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APPLICATIONS OF FLOW VISUALIZATION TECHNIQUE IN WET END CHEMISTRY

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ABSTRACT

A microcomputer-aided flow visualization system consisting of Strobovision analyzer(SVA) and image processing apparatus was applied to the analysis of the effect of a variety of parameters in wet end chemistry on the flocculation behavior of model stock systems. These are (a)single polymer addition systems and dual component additive systems,(b)low and high filler content suspensions,and (c)colloidal force and hydrodynamic shear force.

Analysis by digital geometry was carried out to represent features of projected images of flocs and fiber network supporting flocs. The flocculation states were represented numerically.

It was attempted to test visually and numerically a flocculation hypothesis in a dual component additive system.

Within the scope of the present investigation,there is some limitations in that this system can be applied only for dilute suspensions with concentrations far lower than those of conventional paper stock in a headbox.

INTRODUCTION

With a view to visualize and evaluate quantitatively the flocculation behavior of pulp suspensions, the author had initiated a series of investigations on flocculation phenomena using the image processing method in 1983.

The initial system was based on an image memory unit with effective pixels of 256x240 and 4-bits digitizing levels(i.e.16 gray levels) operated with a 8-bits microcomputer(NEC PC8001). Additional circuits were developed by the author as "Digitizing Level Controller", which permitted quantification of images on real-time basis. Also, softwares for this system were developed using BASIC language. The speed of processing was quite lower compared with the latest "flow visualization system".

Since the flow behavior was taken by a video camera and recorded directly on a video tape, this system had limitations in tracing the flow behavior and freezing a still image owing to the video camera's ability(i.e., shutter speed of 1/30 second). Due to the low digitizing level, only the block image of flocs could be observed and no detailed information on the structure of flocs could be obtained. Although the processing speed was much improved by applying the machine language software instead of the BASIC language one, and by replacing 8-bits microcomputer by 16-bits one, this system had inherent limitations in wider applications owing to its resolution, digitizing level, processing speed, etc. The most profound problem was that this system was not capable of tracing the flow phenomena with a velocity higher than 1/30 second as far as video-recorder was used as initial photographing system(1,2).

In order to overcome drawbacks of previous system, a novel flow visualization system consisting of strobo-photographing and high performance image processing system was adopted. This system was found useful in analyzing flocculation phenomena in high filler content paper suspension under flowing motion and provides detailed structure of flocs with 256 gray levels(3,4,5).

Under these circumstances, this paper presents applications of this system in testing a variety of parameters related to flocculation in wet end chemistry and also presents numerical analysis of flocculation phenomena on the basis of the digital geometrical method.

FLOW VISUALIZATION TECHNIQUE

According to the Flow Visualization Society founded in Tokyo in 1973,"*Flow visualization technique*" is defined as a system of techniques to render *invisible flow phenomena* in nature and in artificial organs *visible and observable*. Computer-aided flow visualization technique(CAFV),in which microcomputer-aided image processing system is used,is one of the major technique among the variety of flow visualization techniques. The author is the first to have applied this technique in combination with a strobo-photographing technique to the analysis of flocculation behavior under flowing motion.

The latest "flow visualization system" in our laboratory consists of Strobovision Analyzer(SVA-1,Sugawara Laboratory,Tokyo) and image processing unit (L500,PIAS Ltd.,Tokyo). Both of these equipments have the effective pixels of 512 x 480 with 256 gray levels. This system is operated with a 16-bits microcomputer(PC9801-VX,NEC, Japan) and permits visualization and quantitative evaluation of pulp/filler suspensions under dynamic conditions.

SEQUENCE OF STROBO-PHOTOGRAPHING AND IMAGE PROCESSING

The commonly used image processing sequence in this work is as follows. A flow image was taken by a CCD camera and the image was frozen in SVA followed by storage in VTR. A stored image in VTR was fed into the image processing system and stored as the still image. Required region of the image(normally 1/4 of the original image) was cut out as the image for further processing. After looking at the range of histogram of the image,the dynamic range was enlarged so that clear-cut contrast of the image was attained. The noise removal was carried out using a series of filtering processes. Binarization of the image by thresholding at certain gray level(normally 65) was performed to separate the floc image from the fiber network image. The binarized floc image was labelled with a number and used for numerical analysis using the digital geometrical method (6,7). An example of fundamental processing scheme is shown in Fig.1.

ANALYSIS BY DIGITAL GEOMETRY

Digital geometry and flocculation analysis

Although fibers,fillers,and fiber/filler flocs in suspension under flowing or agitation conditions are moving randomly in 3-D(three dimensional) directions,the image taken by video camera is the projection of 3-D image on a 2-D plane. After binarization of the original image,the floc image and the network image can be extracted separately and expressed independently.

Within the scope of the present investigation,flocculation states are observed either as the set of independent flocs or the set of flocs supported on the fiber network. That is,the flocculation state can be represented as the combination of flocs and the network supporting flocs. How flocculation state are observed differs according to the fiber/filler ratio and the additive systems adopted.

With a view to analyze the flocculation state numerically,the digital geometry was applied to analyze the images of flocs and the network structure supporting flocs. The following is the mathematical treatment of flocs by digital geometry.

Basic terminology and concept of discrete mathematics

The feature of flocculation state abstracted as a binarized image is the set of discrete flocs existing independently or supported and connected by the fiber network. Therefore mathematically they can be dealt with discrete mathematics such as the *set theory* and the *graph theory*(8).

A *set* is a collection of distinct objects. We write $X=\{x_1,x_2,x_3\}$ to mean that the set named X is the collection of the objects x_1, x_2, and x_3. Also we use the notation $x_1 \in X$ to mean that x_1 is an element in the set X. We use the notation $x_4 \notin X$ to mean that x_4 is not an element in the set X.

A *graph* G is defined abstractly as an ordered

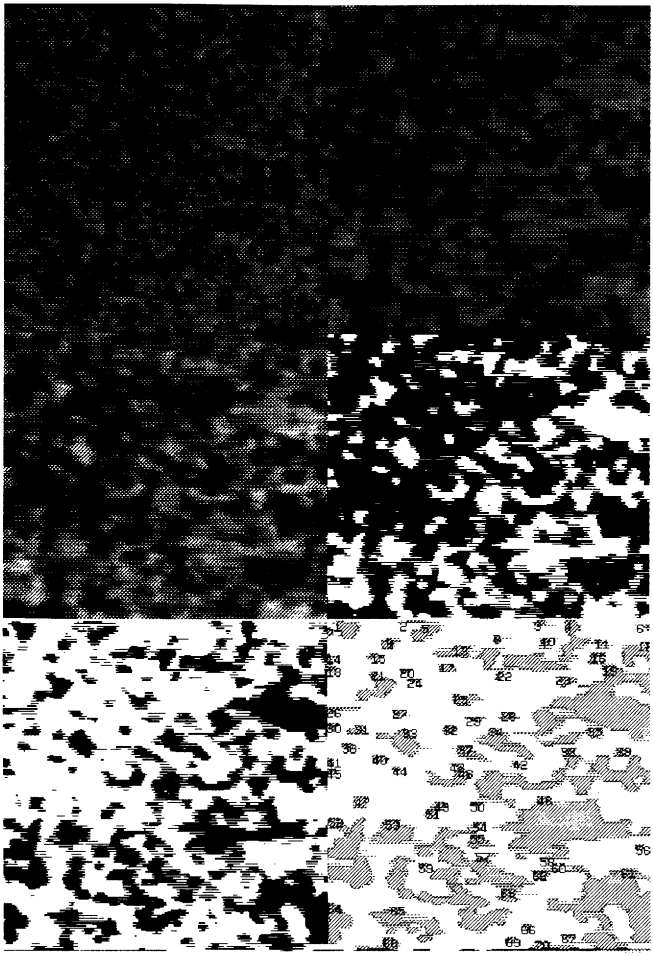

Fig 1- Fundamental image processing scheme for digital geometric analysis(from (A) to (F) sequentially).

