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INFLUENCE OF SUSPENSION NON-UNIFORMITY ON SHEET STRUCTURE

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Synopsis

The subject of this paper is a study of the properties of paper sheets made from suspensions of a known state of flocculation, the sheet formation being performed under controlled conditions. The delay time between end of agitation and start of drainage and the rate of drainage were varied.

The flocculation of the sheet increased with delay time and decreased with increasing drainage rate, indicating a strong qualitative relation between these two phenomena in their influence upon flocculation. The flocculation of sheets increased linearly with the flocculation of suspensions, a quantitative comparison showing that the state of flocculation represented in terms of mass distribution improved during drainage. Tensile strength increased with decreasing flocculation, tear decreased, porosity passed a minimum at intermediate flocculation.

L'influence de l'hétérogénéité d'une suspension de fibres sur la structure de la feuille

Dans ce compte rendu on étudie les propriétés des feuilles de papier formées de suspensions dans un état de flocculation déterminé et dans des conditions de formation bien établies. On a varié l'intervalle entre la fin de l'agitation de la suspension et le commencement de l'écoulement.

On a observé qu'une augmentation de flocculation de la feuille resulte d'une augmentation d'intervalle, mais qu'une augmentation de *la rapidité d'écoulement entraîne une diminution de la flocculation. On déduit de ces observations un rapport qualitatif prononcé entre ces deux variables en ce qui concerne leur influence sur la flocculation.*

La flocculation des feuilles croît d'une façon linéaire avec la flocculation des suspensions. On a constaté une amélioration de l'état de flocculation pendant l'écoulement, lorsque l'état de flocculation est représentée en termes de distribution de masse.

Une diminution de la flocculation provoque une augmentation de la résistance à la traction, et une diminution de la résistance au déchirement. On a également constaté que la porosité atteint un minimum à une valeur intermédiaire de l'indice de flocculation.

Der Einfluss ungleichmässiger Suspensionen auf die Blattstruktur

Es wurden die Eigenschaften von Papieren studiert, die bei bekannter Ausflockung und unter kontrollierten Bedingungen gebildet wurden, wobei man die Verzögerungszeit zwischen dem Ende der Durchmischung und dem Beginn der Entwässerung sowie den Grad der Entwässerung variierte. Die Durchsicht der Bahn verschlechterte sich mit der Verzögerungszeit und mit wachsendem Entwässerungsgrad, was auf eine starke qualitative Beziehung zwischen diesen beiden Phänomenen in ihrem Einfluss auf die Ausflockung hindeutet. Die Durchsicht der Bahn verschlechterte sich linear mit der Ausflockung in der Suspension, wobei ein quantitativer Vergleich zeigte, dass die Durchsicht als Mass für die Stoffverteilung sich während der Entwässerung verbesserte. Mit Verbesserung in der Gleichmässigkeit der Durchsicht nahm die Reisslänge zu, die Durchreissfestigkeit nahm ab und die Porosität durchlief ein Minimum bei mittlerer Durchsicht.

Introduction

THE structure of a sheet of paper is primarily defined by the distribution and orientation of fibres in space. These properties are determined by the same properties of the suspension of fibres from which the sheet was made and the way in which the fibres were rearranged when the suspending liquid was removed—that is, during the process of sheet formation. In an ideal case, the distribution of fibres in the suspension is wholly random and this state is maintained during drainage, producing a sheet of random orientation in the plane of the sheet.

Apart from statistical fluctuations of fibre distribution, such a sheet is homogeneous; but, on account of its bulkiness, it may be useless for many practical purposes. A less bulky sheet requires rearrangement of the fibres from the random state. If such a rearrangement is not under full control, it may lead to decreased uniformity in fibre distribution (flocculation), owing to statistical fluctuations as well as to physical processes.

In practice, the random state of formation is normally approached by allowing the shortest possible time for drainage. Rearrangement of fibres from the random state in the suspension requires delayed drainage or the process must be influenced from external sources.

During the delayed drainage, the fibres are subject to the action of gravity as well as to hydrodynamic forces. At practical head box consistencies, the fibres will (if left at rest) form a coherent network, which is thus uninfluenced by gravity. Such a network is easily interrupted, however, under the influence of external forces and will then break up into aggregates (fibre flocs). In practice, the fibre suspension is kept in motion continuously, therefore the fibres are probably prevented from forming a coherent network. In fully turbulent motion, the suspension appears in optical measurements fully dispersed. This state may be characterised as a state of *dynamic dispersion*, which means that motion is a prerequisite of no aggregation.

