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EFFECT OF FORMING PROCESSES ON SHEET STRUCTURE

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Synopsis

Sheet structure can be fully described in terms of (i) the distribution of fine material, (ii) the degree of fibre orientation and (iii) the degree of fibre flocculation throughout the sheet thickness.

The physical characteristics of common forming processes are discussed—those of the Technical Section sheetmachine, the Fourdrinier machine, uniflow and contraflow vats. The major characteristics of these processes are—relative movement between stock and wire, drainage forces, stock concentration, recirculation of fines, manner of metering stock in relation to area of the formed sheet, conditions under which the forming process ends.

The effects of these physical process characteristics on the structure of the sheet are discussed and available evidence is presented.

It is concluded that all common forming processes can be described by means of component unit processes, which are—orienting, continuous draining, intermittent draining, fractionating, emerging and flocculating. The manner in which these unit processes affect the sheet structure is described. Internal sheet structures typical of the common forming processes are presented schematically.

L'effet sur la structure de la feuille de la manière de sa formation

La structure d'une feuille de papier peut se définir en termes de la distribution des fines, de l'orientation des fibres et du degré de flocculation dans toute l'épaisseur de la feuille.

On compare les caractéristiques des méthodes de formation les plus usitées, la formette anglaise, la machine à table plate et les cuves équi-courant et contre courant. Les principales caractéristiques de ces méthodes sont le mouvement relatif entre la suspension et la toile, *les forces d'égouttage, la teneur en fibres de la suspension, la réintroduction des fines, la manière d'assurer le débit de la suspension par rapport à l'étendue de la feuille déjà formée et les conditions dans lesquelles la formation se termine.*

On expose l'effet de ces caractéristiques physiques sur la structure de la feuille et les connaissances actuelles sont présentées à l'appui.

On en conclut que les méthodes de formation peuvent se diviser en procédés distincts, c'est à dire, l'orientation, l'égouttage continu, l'égouttage intermittent, le fractionnement, la sortie de la feuille d'une suspension et la flocculation. On décrit la manière dont ces procédés distincts influent sur la structure de la feuille. On présente des diagrammes indiquant les structures internes des feuilles qui sont caractéristiques des méthodes de formation étudiées.

Einfluss der Blattbildung auf die Bahnstruktur

Die Bahnstruktur kann vollständig durch die Verteilung des Feinstoffes, den Grad der Faserorientierung und den Grad der Faserflockung durch die Bahndicke hindurch beschrieben werden. Für die bekannten Blattbildungsverfahren auf dem Labor-Blattbildner, der Langsiebmaschine und dem Gleichstrom- und Gegenstromsieb wurden die physikalischen Eigenschaften diskutiert und festgestellt, dass die relative Bewegung zwischen Stoff und Sieb, die Entwässerungskräfte, Stoffkonzentration, Zurückführung des Feinstoffes, Art der Stoffführung im Bezug auf die zu bildende Bahnfläche und die Bedingungen, unter denen der Blattbildungsprozess endet, von besonderer Bedeutung sind. Es wurde ausgeführt, dass alle bekannten Blattbildungsprozesse aus den Komponenten—Orientierung, kontinuierliche Entwässerung, unterbrochene Entwässerung, Fraktionierung, Untertauchen und Ausflockung—bestehen, deren Beziehungen zueinander die Blattstruktur bestimmen. Abschliessend wurden schematisch die Blattstrukturen für diese Blattbildungsprozesse gezeigt.

Introduction

THE problem of papermachine design is that of achieving optimum properties in a sheet of paper in the most economical way. With any given stock the properties of the sheet can broadly be attributed to —

(*a*) sheet structure,
(*b*) treatment given to the formed web.

Each forming process produces a characteristic sheet structure. A thorough understanding of the relationships between forming process, sheet structure, treatment and paper properties can provide a basis for a solution to the problem. As a first step, this paper discusses the types of structure characteristic of four common forming processes.

Definition of internal sheet structure

THE components of a sheet of paper can be divided arbitrarily into fibres and fine materials. Fibres can be assumed to be distributed fairly evenly through the thickness of a sheet. Their distribution is rarely random and can be described in terms of their orientation and flocculation. The fibres form a rather porous network within which fines are distributed, though not uniformly.

Internal sheet structure can therefore be described in terms of—

(*a*) degree of fibre orientation,
(*b*) degree of fibre dispersion,
(*c*) distribution of fine material,

throughout the sheet thickness. This definition does not include defects of the sheet like uneven substance or wire mark, because they are not necessarily inherent in a process; they are not dealt with here.

To describe the effect of forming processes on sheet structure, it is necessary first to analyse the characteristics of the forming processes.

Characteristics of forming processes

FIG. 1 presents the characteristics of four common forming processes—laboratory sheetmachine, Fourdrinier machine, uniflow vat and contraflow vat.