(A)	(B)
(C)	(D)
(E)	(F)

(Pulp+zeolite+cationic PAA+bentonite).
(A)Original image, (B)Extraction of region to be processed, (C)Dynamic range enlarged, (D)Image binarized at threshold level of 65, (E)Reversed binarized image, (F)Labelled Image for digital geometric analysis.

pair(V,E), where V is a set and E is a multisets of two elements from V, namely, binary relation on V.

$$G=(V,E) \quad (1)$$

The elements in V are called the *vertices*, and the ordered pairs in E are called the *edges* of the *graph*.

$$V=\{v_1, v_2, \ldots v_n\} \quad (2)$$

A *graph* G can be represented geometrically as a set of marked points V with a set of lines E between points.

$$E=\{l_1, l_2, \ldots l_n\} \quad (3)$$

Expression of floc images

As stated already, floc images obtained in this work are the projection of 3-D images on 2-D planes. Since each floc image can be converted to a closed curve(f_i) by edging procedure of image processing, the set of flocs $\{f_1, f_2, \ldots f_n\}$ in one image area can be expressed as the set of closed curves as in the following. Let F be the total projected area of flocs, then we have,

$$F=\{f_1, f_2, \ldots f_n\} \quad (4)$$

$$F=\Sigma f_{i\ (i=1\ \text{to}\ n)} \quad (5)$$

Therefore, conventional *"digital geometry for closed curves"* can be used in its analysis. The following parameters can be used to express the state of flocs numerically and depicted in Fig.2.

The number of flocs(denoted as "Floc.no."in legends of figures): Each flocs can be labelled by number and the number of flocs on an image area(n) can be counted automatically by software. The difference of the number of flocs before and after the addition of paper chemicals and by the change in agitation velocity is an indication of the progress of flocculation. The number of flocs corresponds to the number of *"connecting numbers"* in digital geometry.

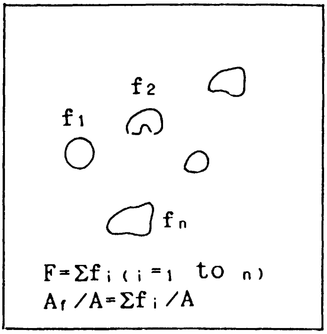

Fig 2 -Abstraction of floc images as the set of closed curves.

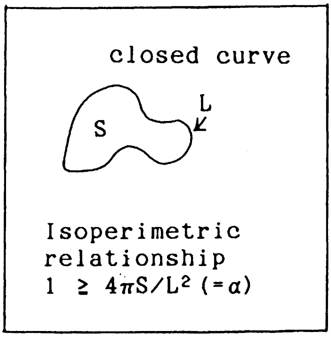

Fig 3 -The area vs. perimeter relationship for closed curves.

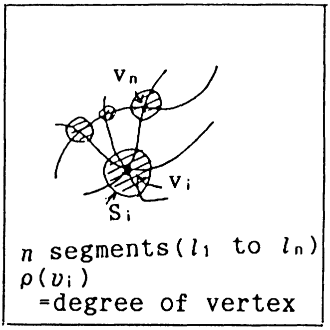

Fig 4 -Expression of the network supporting flocs as a graph.

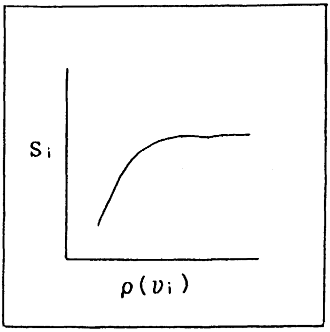

Fig 5 -Floc area vs. degree of vertex relationship.

Fraction of floc area on image area("Floc.fr."):The fraction of image area occupied by floc image(A_f) is also an indication of flocculation level. Let A be the total image area,then we have,

$$A_f/A=\Sigma f_i/A \qquad (6)$$

Mean floc area("mean fl.area"):Distribution of floc areas is an indication of dispersedness of floc sizes. Distribution closer to monodisperse means good distribution and expected to lead to good formation of the sheet. Mean floc area is,

$$A_f/n=\Sigma f_i/n \qquad (7)$$

Roundness coefficient("Roundness"):The ratio of the square of perimeter(L) to the area of each floc(S) is an indication of the roundness or complexity of the shape of each floc. This is the isoperimetric inequality relationship expressed as follows(Fig.3):

$$L^2 - 4\pi S \geqq 0 \qquad (8)$$

This relationship can be rewritten as

$$1 \geqq 4\pi S/L^2 \ (=\alpha) \qquad (9)$$

α equals 1 for circle and α will be smaller away from 1 as the shape of the object area will be more irregular and complex. This parameter can be used to test the roundness of floc shape.

Center of gravity:Distribution of the center of gravity is a measure of the uniformity of distribution of the location of flocs in suspension.

Let the first order moment of the digital image f(x,y) be $\Sigma\Sigma xy\cdot f(x,y)$,then we have the first order moment with respect to x axis and y axis as SIGX and SIGY,respectively.

$$SIGX=\Sigma\Sigma y\cdot f(x,y) \qquad (10)$$

$$SIGY=\Sigma\Sigma x\cdot f(x,y) \qquad (11)$$

The zero order moment of f(x,y) is defined as

SIGOO.

$$SIGOO=\Sigma\Sigma f(x,y)$$
$$(=\text{area of binarized image}) \quad (12)$$

The location of the center of gravity (XCENT,YCENT) of digital image f(x,y) is defined as:

$$XCENT=SIGX/SIGOO \quad (13)$$

$$YCENT=SIGY/SIGOO \quad (14)$$

Uniform distribution of flocs is a prerequisite to good formation of the sheet. Although the data on the distance between the center of gravity were obtained,the data were not used to represent the feature of the distribution of flocs at this stage.

Expression of network images

The network of fibers supporting flocs can be obtained by skeletonization(=line-thininning procedure) of the image consisting of fibers and flocs. That is,the skeleton line of an image can be obtained by removing pixel by pixel from the edge line to the center of the floc image. Although this skeleton line can be obtained by line-thinning procedure,one cannot guarantee it as the real network image. However,the network obtained by this procedure is quite logically understood as fiber network supporting flocs.