In this state, the distribution in space of the fibres can be just as random as in a stationary suspension at lower concentration. When a sheet is formed by drainage, the sheet will in either case (static or dynamic dispersion) be formed from a suspension of random fibre distribution and the state of motion introduced during drainage will have a similar effect in both cases. A stationary fibre suspension of low concentration may therefore be used as a model substance for studies of the behaviour of fibres during sheet formation.

By comparing the properties of the suspension and the sheet made from the suspension, such a procedure can be used for studies of the influence of delayed drainage of a stationary suspension and the influence of drainage rate, alternatively in combination with delayed drainage. Certain formation improving measures such as vibration can also be investigated, though the system is not useful for studies when flow is involved.

Experimental

THE present report will deal with a study of the relationship between sheet properties and suspension properties performed on a Norwegian type of sheetmachine[1] (rectangular cross-section). The machine was provided with a drainage rate control and the suspension container was made of transparent plastic so that photographic records of the suspension could be made at different stages of drainage (Fig. 1). These records could be used for flocculation measurements.[4] The paper sheets produced in the experiments could be used for standard measurements of sheet properties, also for measurement of formation. In all the experiments, the initial concentration of the suspension was 0.13 g/litre and the fibres were dispersed mechanically by stirring according to the standard prescribed for the sheetmachine.[1] Tensile strength is given as breaking length of 100 mm × 15 mm strips and porosity in seconds, recorded by the Gurley porosity meter. Extremely

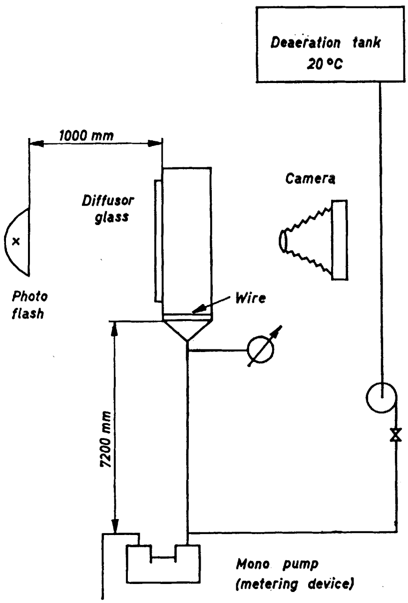

Fig. 1—Sketch of sheet formation apparatus, camera and photo-flash

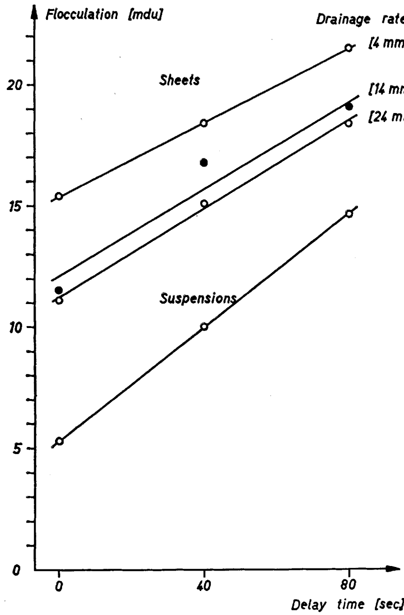

Fig. 2—Flocculation of sheets and suspension at various delay times: bleached sulphite pulp, 45° S.R.

dense sheets were measured in an air permeability meter built at the Central Laboratory of the Swedish Papermills,[2] readings being converted to Gurley seconds. Formation readings are all given in optical density units.

In suspensions of ordinary papermaking fibres, such readings are proportional to the standard deviation of the distribution of matter, so long as the fibre concentration is less than 30 g/m^2 perpendicular to the light beam. These conditions are fulfilled in the suspensions used [3] and are probably reasonably valid for the sheets. The factor of proportionality is generally different for the sheets and the suspensions.