Relative movement—On the Fourdrinier machine, the initial stock/wire speed ratio is controlled and is usually slightly less than 1.0. Andersson and Bergstrom[1] have shown that the stock rapidly assumes the wire speed; consequently, no relative movement is present in the later stages of formation. On slower machines, relative movement introduced by the shake has to be considered.

In both types of vat, relative movement is big and it varies around the vat circle. In the ideal uniflow vat, no relative movement occurs; for reasons such as hydraulically manageable volumes, an appreciable relative movement is usually observed. The stock/wire speed ratio can be as low as 0.3.

	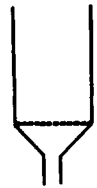	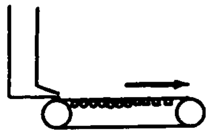	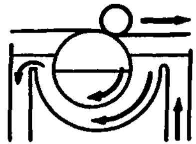	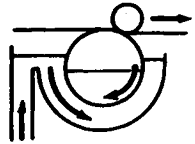
RELATIVE MOVEMENT	NIL	SMALL → NIL	MEDIUM	BIG
INLET STOCK CONCENT.ION	VERY LOW	MEDIUM to HIGH	MEDIUM	MEDIUM to HIGH
DRAINAGE v. TIME				
RECIRCULATION & EFFECT on FREENESS	NIL NIL	BACKWATER BIG DROP	Overflow + White Water SMALL CHANCE	WHITE WATER MEDIUM DROP
STOCK METERED	To AREA of WIRE	To AREA of WIRE	TO A POOL	TO A POOL
EMERGENCE	—	—	FROM A POOL (overflow stock)	FROM A POOL (inlet stock)

Fig. 1—Characteristics of common forming processes

Stock concentration—The very low concentration of the laboratory sheetmachine is not matched by commercial machines.

Drainage force—The continuous drainage force of all other machines stands in contrast to the intermittent forces produced by the table rolls of a Fourdrinier machine. A good understanding of the working of the table rolls has been obtained in the last decade.[2-5]

Recirculation—As a result of recirculation, stock freeness at the inlet to the forming section can differ greatly from the freeness at the machine chest.

Stock metering—In a laboratory sheetmachine and on a Fourdrinier machine, a measured volume of stock is supplied in such a manner that the area of the sheet to be formed from it is predetermined.

On a vat machine, the stock is supplied to a pool and that supplied at any moment can participate in the formation of a large area. Stock supplied while the mould travels 1 ft, for example, has been found to be spread over a length of 50 ft.

Emergence—In vat machines, the forming process ends with the web emerging from a pool. Further structural features may be added here.

The various forming processes are seen to have some constituent parts in common, although some constituents are peculiar to one or another process. These constituents have their own effects on sheet structure.

Effect of forming characteristics on sheet structure

Fibre orientation

LUND[6] stated—'Because of relative speed between the wire (or the sheet already formed) and the fibres, they will be dragged with the wire (or the sheet already formed) in the machine-direction.' Relative movement still stands as the major cause of fibre orientation.

Sometimes fibres within the stock already show a degree of orientation and this initial orientation adds to that developed during formation.

Fibre dispersion

A tendency to flocculate is an ever-present stock characteristic. The reasons for it are not understood to the desired extent nor are there satisfactory ways of overcoming it.

On the forming machine, stock concentration, turbulence within the stock, time available for flocculation to occur and mechanical factors like relative movement and table roll disturbance appear to be the most important factors affecting the degree of flocculation.

Stock concentration has a well-known effect on flocculation and, as a rule, machines are operated with the minimum concentration allowed by other conditions. Robertson and Mason[7] studied the effect of turbulent motion on flocculation. Andersson[8] investigated in the laboratory the relationship between flocculation and sheet properties. Finger and Majewski[9] demonstrated the dispersing effect of relative movement on flocs.

Distribution of fine material

In considering the distribution of fine materials, it is assumed that fibres are fully retained by the forming wire.

Continuous drainage—This is the case of a simple filtration process of a heterogeneous material. In the course of drainage, fibres (originally uniformly suspended throughout the thickness of the suspension) gradually collapse into a rather porous mat. It can be assumed that their relative positions within the mat are the same as within the original suspension. A fine moves towards the mat already deposited in the same manner as neighbouring fibres. When the mat already deposited is reached, the fine can be retained directly on the surface. The chance that this will occur is rather slight, because of the porosity of the mat. The fine, most likely, will penetrate the network, either to be retained within it or to pass through it. In the early stages of deposition, passage through the thin mat is very frequent, but, with progressive deposition, each retained particle reduces the porosity. The oncoming fines are retained more readily in this region of reduced porosity. The downward movement of fines and the gradual build-up of a retentive layer in the wire side of the sheet result in a distribution of fines with a distinct maximum close to the wire side and a minimum at the top surface. Experiments to show this effect are described in the appendix.

Intermittent drainage—The term *intermittent drainage* is used here to cover all aspects of table roll action: this type of drainage is characteristic of Fourdrinier machines. Very poor retention on the wire, sometimes as low as 50 per cent,[2] stands in contrast to all other processes. That mostly the fine fraction goes through the wire can be seen from the drop in freeness when backwater is mixed with new stock from the machine chest. Underhay[10] mentions a drop of Canadian freeness from 173 points to 64 points for a machine running between 800 and 1 000 ft/min. Similar data are given in Table 1 for a slower machine.