The network structure is mathematically dealt with the graph theory. Consider a network consisting of crossing lines(=segments). The lines in network have vertices consisting of end points(=terminal points) and branch points(=crossing points). We call the number of lines crossing at a branch point as "degree". A segment has two end points. Crossing two segments have at least one branch point. Both end points and branch points are called "vertex" in graph theory. The number of vertex is the sum of end points and branch points.

For instance,assume that a graph G consists of n segments(l_1 to l_n). Then,the degree of vertex(v_i) is the number of segments crossing at v_i and expressed as $\rho(v_i)$.

$$\rho(v_i)=\text{degree of vertex} \quad (15)$$

The sum of the degree of vertex $\Sigma\rho(v_i)$ is a measure of the complexity of the network.

$$\Sigma\rho(v_i) = \text{complexity of network} \quad (16)$$

The above description is depicted in Fig.4.

Synthesis of floc image with network image

In the case of flocculation of high filler content suspensions,flocs are observed on the fiber network. The floc image can be synthesized with the network image using logical AND procedure for two images. The floc area is plotted as a function of the degree of vertex(= the number of branches) and used for testing the balance between the colloidal force and the hydrodynamic shear force(Fig.5).

RESULTS AND DISCUSSION

Images were displayed on CRT either in 256 gray levels or in 16 pseudo-color levels. However,images in this paper are shown in 64 gray levels as output from the ink-jet printer(SHARP IO-725,Japan). Actual images with 256 gray levels were displayed on CRT with much higher contrasts. Numerical data are shown as the unit of pixels. The scale of images of objects determined using a standard scale sample is as follows. The unit length per pixel(both for hoizontal and vertical directions) is 0.000980cm. The unit area per pixel is 0.000001cm^2.

Comparison of single and dual component additive systems

Two kinds of dual component additive systems were tested. In cationic PAA+anionic PAA system,flocculation proceeds further after the addition of anionic PAA to give larger flocs,probably by the formation of tenacious polyion complex bridges between residual cationic PAA and anionic PAA(Fig.6). In Hydrocol(cationic PAA)+ Organosorb(modified bentonite) system(9,10),results are shown numerically as well as visually. It is observed that after the addition of bentonite,floc sizes

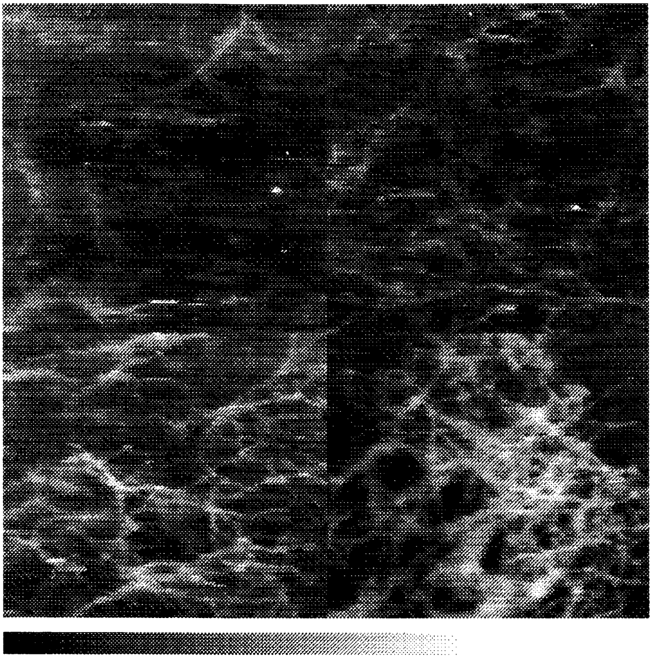

Fig 6 - Flocculation in high filler content suspensions by dual component additive system. (A)Pulp+zeolite, (B):(A)+cationic PAA(1%) (C):(B)+anionic PAA(0.5%), (D)flow stopped in(C).

A	B
C	D

decreased clearly(Fig.7). Particularly,the action of bentonite to render floc sizes smaller is numerically shown in Fig.8.

Flocculation by single component additive system is shown in Fig.9 and 10.

Comparison of low and high filler content suspensions

In suspensions with low filler ratio(Fig.10,11 and 12),the flocculation phenomena were clearly observed both in single and dual component additive systems. However,the numerical evaluation of flocculation level can not be easily made at the present stage owing to the difficulty of the separation of floc images from the fiber network supporting flocs.

In high filler content suspensions,floc images were clearly observed both for zeolite fillers(Fig.7 and 13) and kaolin fillers(Fig.9,14,and 15),permitting the numerical evaluation of flocculation.

Balance between colloidal force and hydrodynamic shear force

The optimization of flocculation levels by controlling the balance between the colloidal force and the hydrodynamic shear force is an important factor for the manufacture of papers with good formation. The observed images of flowing suspensions are under dynamic equilibrium between the colloidal force and the hydrodynamic shear force. The colloidal force can be controlled by the addition of a variety of paper chemicals. The hydrodynamic shear force can be controlled by controlling the flow velocity or agitation velocity in the flow cell for the test.

The effect of colloidal force can be tested by observing the effect of addition of paper chemicals under constant agitation speed. Both in single(Fig.10) and in dual(Fig.7,8,and 14) component additive systems, it is clearly observed that flocculation proceeds by addition of chemicals.

Similarly,the effect of hydrodynamic shear force can be tested by observing the effect of agitation velocity under constant addition level of chemicals. Also,both in single(Fig.12) and in dual component additive systems(Fig.9,11,13,and 15),it is clearly

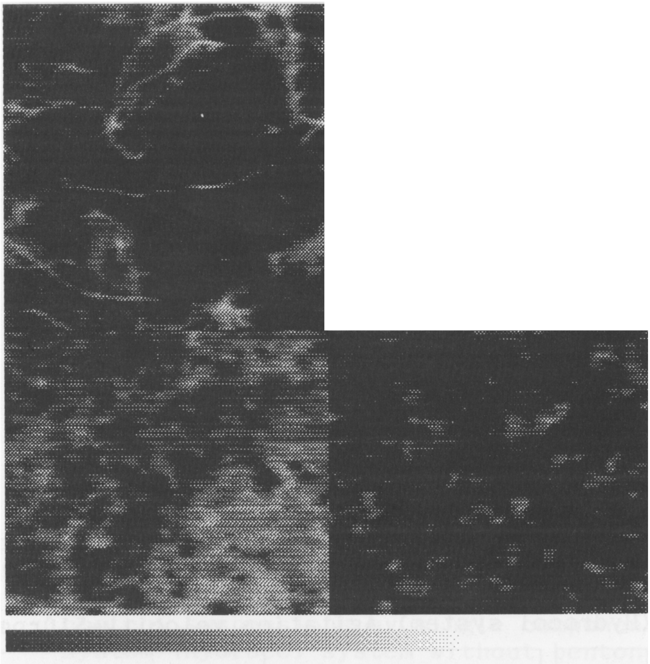

Fig 7 — Flocculation in high filler content suspensions by dual component additive system. (A)Pulp only, (B):(A)+zeolite, (C):(B)+cationic PAA(5%), (D):(C)+bentonite(5%).