Results

THE results of some preliminary experiments are demonstrated in Fig. 2, showing the influence of delay time on the flocculation of the suspension at the moment drainage started and the flocculation of the sheets resulting after drainage. The delay times were 0, 40 and 80 sec and the drainage rates 4, 14 and 24 mm/sec. The diagram demonstrates the well-known nearly linear increase in flocculation as drainage is delayed and a decrease in

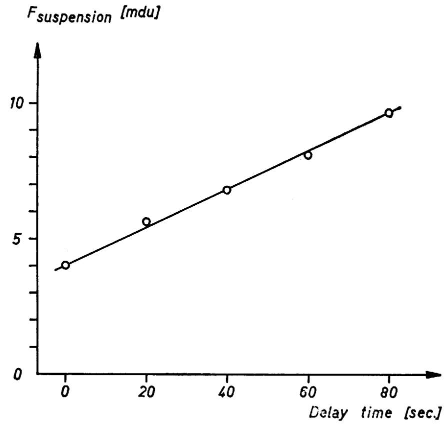

Fig. 3—Flocculation of the same bleached sulphite pulp as in Fig. 2 at five different delay times

flocculation of the sheets as the rate of drainage is increased. The linear increase in flocculation is true both for the suspension and the sheets. The pulp used in these experiments was a bleached sulphite pulp, beaten in a laboratory beater to 45° S.R. and the initial concentration 0.13 g/litre.

In another set of experiments using the same pulp, measurements were made at five different delay times and five different constant drainage rates, also at free drainage using a one metre suction leg. The variation of the flocculation of the suspension with delay time is shown in Fig. 3 and again a nearly linear relationship is found. A plot of the flocculation of the sheets as a function of drainage rate is shown in Fig. 4. The two curves correspond to zero delay time and 80 sec delay time. In both cases, there is a steep decrease in flocculation with drainage rate at low rates. This suggests plotting against inverse velocity. Such a graph is shown in Fig. 5, which demonstrates a nearly linear relationship between flocculation of the sheet and inverse rate of drainage. The similarity between Fig. 3 and Fig. 5 is quite striking. Furthermore, Fig. 6 shows a linear relationship between the flocculation of the sheet and drainage delay. Comparison of Fig. 5 and Fig. 6 suggests that the mechanism responsible for flocculation is the same in the two experiments. The horizontal axis of Fig. 5 becomes a time axis, if the inverted velocity is multiplied by a factor having the dimension of a

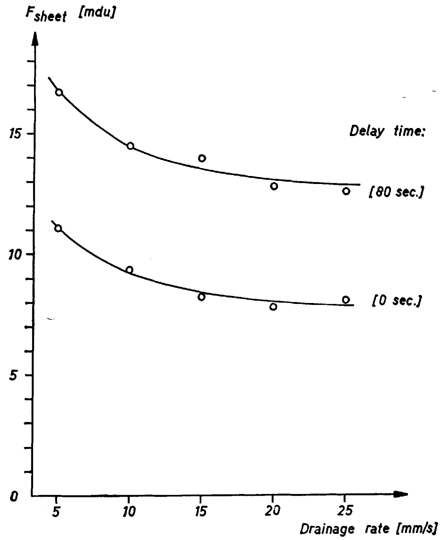

Fig. 4—Flocculation in sheets at five different drainage rates

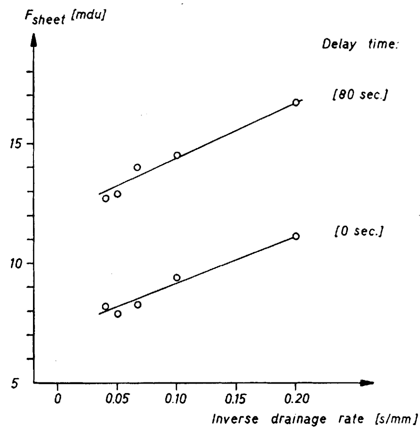

Fig. 5—Fig. 4 replotted against inverse drainage rate

distance. The slope of the lines will be equal to the slope of the lines shown in Fig. 6, if this factor is 25 cm. This is the level from which a volume element travels at a drainage rate according to Fig. 5 to give the corresponding delay time of Fig. 6. Since the height of the liquid column of the sheetmachine is 38 cm, the average distance travelled is 19 cm. This would be the joining factor between the diagrams of Fig. 5 and 6, if each sedimented layer contributed linearly to the resulting flocculation of the sheet. This is not generally the case and the experimental value of 25 cm suggests a very strong similarity between the mechanism of flocculation at delayed drainage and at different drainage rates. A consequence is that, during the process of drainage in the sheetmachine used, the changes imposed on the state of flocculation are only little influenced by the state of flocculation itself.

