m ²	Formation number		Optical density RMS Microscanner	Floc formation index (FFI)
		Radio-graphy	Trans - mission		
No. 1	48.7	0.080	0.109	0.076	2.41
No. 2	50.0	0.062	0.080	0.063	1.71
Ratio:					
type No.2/type No.1		1.29	1.36	1.21	1.41

technique to reproduce the distribution of local grammage obtained by radiographic techniques for this type of paper. Thus the same machine made TMP paper was analyzed by an Ambertec β -radiographic facility, by the Paprican Microscanner and by light transmission image analysis. Measurements from the Ambertec system provide the standard deviation of local grammage (g/m²), and from the Microscanner give the standard deviation of opti-

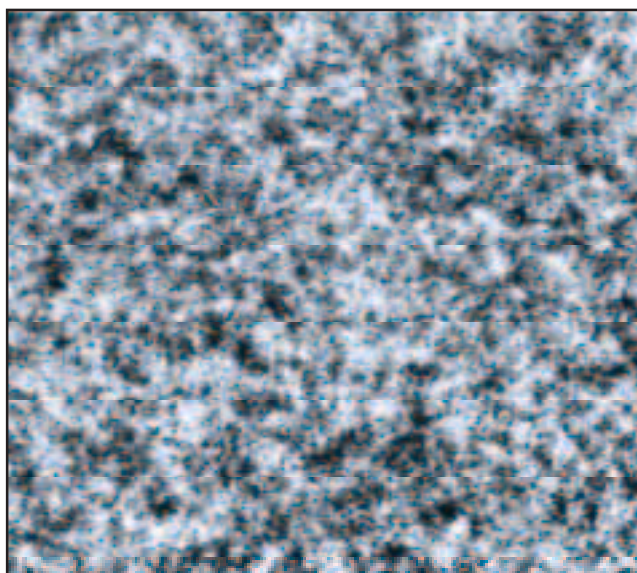
cal density (RMS), which theoretically is closely related to the standard deviation of grammage. The resolution of the Ambertec equipment is 1 mm, and 0.35 mm for the Microscanner, and the resolution for the light transmission equipment was set at 1 mm.

The results, **Table I**, show a clear coherence between the indices determined by the three methods. As the β -ray map and light transmission maps were not for the same

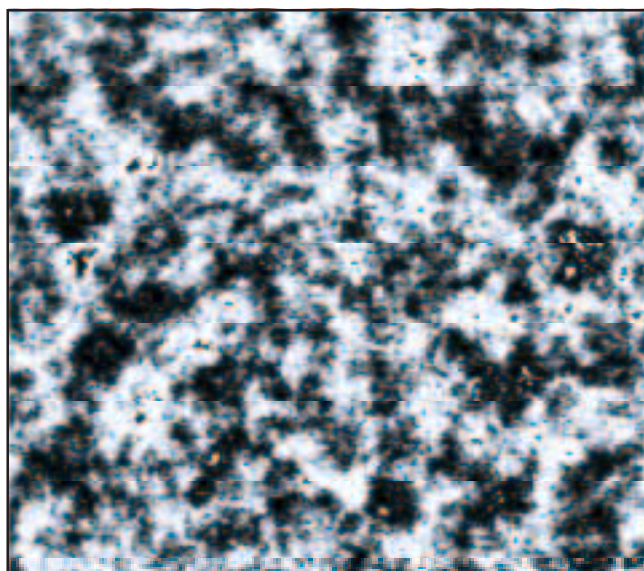
6. Basis weight map of a machine-formed TMP sheet, from β -radiography. Resolution 3.5 mm.



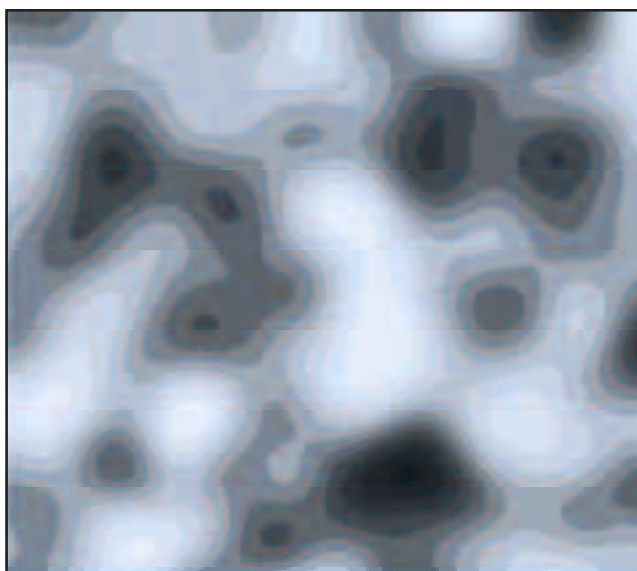
7. Good formation paper. Resolution 0.15 mm.