A	B
C	D

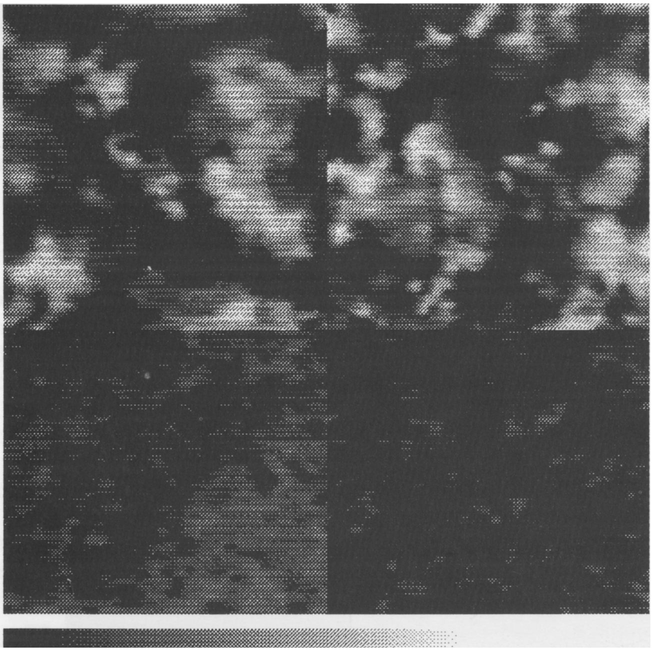

Fig 8 - Effect of bentonite addition on flocculation in high filler content suspensions(Kaolin and zeolite) by dual component additive system (Hydrocol system). Agitation velocity=510rpm.

(A) Kaolin Pulp PAA 5% →	(B) + bent. 5%
(C) Zeolite Pulp PAA 5% →	(D) + bent. 5%

(A) Floc. no. =19 Floc. fr. =0. 37 Mean fl. area=1313 Roundness=0. 11	(B) Floc. no. =28 Floc. fr. =0. 41 Mean fl. area=1008 Roundness=0. 22
(C) Floc. no. =48 Floc. fr. =0. 44 Mean fl. area=680 Roundness 0. 18	(D) Floc. no. =57 Floc. fr. =0. 07 Mean fl. area=86 Roundness=0. 35

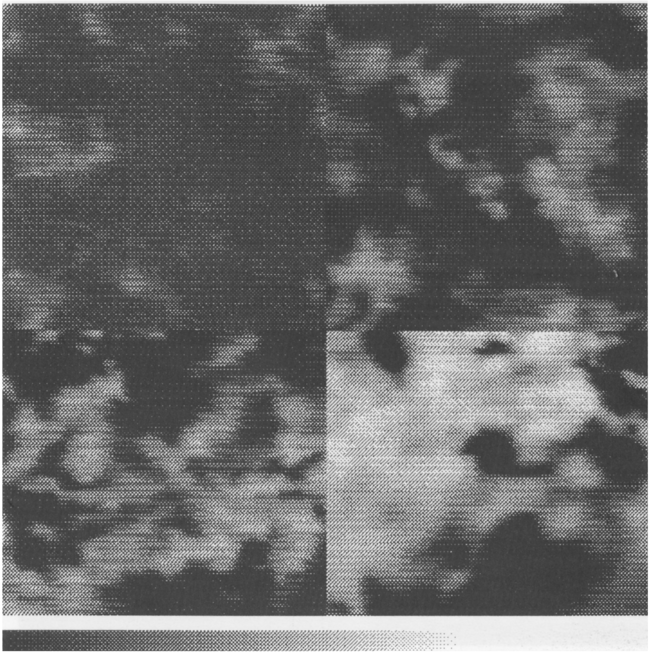

Fig 9 Effect of cationic PAA addition and agitation velocity on flocculation in high filler(kaolin) content suspensions by single component additive system. (Hydrocol system without bentonite).

(A) PAA 4% 510rpm	(B) PAA 5% 510rpm
(C) PAA 5% 210rpm	(D) PAA 5% stop

(A) Floc. no. =42 Floc. fr. =0. 12 Mean fl. area=199 Roundness=0. 11	(B) Floc. no. =19 Floc. fr. =0. 37 Mean fl. area=1313 Roundness=0. 11
(C) Floc. no. =15 Floc. fr. =0. 47 Mean fl. area=2314 Roundness=0. 13	(D) Floc. no. =10 Floc. fr. =0. 57 Mean fl. area=3985 Roundness=0. 17

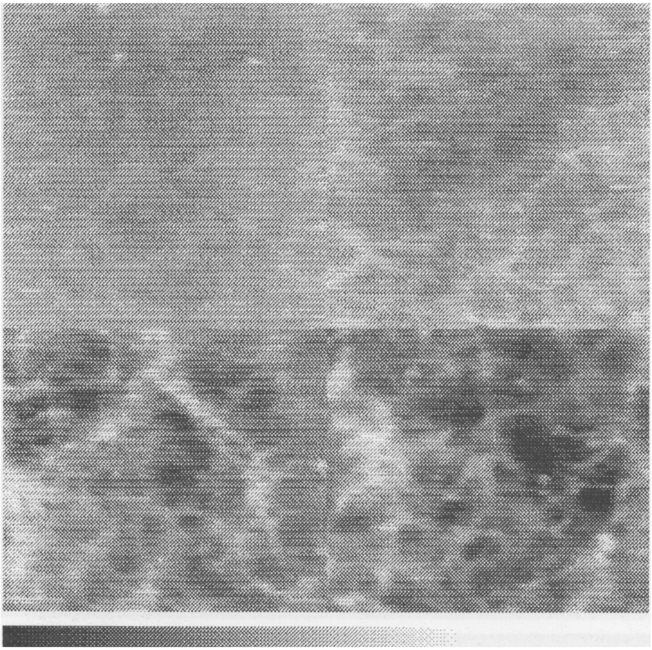

Fig 10 - Effect of cationic PAA addition on flocculation in low filler content suspensions by single component additive system(Percol system). Agitation velocity=510 rpm.