The influence of the state of flocculation of the suspension on the flocculation of the sheet is demonstrated in Fig. 7. In these diagrams, the flocculation of the suspension at the start of drainage is plotted as the independent variable and the different curves correspond to different drainage rates. The linearity displayed in this diagram is a direct consequence of the linearity in Fig. 5 and 6. If the flocs from the suspension are deposited in undisturbed form at sheet formation, the slope of these lines should be equal

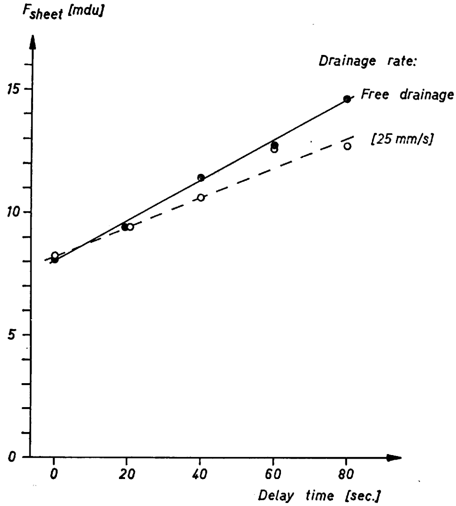

Fig. 6—Flocculation of sheets made of the suspension shown in Fig. 3

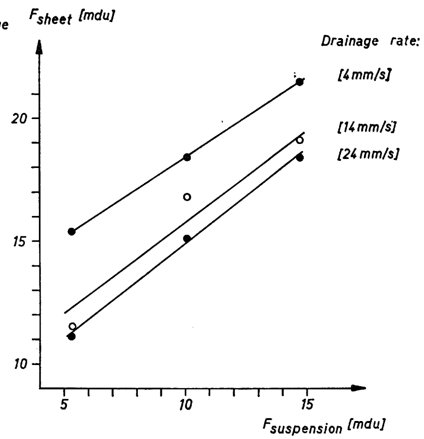

Fig. 7—Relationship between flocculation of sheets and flocculation of suspension replotted from Fig. 2

to the ratio of average extinction of the sheet and the suspension. A deviation between these two quantities may be taken as a measure of the change of the state of flocculation owing to sheet formation.

The slopes of the straight lines (Fig. 7) are listed in Table 1. The co-ordinates of Fig. 7 are commensurable and hence the slopes listed in Table 1 (under the heading *optical ratio*) demonstrate the ratio of optical density of the sheets and the suspensions. Since the optical density of sheets and suspensions is differently influenced by the structural properties, these figures have to be modified accordingly. The law of Lambert-Beer can be assumed to be applicable to the suspensions,[3] but its validity for paper sheets is questionable. In the particular experimental series dealt with here, the sheets were, because of their relatively high degree of beating, quite grease-prooflike in appearance, therefore the optical density of the sheet may be assumed to represent its basis weight. Then the ratios listed in Table 1 can be modified by application of a factor equal to the ratio of the optical density of the suspension and the optical density of the sheet. Such modified quotients are listed in the third column of Table 1 under the heading *mass ratio*.

TABLE 1—THE RATIO OF FLOCCULATION OF PAPER SHEETS AND SUSPENSIONS, REFERRING TO THE FLUCTUATIONS OF OPTICAL DENSITY AND OF MASS DENSITY CALCULATED THEREFROM BY THE LAW OF LAMBERT-BEER

Drainage rate, mm/sec	*Optical ratio*	*Mass ratio*
4	0.66	0.27
14	0.74	0.30
24	0.78	0.32

The optical ratios are all less than unity and so are the mass ratios. This demonstrates among other things that the lightscattering component of the optical density is less in the sheet than in the suspension from which it was made. A consequence of this is that the flocculation of a sheet of paper as it appears visually is less than the flocculation of the sheet-producing suspension.

On the other hand, the irregularities in mass distribution owing to fibre flocculation are less in the sheet than in the suspension from which the sheet was made. Such a result can be expected, if it is assumed that the smoothing process occurs when the fibre flocs are deposited on the wire during sheet formation. The fibres and fibre flocs, in other words, do not settle along linear paths, but adjust themselves according to the availability of 'holes' in the sheet. The same result would obtain if flocs are broken up during sheet formation. This is less probable, however, since fibres have always shown a tendency on the contrary to flocculate during sedimentation or laminar motion.

Any one of these two effects will be improved by slow drainage: adjustment to 'holes' and breaking up of flocs will have a higher probability of occurrence, if the suspension is given longer time to drain. This is in agreement with Table 1, which demonstrates a higher mass ratio at higher drainage rates.