8. Poor formation paper. Resolution 0.15 mm.



9. Floc contour map for good formation paper of Fig. 7. 70 x 80 mm sheet



area of each paper, local comparison was not possible. By comparing the two histograms, we produced the gray level–basis weight histogram-based calibration curve (**Fig. 5**). The curve obtained was totally compatible with Eq. 2. From this curve, the response is 0.43 g/m² per gray level for TMP paper, somewhat greater than the value of 1.26 found for kraft handsheets.

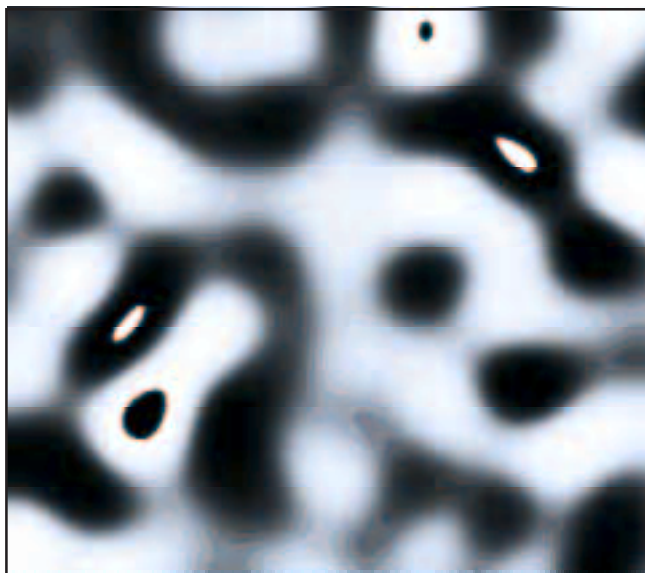
Other papers

Papers which are more “light transmission unfriendly” than the machine formed TMP examined above have optical properties introducing a large scattering in the light intensity/local basis weight calibration (2). In such cases, i.e., when $\xi(x, y)$ is large, advanced techniques may make it possible (a) to determine the local basis weight map in spite of a large $\xi(x, y)$, or (b) to obtain a less

detailed, but still useful, quantitative description of paper formation. Thus work in progress suggests that useful information may be obtained by new light transmission techniques for the case of heavily wiremarked machine formed paper. Procedures for reducing the currently accepted limitations to the use of light transmission for difficult types of paper will be the subject of a subsequent communication.

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10. Flocs contour map for poor formation paper of Fig. 8. 70 x 80 mm sheet



II. Test of sensitivity of FFI relative to formation number

	Retention time t		
	<1 s	10 s	100 s
Floc formation index			
Mean value	2.04	2.44	6.65
Std. dev.	0.106	0.176	0.626
Formation number			
Mean value	0.2	0.21	0.25
Std. dev.	0.05	0.04	0.06
Mean value (t) / mean value ($t < 1$ s)			
FFI		1.20	3.26
Formation no.		1.05	1.25

Floc structure

A new approach

The usual formation number (standard deviation of local grammage divided by mean grammage) provides only an incomplete description of formation. This feature was demonstrated by applying the light transmission image analysis technique to handsheets produced from the same kraft pulp, but with intentionally different formations: from good quality uniform formation to a poor quality, highly flocculated sheet. Although the difference in formation was visually obvious, the formation numbers were nevertheless identical!

Although the ultimate relevance of the floc structure is in the end use of the paper, it is also important at the paper machine for control of formation and may be important for the drying and calendering stages of papermaking. But no method has been reported for obtaining a contour map of paper, with a clear definition of the floc and inter-floc regions. Instead, methods have been developed for statistical characterization of the floc population. The inherent difficulty in obtaining a map of the floc structure is illustrated in

actual size by **Fig. 6**, the β -ray determined basis weight map of a sheet of TMP paper with a 3.5-mm resolution. As high basis weight squares (black) are neighbors with low basis weight squares (white), there is not necessarily a floc where there are a few high basis weight squares, but rather where a reasonable number of reasonably high basis weight squares occur in a reasonably small area. It is to evaluate these highly subjective concepts that second order statistics are used. From an image such as Fig. 6, it is impossible to extract a floc contour map with standard smoothing methods such as bidimensional local averaging. The limitations of the approach of second-order statistics with respect to flocs provide an incentive for the development of a method for determining the floc structure of paper, a method that would provide numerical results which relate directly to the visual evaluation of paper formation.