(A) PAA=0%	(B) PAA=0.2%
(C) PAA=0.4%	(D) PAA=0.5%

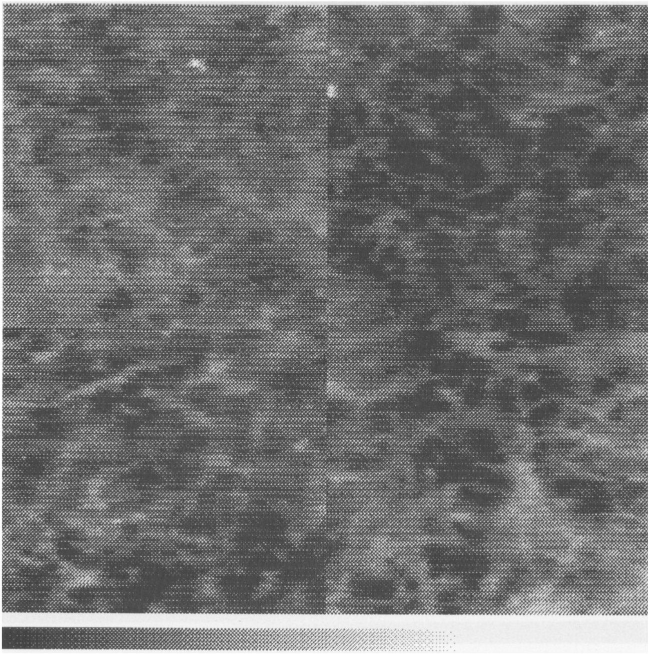

Fig 11 - Effect of agitation velocity on flocculation in low filler(kaolin) content suspensions by dual component additive system.
cationic PAA 0.4%, Bentonite 0.5%.

(A) 840rpm	(B) 510rpm
(C) 210rpm	(D) stop

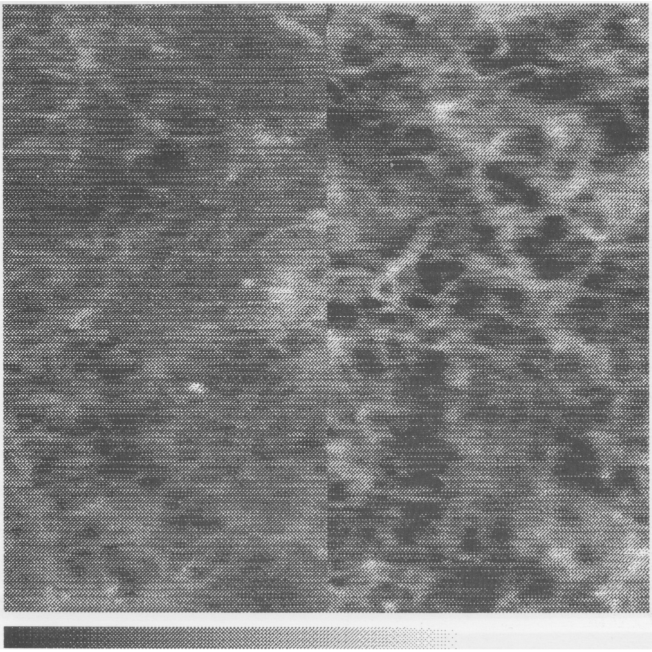

Fig 12 - Test of hypothesis for dual component additive system(Hydrocol system).
Cationic PAA 0.4%.
Bentonite 0.5%.

(A) → Pulp+kaolin 510 rpm	(B) +cationic.PAA 510 rpm ↓
(D) ← +bentonite 840 rpm	(C) 840 rpm

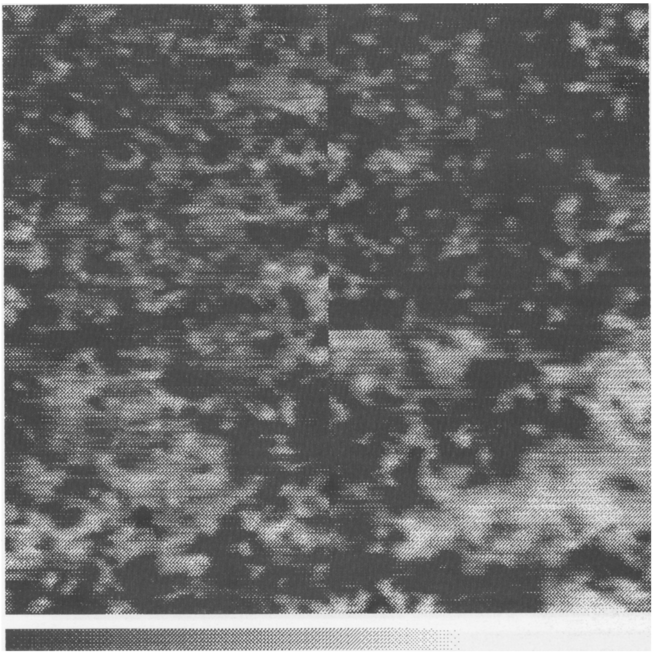

Fig 13 - Effect of agitation velocity on flocculation in high filler content suspensions by dual component additive system(same system as Fig.1).

(A) 840rpm	(B) 510rpm
(C) 210rpm	(D) stop

(A) Floc. no. =70 Floc. fr. =0.34 Mean fl. area=328 roundness=0.32	(B) Floc. no. =62 Floc. fr. =0.22 Mean fl. area=242 Roundness=0.36
(C) Floc. no. =36 Floc. fr. =0.44 Mean fl. area=883 Roundness=0.31	(D) Floc. no. =19 Floc. fr. =0.53 Mean fl. area=1887 Roundness=0.26

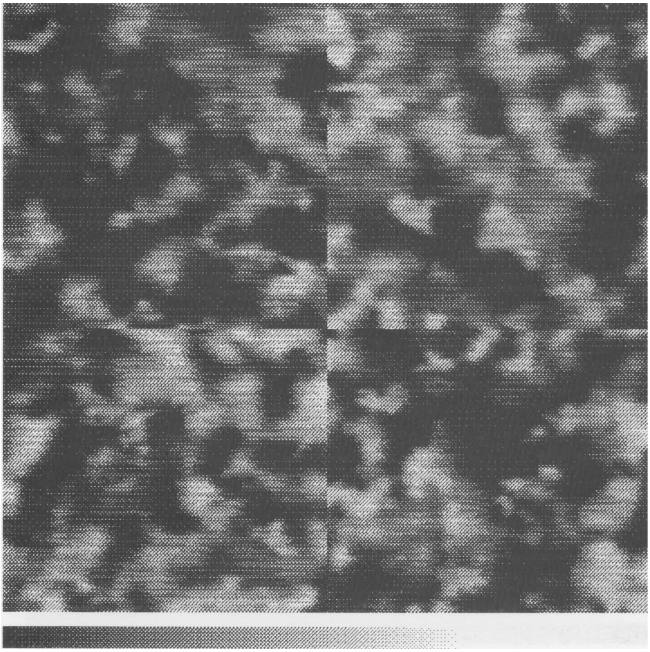

Fig 14 Effect of bentonite addition on flocculation in high filler(kaolin) content suspensions by dual component additive system(Hydrocol system). Cationic PAA=5%.