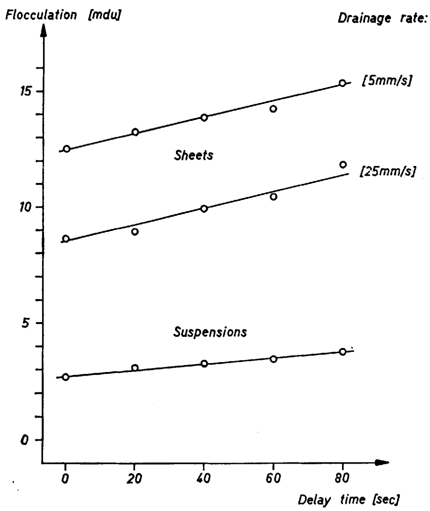

Fig. 8—Flocculation of sheets and suspensions against delay time: mechanical pulp

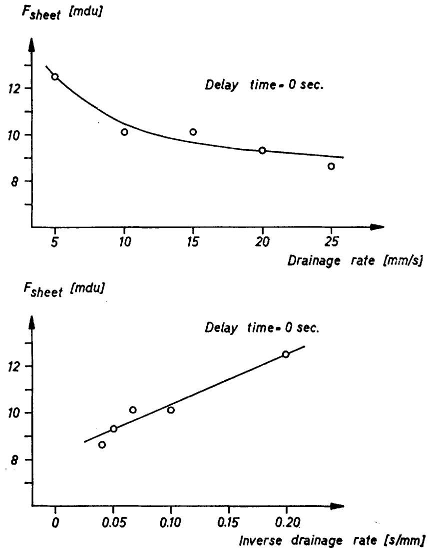

Fig. 9—Flocculation of paper sheets plotted against drainage rate and inverse drainage rate: mechanical pulp

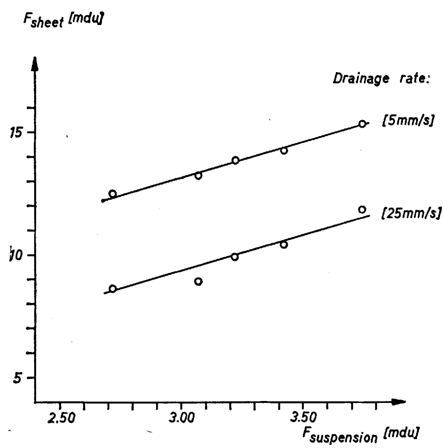

Fig. 10—Relationship between flocculation of sheets and suspensions replotted from Fig. 8: mechanical pulp

Quick drainage is thus disadvantageous in formation of a sheet from a given suspension; on the other hand, with quick drainage, a less flocculated suspension will be presented to the wire.

Fig. 8–10 demonstrate the result of similar experiments using mechanical pulp. The results agree with those from sulphite pulp, except in comparing the slopes of Fig. 10, which are almost equal and indicate no influence of drainage rate.

The resistance to air permeation (given in sec per 100 ml of air measured on the paper sheets) is listed in Table 2. The data seem somewhat scattered, but there is a large number of single observations behind each value. A greater number of parameter combinations could have given a clearer picture of the behaviour of the sheets. It is quite clear from the table, however, that at low flocculation there is a low density (air resistance), in the intermediate

TABLE 2—AIR RESISTANCE OF SHEETS AT VARIOUS DELAY TIMES AND DRAINAGE RATES—BLEACHED SULPHITE PULP, 45° S.R.

Drainage rate, mm/sec	*Air resistance (Gurley), sec/100 ml* — *Delay time, sec*				
	0	*20*	*40*	*60*	*80*
5	2 768	—	—	—	3 523
10	3 523	—	—	—	3 370
15	3 875	—	—	—	3 875
20	3 875	—	—	—	2 870
25	2 672	2 981	3 229	3 523	2 583
Free drainage	2 214	3 875	3 370	2 422	2 870

TABLE 3—BREAKING LENGTH OF SHEETS AT VARIOUS DELAY TIMES AND DRAINAGE RATES—BLEACHED SULPHITE PULP, 45° S.R.

Drainage rate, mm/sec	*Breaking length, m* — *Delay time, sec*				
	0	*20*	*40*	*60*	*80*
5	7 903	—	—	—	7 051
10	7 938	—	—	—	7 372
15	8 107	—	—	—	7 674
20	8 601	—	—	—	7 691
25	8 660	8 181	8 285	8 387	7 679
Free drainage	9 190	8 189	8 592	8 322	8 246

region there is a high density, but at high flocculation the density declines again. This picture is quite reasonable if it is assumed that quick drainage gives an open sheet of low flocculation, slower drainage gives a more closed sheet though more flocculated; at still slower drainage, the flocculation is so pronounced that, although the sheet is dense, the flocs produce thin areas that allow air to pass more easily.