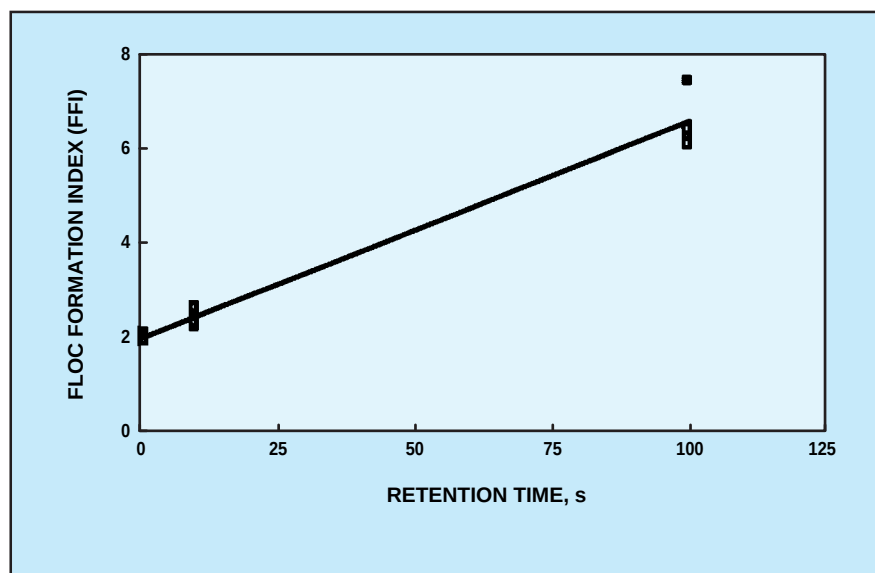
A method has then been developed here based on a FFT treatment of the data that can extract a contour map of the flocs in the paper. This method is based on a frequential treatment of the grid of pixels, seen as a grammage matrix.

A two dimensional Fourier transform-based process allows extraction of the frequency/amplitude plane of the image. The frequency spectrum is then filtered, and the data reprocessed by an inverse FFT to provide a frequency-filtered image. Processing the original and the processed image together is the final step. Additional features in the treatment avoid the usual problems occurring with frequential treatment and filtering.

A quantitative basis must be adopted for definition of what is a floc and what is an inter-floc region. The two possibilities are:

- Define a cut-off basis weight between flocs and inter-floc regions. This basis weight can be $(1 + \varepsilon)B$ (related to mean grammage B) or $B + \eta\sigma$ (related to the mean, B , and standard deviation of grammage, σ), where ε and η are parameters chosen by the user. With ε taken as zero, this corresponds to the criterion for the floc definition used by Kallmes and Ayer (7). Jordan and Nguyen (6) use the median basis weight as threshold value.
- Select an area ratio, for example that flocs are the heaviest 1/4 or 1/3 of the paper.

11. Sensitivity of the floc formation index (FFI) to sheet formation time



Since the criterion for flocs is applied after the data processing this arbitrary choice has no influence on the data, only on alternate ways to represent the data. Neither the floc contour map nor the formation index to be defined below depends on this choice. They depend on the choice of the cut-off frequency, or of a cut-off wavelength, which constitutes the user-defined dimensional criterion, which indirectly defines the minimum floc size.

Experimental results

Kraft handsheets were formed using three retention times: near zero (this limiting value is the normal TAPPI method T 205 om-88), 10 s and 100 s. Five sheets were made for each of these values of retention time.

Retention time has a well-known influence on formation due to flocculation of pulp suspensions. The difference in sheet formation becomes evident visually to experienced observers for retention times above about 10 s. Thus the difference in formation between sheets formed with 10 s retention and the minimum possible retention time approximates the limit of

discrimination possible by visual observation of paper.