(A) bent. 2%	(B) bent. 3%
(C) bent. 4%	(D) bent. 5%

(A) Floc. no.=32 Floc. fr.=0.30 Mean fl.area=633 Roundness=0.11	(B) Floc. no.=18 Floc. fr.=0.51 Mean fl.area=1958 Roundness=0.13
(C) Floc. no.=28 Floc. fr.=0.50 Mean fl.area=1217 Roundness=0.10	(D) Floc. no.=28 Floc. fr.=0.41 Mean fl.area=1008 Roundness=0.23

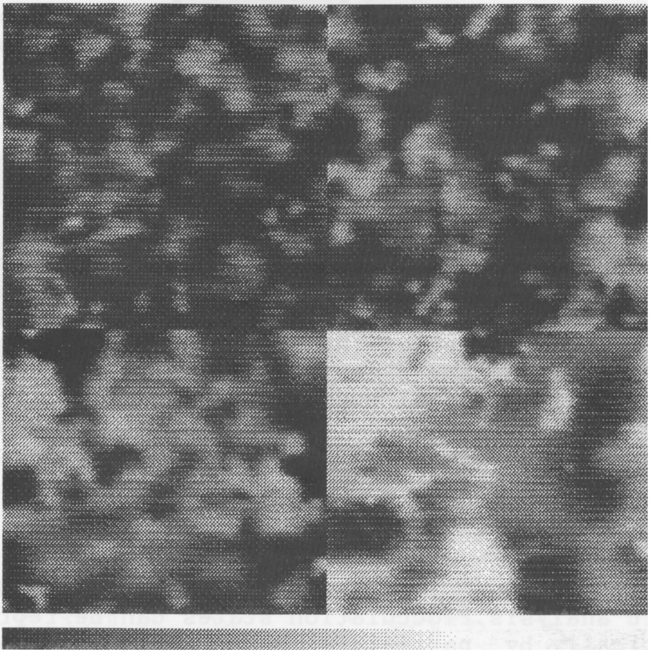

Fig 15 - Effect of agitation velocity on flocculation in high filler(kaolin) content suspensions by dual component additive system.
Cationic PAA=5%, bentonite 5%.

(A) 840rpm	(B) 510rpm
(C) 210rpm	(D) stop

(A) Floc. no. =60 Floc. fr. =0.34 Mean fl. area=393 Roundness=0.12	(B) Floc. no. =28 Floc. fr. =0.41 Mean fl. area=1008 Roundness=0.22
(C) Floc. no. =16 Floc. fr. =0.60 Mean fl. area=2660 Roundness=0.22	(D) Floc. no. = 4 Floc. fr. =0.80 Mean fl. area=1471 Roundness=0.10

observed that flocculation proceeds by decreasing the velocity of agitation. Agitation of suspensions will simulate turbulent conditions in a headbox to some extent as used in the Britt drainage jar.

In the case of dual component additive system consisting of cationic PAA and anionic PAA,the floc image and fiber network image were obtained separately by thresholding. These two images gave a synthesized image as shown in Fig.16(D). Figure 17 shows the number of pixels of each floc(i.e. floc area) as a function of the number of branches in each floc. It is suggested that flocs exist at branch points of fiber network rather than at fiber itself. It is also suggested that the floc area increases as the number of branches increases. However,the floc area does not increase any more above certain level even the number of branches increase. This means that the colloidal flocculating force and the hydrodynamic deflocculating force are balanced at this level.

Numerical representation of flocculation state

Using the numerical data obtained from digital geometric analysis,flocculation states can be represented numerically by parameters such as the number of flocs,fraction of flocs,mean individual floc area,roundness coefficient,and the location of the center of gravity.

It is noted in Fig.13 that the number of flocs decreases with the progress of flocculation by decreasing the flow velocity. The fraction of flocs and mean floc area show generally increasing tendency. However, roundness coefficients do not show any significant tendency. Figure 9 and Fig.15 shows the similar tendency as in Fig.13.

Figure 14 shows that the four representative parameters do not show any significant tendency by changing the amount of bentonite added,suggesting that the effect of bentonite on flocculation is nearly saturated at the addition level of 2%.

Figure 8 shows that the number of flocs increases by addition of bentonite both in the case of kaolin and zeolite fillers. The mean floc areas decreased and the roundness coefficients increased in these cases.

Figures 18 and 19 shows the changes of the location

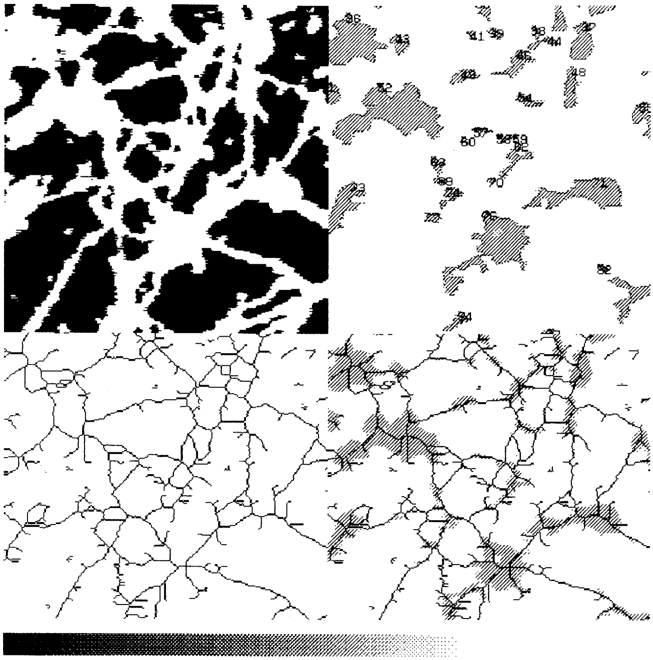

Fig 16 - Sequence of image processing for floc and network extraction.

A	B
C	D

Dual component additive system (cationic PAA + anionic PAA).
(A)Pulp + zeolite network image, (B):Floc image extracted from (A), (C):network structure extracted from (A),
(D):synthesized image of (B) and (C).

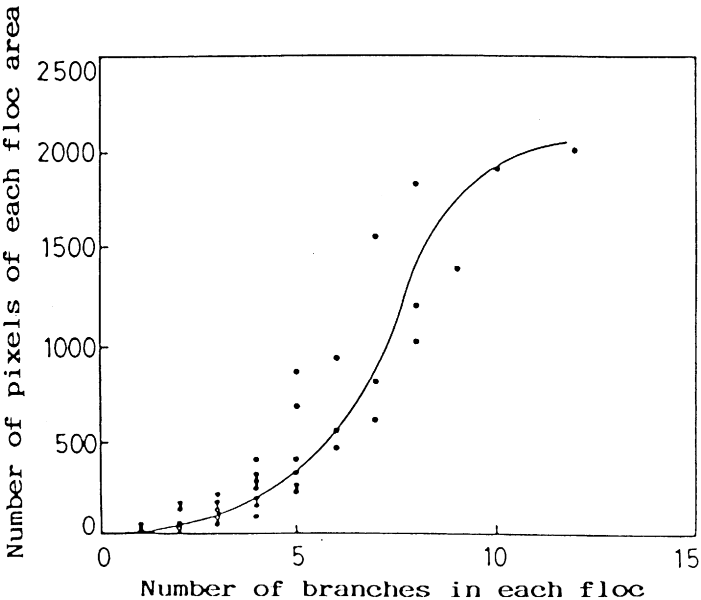

Fig 17 - Floc area vs. number of branches relationship(colloidal-hydrodynamic balance of flocculation).

of the center of gravity of flocs by flocculation.