Breaking length increases with increasing drainage rate and decreases with increasing delay time—that is, inferior formation corresponds to lower strength. An influence of openness of the sheet—as observed in connection with air permeability—was thus not observed in tensile strength. The elongation to rupture is listed in Table 4 and shows no relationship to structural parameters. Since breaking elongation is determined predominantly by fibre properties and by drying, a relationship with sheet formation could hardly be expected.

TABLE 4—ELONGATION AT RUPTURE OF PAPER SHEETS AT VARIOUS DELAY TIMES AND DRAINAGE RATES—BLEACHED SULPHITE PULP, 45° S.R.

Stretch, per cent

Drainage rate, mm/sec	*Delay time, sec*				
	0	*20*	*40*	*60*	*80*
5	7.8	—	—	—	7.0
10	8.2	—	—	—	7.6
15	7.6	—	—	—	7.0
20	8.4	—	—	—	7.0
25	7.8	8.0	6.8	7.6	6.6
Free drainage	7.0	8.4	6.6	6.2	6.6

TABLE 5—TEAR FACTOR OF SHEETS AT VARIOUS DELAY TIMES AND DRAINAGE RATES—BLEACHED SULPHITE PULP, 45° S.R.

Tear factor (Elmendorf)

Drainage rate, mm/sec	*Delay time, sec*				
	0	*20*	*40*	*60*	*80*
5	63.0	—	—	—	74.4
10	75.3	—	—	—	72.8
15	60.2	—	—	—	69.4
20	69.9	—	—	—	73.0
25	70.3	67.4	70.5	67.3	70.0
Free drainage	68.4	70.2	66.5	68.9	71.3

The tearing strength is listed in Table 5. No significant change with delay time can be established, but there is a decrease with increasing drainage rate—that is, opposite to the variation of tensile strength—as could be expected.

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Transcription of Discussion

DISCUSSION

MR. P. G. SUSSMAN: In the reports[1] of the Technical Section's Pulp Evaluation Committee describing handsheet making in the standard sheetmachine, a delay of 10 sec is recommended between the final removal of the stirrer and the opening of the drainage cock. This delay results in a small but definite increase in burst factor over sheets made immediately after stirring and it is suggested that this is so because the delay allows any small degree of swirling to subside.

I should like Dr. Andersson to comment on this delay time. Perhaps there is a difference between the stirring equipment in the Norwegian and British sheetmachines?

DR. O. ANDERSSON: I agree that the stirring of the suspension is extremely important in all experiments of this kind. We applied a perforated plate that moves up and down according to a certain standard, which was repeated each time.

MR. G. F. UNDERHAY: Have you any relationship between the optical measurements you were making and the actual weight of materal involved? I am always a little suspicious of optical measurements as a means of determining other quantities and would be interested to know, particularly in the sheets themselves, whether you have done any correlation between the changes of basis weight from place to place and the optical measurements that you have been making?

DR. ANDERSSON: No, I have no equipment for such measurements, otherwise I would have used that instead. The optical method has several disadvantages, however, in measurement of mass distribution.

DR. M. KROFTA: The forming of floc is a very complex process. I would therefore like to ask whether the temperature and pH value of the fibre suspension were controlled or kept constant or if this test was carried out with or without the use of flocculants.

1 Interim Report (October 1929), pages 43, 75;
Second Report (July 1936), pages 79, 80

DR. ANDERSSON: As pointed out, we checked the temperature, but we did nothing about the chemical nature of the water, which was ordinary tap water stored for one day in a large tank for de-aeration and stabilising its temperature.

MR. E. J. JUSTUS: If you can do the same thing with kraft paper, maybe we could believe you a little more and help my unbelief on this.

MR. J. MARDON: In running a papermachine, there are two different things one looks at in the sheet it produces—(*1*) genuine flocs, where one looks for some degree of fibre entanglement and (*2*) the difference in distribution of fibres, which a papermaker would not call flocs.

DR. A. C. NIXON: I notice on Fig. 7 (which is a replotting of Fig. 2) that the data for a drainage rate of 14 mm/sec is much worse than your general data, most of which has good internal consistency. Why was that so? The open circles depart quite widely from the straight line. Was there something happening uniquely in that range?

DR. ANDERSSON: Yes, we had much trouble over that, but we applied a mathematical process to draw this line, which we preferred to repeating the experiment, since that would have taken another three weeks.