Floc contour map. For 60 g/m² kraft handsheets, of different formations, **Fig. 7** is a gray level map for a sheet of highly uniform formation, **Fig. 8** of a poor formation handsheet. The size of the sample is ca. 70 mm x 80 mm (pixel size 0.15 mm). The difference of formation clearly appears. This difference is high enough to appear in the standard formation number (0.20 for **Fig. 7**, 0.25 for **Fig. 8**, difference statistically significant from a *t*-test). Floc contour maps obtained as described above for each of these papers, **Figs. 9 and 10**, show the different formations of these sheets. For **Figs. 7–10**, which are shown in actual sheet size, the contrast has been increased in order to make the results appear more clearly. This change in the gray level distribution in no way affects the results because the same contrast enhancement was applied to **Figs. 7 and 8**, and to **Figs. 9 and 10**. Therefore the same optical conditions were used for all the images.

Floc formation index (FFI). During the data processing described above, it is possible to obtain from the frequency/amplitude analysis a nondimensional index related

to the formation of the paper. We have named this index the FFI (floc formation index).

The FFT provides the power spectral density that can, like the co-occurrence matrix, be related to the scale of the change of local grammage. A change in grammage between two adjacent pixels affects the FFT differently from a change in grammage between two distant pixels. The standard formation number does not make this differentiation, which explains the interest of second-order analysis. Therefore the frequency/amplitude data processed by the FFT show the change in local grammage with respect to the dimensional factor. The lowest frequencies are linked to the large scale changes, i.e., the flocs. The FFI measures the intensity of the low frequencies in the power spectrum and thus provides information on the flocs only, not on the small scale changes. In order to achieve this objective, the FFI processing is based on the numerical integration of the frequency/amplitude plane between zero and cut-off frequencies.

With the processing technique used, a sheet with a perfectly uniform local grammage and hence without flocs would have an FFI value of zero, as for formation number. The higher the FFI, the poorer the formation. As an example, **Table I** lists for TMP papers from two paper machines the values of FFI along with other measures of formation. When the poorer formation TMP sheet (No. 1) is compared with the better one (No. 2), it is seen that the FFI is higher by 41% whereas the other three indices of formation are higher by only an average of 29%. Even for the standard formation number, **Table I** shows that relative to the β -radiography based values, those based on the present light transmission measurements show greater sensitivity, being 36% rather than 29% higher for the poorer quality TMP sheet.

To further assess the validity of this index, the FFI has been pro-

Formation Analysis

cessed for the various formation handsheets mentioned above. Results for this test, **Table II** and **Fig. 11**, are positive. As retention time goes from the minimum value to 10 s, the corresponding increases in the two formation indices are 20% for FFI but only 5% for standard formation number. The difference in FFI between the minimum and 10 s retention time is statistically significant, the difference between the mean values being three times the standard deviation of the samples. Thus the FFI criterion easily discriminates between differences in formation which are at the limits of visual capability.

A further test of the relative sensitivity to formation of the FFI criterion relatively to standard formation number was provided by using these indices, at the same resolution, to quantify the decrease in quality of formation from the best kraft handsheet to machine-formed kraft paper. For this case, where formation number increased by only 10% from the handsheet to the papermachine kraft paper (9.1 vs. 8.2), the FFI increased by 50% (4.1 vs. 2.7). Consistently, then, the FFI is a much more sensitive indicator of variation in quality of formation than is the conventional formation number.

Development of a stable self-testing method, currently under way, will permit the program to make independently the discrimination between the floc and inter-floc regions rather than use an area or basis weight criterion as illustrated here.

With the technique reported in the present investigation, the time required from acquiring the picture to having the formation number, floc contour map and the FFI is about 8–10 min. With recent implementation of this analysis using a Power-Macintosh 8100/100 computer and

corresponding software, this time has been reduced to 30–50 s.

Summary

A light transmission image analysis system, including an image analysis friendly computer, was tested. The objective was to determine whether improved equipment and data processing methods could appreciably reduce the currently accepted limitations on the use of light transmission based techniques to evaluate paper formation. Good results were obtained for kraft paper and for machine formed TMP paper. A high correlation was found between light transmission and radiography-determined local grammage maps.

By contrast to previously reported methods, this technique also enables production of a contour map of the flocs. Thus an original FFT-based method was developed with which floc contour maps may be produced for sheets of any quality of formation.

This technique was further extended to the definition of a new index of paper formation, the floc formation index (FFI). The results of preliminary testing of the FFI criterion for the quality of paper formation were positive, showing that relative to the standard formation number, the FFI is much more sensitive to formation. Further development of this approach by testing with other types of paper is currently in progress. 

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