To summarize the digital geometrical analysis data, the number of flocs generally decreases with the progress of flocculation by decreasing the flow velocity.Bentonite has the action of increasing the number of flocs in the case of high filler content suspensions. The fraction of flocs and mean floc area generally increase with the progress of flocculation by decreasing the flow velocity.

The mean floc area decreases to some extent by addition of bentonite. Although bentonite has the action of increasing the roundness coefficient in some case, generally no substantial change was observed for the roundness coefficient within the scope of the present experiments. The location of the center of gravity of flocs becomes more evenly distributed at lower flocculation levels. The floc area and fiber network relationship is shown in Fig.17.

Test of hypothesis for new additive system

Recently,a variety of new dual component additive systems with the advantage of higher retention without detriment to formation has been proposed on the paper chemicals market. It was attempted to test a hypothesis of this sort of flocculation mechanism visually and numerically using this system.

A dual component additive system consisting of cationic polyacrylamide(Hydrocol) and modified bentonite (Organosorb) has been proposed by Allied Colloid Limited in the United Kingdom,in which "Supercoagulation" hypothesis is presented. The sequence of addition of chemicals in this system is that addition of Hydrocol under normal agitation in a headbox followed by increasing the agitation velocity to give disrupted irregular flocs. By the addition of bentonite,the size of flocs becomes smaller and uniform in size to give good formation of the sheet(9,10). This sequence was tested and the result is shown in Fig.12.

Since the numerical data from the image could not be obtained in this figure,a general tendency proposed in the hypothesis could not be ascertained clearly within the scope of the present investigation. However, the action of bentonite to give smaller flocs with higher roundness is numerically shown in Fig.8,suggest-

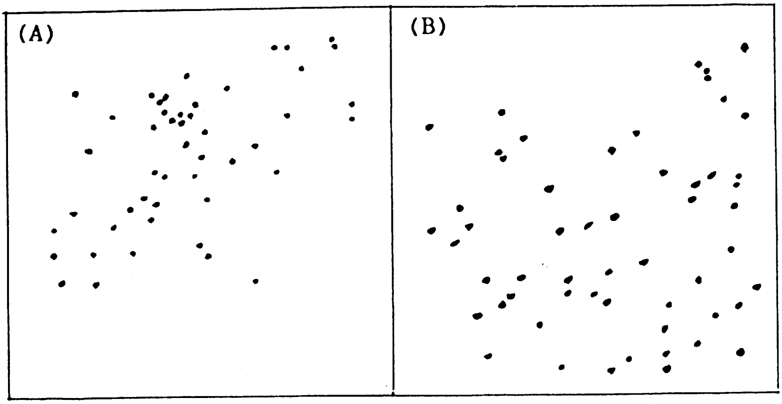

Fig 18 - Changes of the center of gravity of flocs by bentonite addtion. (A) and (B) correspond to (C) and (D) in Fig. 7, respectively.

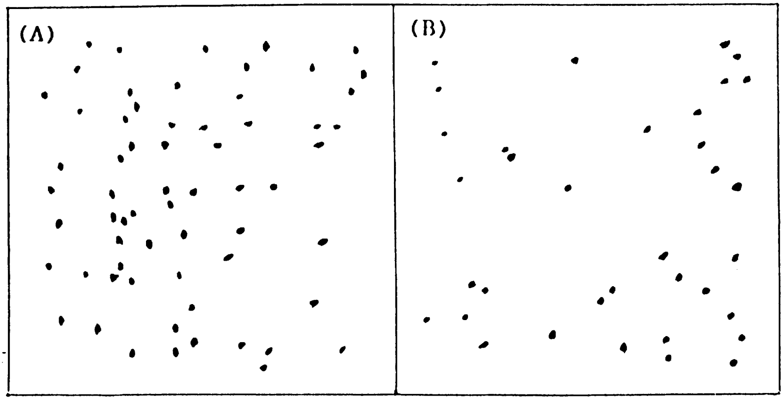

Fig 19 - Changes of the center of gravity of flocs with increase in flocculation level by decrease in agitation velocity. (A) and (B) correspond to (B) and (C) in Fig. 13, respectively.

ing a high possibility of that hypothesis in the concentration region of this work. The main cause for the inconsistency of our results with those by that hypothesis at this stage is that the consistency of our suspensions is far lower compared with those recommended in the catalogue.

POTENTIAL APPLICATIONS IN WET END CHEMISTRY

A microcomputer-aided flow visualization technique together with the digital geometrical method provides means for analyzing a variety of dynamic flocculation-based physicochemical phenomena in wet end chemistry.

Although there still remains many problems to be solved before applying to actual papermaking systems,the technique presented in this paper has potential applications in wet end chemistry.

On the market of paper chemicals,many kinds of new dual component additive systems have been proposed recently. Flocculation tendency,more precisely the ability of forming tenacious and uniform flocs,of a variety of additives can be evaluated using this system.

Flocculation-related phenomena like retention,drainage,and formation are correlated closely. Although the high level of flocculation leads normally to good retention and good drainage,but leads normally to bad formation in conventional additive systems. Therefore, the optimum control of flocculation level is the prerequisite for good formation of paper sheets.

Preliminary operational experiences of this system in our laboratory suggests that the present method can be used as a novel method to correlate these phenomena quantitatively to find out the optimum additive level. Experiments in this domain are underway in our laboratory.

CONCLUDING REMARKS

Since the present system utilizes a transmitted light from the strobo-light source as illuminating light through suspension,this system is applicable only for dilute suspensions at the present stage. However,concentrated suspensions may be analyzed when reflected lights or other illuminating devices are used instead of the transmitted light.

Although simple agitation is used to induce turbulence at the present stage,the flow conditions should be more precisely controlled in order to simulate the actual turbulent conditions in a headbox more closely using more sophisticated flow devices.

Only 2-D projected images of flocculation are available from 3-D images,a question still remains how 2-D images reflect the actual locations of flocs in 3-D space.

Experiments using model particles will provide more precise information on the dynamic equilibrium of the colloidal force and the hydrodynamic shear force. That is,the present technique provides analytical means for microrheological studies of suspensions.

EXPERIMENTAL

Stock systems

Bleached hardwood sulfate pulp fibers were beaten to ca.400ml CSF and mixed with fillers to form suspension of one liter. Georgia Kaolin(obtained through Shiraishi Kogyo Ltd.) and Ca-zeolite(Nihon Chemical Ind.Ltd.) were used as fillers. Fiber/filler ratios were 100/30 for low filler content suspensions and 10/90 for high filler content suspensions. Initial consistency of pulp suspensions were conventionally 0.02% for both low and high filler content suspensions. Consistency increases by the addition of fillers(e.g.,0.2% in high filler content suspensions). Deionized water was used for preparing suspensions.