DR. NIXON: In my experience, people often overlook something unique in an effort to simplify the whole story; it might be worth considering whether something unique had happened with this particular drainage rate.

DR. ANDERSSON: We have considered this quite a lot, but have been unable to trace it back to any reasonable source.

PROF. J. D'A. CLARK: The 10 sec pause after stirring in making standard sheets is a compromise between allowing the swirl to stop and flocs to form.

DR. O. J. KALLMES: It is relatively easy to define and describe the mass distribution per unit area, but it is quite another matter to define the size, area, number of fibres, etc. involved in a 'floc'—in fact, its definition is vague and rather arbitrary.

PROF. B. G. RÅNBY: If the fibres are sufficiently long, are flocs not obtained then with, for example, virgin cotton fibres? Furthermore, when you look at the wire on a papermachine, it really looks as if flocs were present in those circumstances when the paper made has what we call poor formation.

DR. ANDERSSON: Of course. Even if the fibre suspension is dilute enough when the fibres deposit and form a sheet, it is not easy to distinguish the separate flocs, for they form a coherent network. In a mathematical analysis of sheet non-uniformity, it would be more fruitful to look not for flocs, but merely for distribution of material.

DR. S. G. MASON: I would like to clarify the last point a little. I think there is no doubt whatever that, down to sufficiently low concentrations (for example, the concentrations used with the standard sheetmachine), there are flocs. For a number of years, however, we have recognised that, when the concentration is increased, one reaches a region in which there is a continuous network of fibres. This region is reached much below practical head box concentrations. We now recognise that at head box concentrations undergoing 'plug' or 'frozen' flow, one deals with a single continuous floc, within which there are statistical variations in concentration that reflect the previous history of the sample, particularly its history of turbulence. Perhaps, Robertson will expand on this point when he presents our joint paper later. I think you are wrong, however, to state that flocs do not exist at low concentrations.

DR. ANDERSSON: I made an important additional remark at the end: I said 'in paper sheets'. The existence of flocs in suspensions is an entirely different affair. I agree with you entirely there. We know that there is one big floc at head box consistencies, but there may be irregularities in mass distribution and, below some critical concentration, there are fibre flocs. I know, because I have counted them.

DR. MASON: Have you tried any of the peeling-off techniques described yesterday? I think there would be quite a good possibility that these would reveal flocs in handsheets.

DR. ANDERSSON: I would like to add another point here, that the huge single floc when pressed out of the head box through the slice must rupture into small pieces: therefore, in considering flocculation, we have to remember that the creation of these irregularities may be the result of a process of destruction rather than construction.

MR. MARDON: The conversation has taken a turn somewhat peculiar to anyone used to running papermachines. If I may steal the words of an English colleague, the meeting seems to be composed of scientists who look at fibres and do not look at papermachines and of papermakers who look at papermachines and do not look at fibres; what we have here is the fact that the two are unable to find common ground.

Flocs *do* exist and a practical papermaker, when he looks at a sheet, will distinguish between flocs in the sheet and differences in the aggregation of the distribution of fibres. They are two distinct things that any man, looking at a sheet of paper every day of the week for his living, will normally be able to tell you about. We are verging on the ridiculous by the trend that the discussion is taking.

MR. P. B. WAHLSTRÖM: I know that this is included in your paper, but I think the question *is* pertinent to the proper understanding of your work—what was the basis weight of the sheets made and were there any variations of these conditions during the test?

DR. ANDERSSON: No. There was only one basis weight, that stated in my paper.

MR. WAHLSTRÖM: Yes, I knew that. I asked the question because I think there is a definite relationship between the results obtained and the consistency and basis weight under which these tests are run. The correlation between flocculation in the suspension and in the sheet will be dependent on the consistency of the suspension and the basis weight of the sheet.

DR. ANDERSSON: The conditions were those for standard sheetmaking.

MR. B. RADVAN: I think Andersson's remark that flocs are the result of breaking up, rather than coagulation, is most important. That this is so is clearly shown by their shape. Start with a stock pond some 8 in high, squeeze it into a depth of about $\frac{1}{2}$ in; if there is no breaking up of the flocs, they will have a length/breadth ratio of 16:1. In fact, they are nothing of the kind, they are just about circular again. The irregularities that we see in the paper are largely the result of this breaking up. I understand that Mason intended to do some experiments on these lines; could he tell us anything about it?