Additive systems

In single component system,the additive was cationic PAA(Percol-47;Allied Colloid Co.Ltd.,obtained through Kyowa-Sangyo Ltd.). In dual component systems, polymer-polymer and polymer-inorganic pigment systems were used. That is,either (a)cationic PAA+anionic PAA (Hakuto Chemical Co.Ltd.) or (b)cationic PAA(Hydrocol-803)+modified bentonite(Organosorb)(Allied Colloid Co. Ltd.,Kyowa-Sangyo Co.Ltd.) was used. (%) of additive in figures is the percent of additive with respect to the oven-dry weight of pulp.

Flow visualization system

A horizontal flow cell(Fig.20),in which flow was induced by water pressure of the tank,was used for preliminary experiments and a vertical cell(Fig.21),in which flow was induced by agitation,was used for most of the experiments in this work. Agitation velocities were 840,510,and 210 rpm. Details were described previously.

Strobovision analyzer(SVA) is capable of taking high speed images by synchronizing strobo flash with the shutter of CCD camera(NEC TI22AII) and permits storage of images electronically. The maximum shutter speed is $1/10^6$ second. The effective pixels are 512 x 480 for both SVA and the image processing unit. Details were mentioned elsewhere(3).

Acknowledgement

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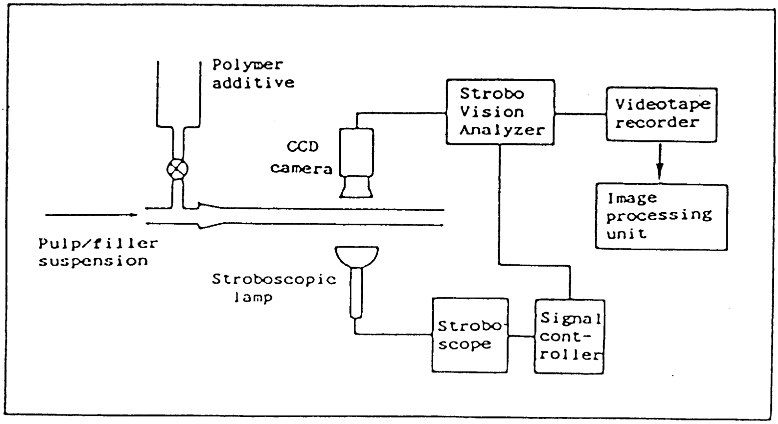

Fig 20 - Flow visualization system with horizontal flow cell.

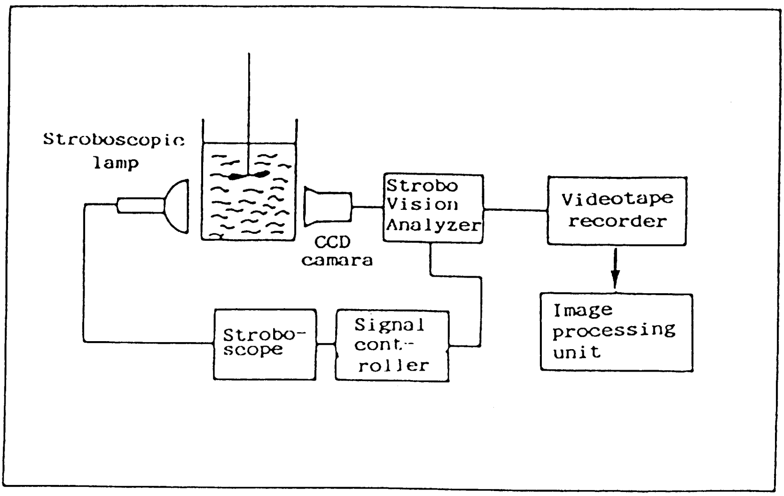

Fig 21 - Flow visualization system with vertical flow cell.

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Transcription of Discussion

APPLICATIONS OF FLOW VISUALISATION TECHNIQUES IN WET END CHEMISTRY

F. Onabe and K. Sakurai

Dr. H.J. Kent, International Paper

When you digitize an image of an essentially fuzzy object such as a fibre floc, the results are very dependent on the threshold which you use for binarization. Things like floc number and floc area are very dependent on threshold. Which criteria did you use to select your threshold?

Prof. F. Onabe Dept of Forest Products, University of Tokyo.

As you have mentioned, numerical data by digital geometry are certainly dependent upon the threshold value of binarization. After a number of preliminary experiments, we have decided to adopt a threshold value that can clearly differentiate between fibres and fillers under our illumination conditions.

The threshold value adopted was 64 and we have 256 grey levels altogether in our system. Many trials have shown, up to now, that this threshold value is one of optimum values.

Dr. D.H. Page, PPRIC

Yesterday, I showed pictures taken in a refiner with a one micro second flash, and with this technique, we could resolve single fibres. What is your capability using modern techniques? I noticed that one micro second is in fact the limit of speed of your system. Can you take sequences and how many can you take, e.g. 100,000 frames per second?

Prof. F. Onabe

The shortest flash duration of the Strobovision analyzer is 1 x 10^{-6} sec. However, since our video system is of the NTSC type, we have to wait 1/30th of a second to take the next picture sequentially. So we have many problems when we attempt to take many frames in a short period of time.

Dr. D.H. Page

Is the equipment state of the art with video imaging?

Prof. F. Onabe

For image analysis studies of high speed phenomena, the Strobovision analyzer has tremendous capability. I believe that our system is in the forefront of this sort of technology. But to apply our practise and theory to complex systems such as paper suspensions, we have many problems to be solved in our future work.

A. Ibrahim, PAPYRUS

In papermaking practice, we measure hydrodynamic forces by the velocity in the pipe in metres or feet per second. Can you tell me your revs per minute as metres per second?

Prof. F. Onabe

We have represented a velocity level of hydrodynamic flow in agitation speed (i.e. rpm) in the case of a vertical flow cell. This is a very simple agitation system to see the dynamic equilibrium between the colloidal and hydrodynamic forces.

We have not calculated any significant hydrodynamic figures like Reynold's number up to now. At the present stage we have just tried to compare the two kinds of forces in dynamic equilibrium. However, I think we should apply more controlled flow conditions in future work.

So, agitation speed is an approximate figure to indicate hydrodynamic shear force as far as our work is concerned. However in our previous work using horizontal flow cells, the hydrodynamic force was represented by flow velocity in a cell.

Prof. H. Kropholler, UMIST

Just to comment on Dr. Pages' question, very much faster speeds are possible in collecting images, but one must use a transputer based computer system.

Prof F. Onabe

Thankyou for your enlightening suggestions. I will try to apply the computer system which can go beyond the limitations of our system.

Dr. B.D. Jordan, PAPRICAN

Could you comment on the sensitivity of your parameters, e.g. the roundness or number of flocs, to your measurement conditions how you were doing the measurements? If you were to have a change in your digitizing conditions, how significant would the difference be between 25 and 30 flocs or roundness of one number or another?

Prof. F. Onabe

First, the constant illumination is an important factor to give reliable and reproducible data. A slight change in illumination conditions gives a difference in digitized images and digital geometrical figures. In our preliminary experiments we had suspicions about the reproducibility of the data to some extent and we repeated taking pictures of one object image 10 times. Then we generally obtained similar histograms and we assumed that our method, as applied to paper suspensions was reproducible and reliable.