DR. MASON: We have made an attempt to study the mechanical properties of individual flocs. I think you are referring to our experiments in which we put individual bundles (flocs) of fibres into a 'four-roller' apparatus, first described by Sir Geoffrey Taylor. This apparatus makes it possible to produce shear without rotation of the flocs. In this way, one can pull them apart by the tension forces so generated. In the region of the floc where tension acts, one can see individual fibres being pulled out. Because of experimental difficulties, however, we have been unable to make these experiments quantitative.

DR. H. F. RANCE: I am a little puzzled about Andersson's statement about flocs. Like Mardon, I do not really know what he is suggesting. He admits there are flocs in the suspension from which the paper is being formed, but he denies that there are flocs in the formed paper. Is this not simply a question of definitions? Is he saying that what we call a floc in paper is not a floc but the result of a floc?—or is there something much more profound in what he is trying to say?

DR. ANDERSSON: I wanted a discussion on a rather important matter. As I mentioned, to try to study the structure of a paper sheet by looking for single fibre flocs leads nowhere. I consider it better in a sheet of paper not to look for flocs, but for distribution of irregularities in the material. It is not an attempt at a better definition; it is the only way to approach the geometrical analysis of these irregularities.

DR. RANCE: Is there not an advantage in trying to relate the irregularities in paper to the irregularities of the stock from which the paper has been formed? If we do not use this relationship, are not we throwing valuable information away?

PROF. B. STEENBERG: I think Rance is right. If I understand Andersson aright, it is partly a matter of nomenclature. If you try to define a floc physically and not optically, you would say a floc is a certain portion of the system that behaves like a semi-rigid body and it is not in physical contact with fibres around it. If that is your definition of a floc, then a wet sheet of a paper is one big floc, because all its fibres are entangled with each other. I believe that is the very fact that Andersson wanted to point out: in dilute suspensions, there are discrete fibre aggregates that move as semi-rigid bodies, but at normal papermaking consistencies all the fibres move as one semi-rigid body. It may, however, be broken down and reconstituted; the point is that there is not only breaking up, there is more probably reconstitution, which is an important thing—but you end up with one big floc. Irregularities in the mass distribution of the paper sheet reflects the existence of network fragments, but it must be futile to distinguish individual fragments by looking through the paper sheet.

DR. KALLMES: The word floc means something different to everyone. Unless we define it in terms of some type of distribution, we will never reach the stage of a paper science, which is quite different from the arbitrary terms applied to non-uniformity in sheets—cloudy, floccy, etc.

MR. JUSTUS: For many years, we have been making paper from a formation of flocs instead of a formation of fibres; the very heart of our formation development is to try to break down the size of the bricks or building blocks we are using, particularly in the kraft paper field. What we need and what we think we are working for is understanding how to build papers out of fibres instead of out of flocs of fibre.

PROF. A. H. NISSAN: For studying mass distribution, X-rays would be very useful. In case anyone is thinking of taking it up, there are two things to remember. One has already been mentioned: they should be soft X-rays (low energy X-rays); the other is a matter of cost. An X-ray machine is fairly expensive and I pass on a wrinkle: instead of buying a machine, take a primary emitter, mix some tungsten oxide with it and so produce soft X-rays as a secondary emission. The undesirable primary rays are shielded and photographic means can be used for a receptor.

MR. UNDERHAY: The soft X-ray technique sounds to me to be very interesting. Is it possible to use it for the measurement of the mass variation in handsheets in the way suggested and, if that is so, is it possible to use it also for the measurement of the condition of flocculation of stock in suspension? What size of area has been measured in Andersson's work?

Another question is that, if this soft X-ray technique can be used conveniently for measuring mass, does this provide the key to the equipment we have all been looking for for a long time—a means of measuring the consistency of low consistency stock?

DR. ANDERSSON: In our experiments, we used an image ratio of 1:1 and 9 cm × 12 cm photographic plates, the size of the sheetmachine being 24 cm × 40 cm.

MR. P. E. WRIST: A comment on the soft X-ray technique. We have investigated the use of commercial soft X-ray equipment that uses a pulsed

X-ray source to give a high degree of accuracy and speed of response. The method works well on dried fibre sheets. If we refer the results to an absorption coefficient for cellulose of unity, the coefficient for water is about 0·8. This means that the method is suitable for use only on dried sheets and would not be useful for a dilute suspension. The reading is sensitive also to filler material, for example, clays and such like. These have an absorption coefficient of the order of three. The method is therefore more selective than the beta-ray gauge.