The very poor retention of the fine fraction indicates a considerable non-uniformity of distribution within the formed sheet. Underhay[10] observed more than twice as high a concentration of clay in the top side of the sheet as in the wire side. A similar distribution of starch was observed by the author. That the same happens to the fine fibrous fraction can be seen from Table 1. Those figures were obtained by splitting a wet web into two halves.

TABLE 1—FREENESS CHANGES: FOURDRINIER MACHINE

Freeness changes between machine chest and flow box
Freeness differences between top and wire sides of sheet

Machine speed, ft/min	380	340	260	165
*Sheet substance, lb/*D.C. (480)	24	27	35	50
Machine chest freeness, CSF	235	250	240	230
Flow box freeness, CSF	125	120	155	220
Freeness of reslushed sheet, CSF —				
Whole sheet	155	205	195	205
Top side	125	150	155	180
Wire side	225	230	225	215

Intermittent drainage produced by the table rolls[10] results in a distribution of fine material showing a distinct maximum in the top side of the sheet This is exactly the opposite to the distribution produced by continuous drainage.

Metering to a pool—In conventional vat machines, both uniflow and contraflow, the sheet is formed from a pool of stock. In each type, stock flows from the vat inlet to the back while a comparatively great length of wire traverses it. There are two notable consequences of this —

1. Stock entering the vat at any moment participates in the formation of a great length of the sheet.

2. Selective deposition and fractionation of the stock occurs.[11,12]

The relative movement between the pool and the mould introduces turbulent shearing forces that act on the fibres in addition to the forces producing drainage. At the beginning of deposition, drainage rate is very high and fibres are mainly under the influence of the drainage forces. With progressive deposition, an increasing portion of the available drainage force is used to overcome the resistance of the mat and, relatively, the shearing forces grow. Their effect is that a partially deposited fibre can be carried by the turbulent currents away from the mat already deposited and be returned to the pool of stock. For a longer fibre, this process of washing off sets in sooner than for a shorter fibre. Gradually, it extends to the shorter fibres. Conversely, the finer fraction of the stock is accepted into the web as long as effective drainage is taking place.

The effect of this selective deposition on the distribution of fine material within the sheet is that, after the onset of the washing off, shorter fibres and fines become heavily concentrated in the top portion of the formed mat. An example of this can be seen in Fig. 2, in which peelings of the top side and of the wire side of a contraflow sheet are compared.

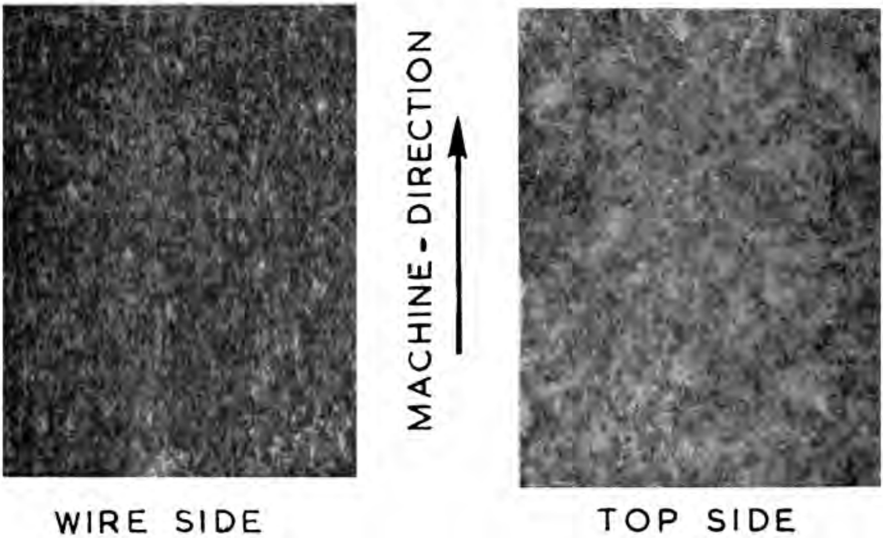

Fig. 2—Sheet structure from a contraflow vat
Peeling of surfaces shows a high concentration of fines in the top side ($\times$ 1)

Another important effect of the selective deposition is that, as it proceeds, the stock becomes fractionated. The finer fraction and water are removed from the pool stock, whereas the longer fraction remains. Freeness and concentration of the pool stock increase as the stock moves from the vat inlet to the vat back. Increases of freeness of up to 200 points and of concentration to more than twice the inlet value are not uncommon and they are observed in both contraflow and uniflow vats. The fractionation is important in regard to the emergence conditions in the uniflow vats and to the output of contraflow vats. The magnitude of fractionation is a measure of selective deposition, also of the consequent unevenness of distribution of fine material.

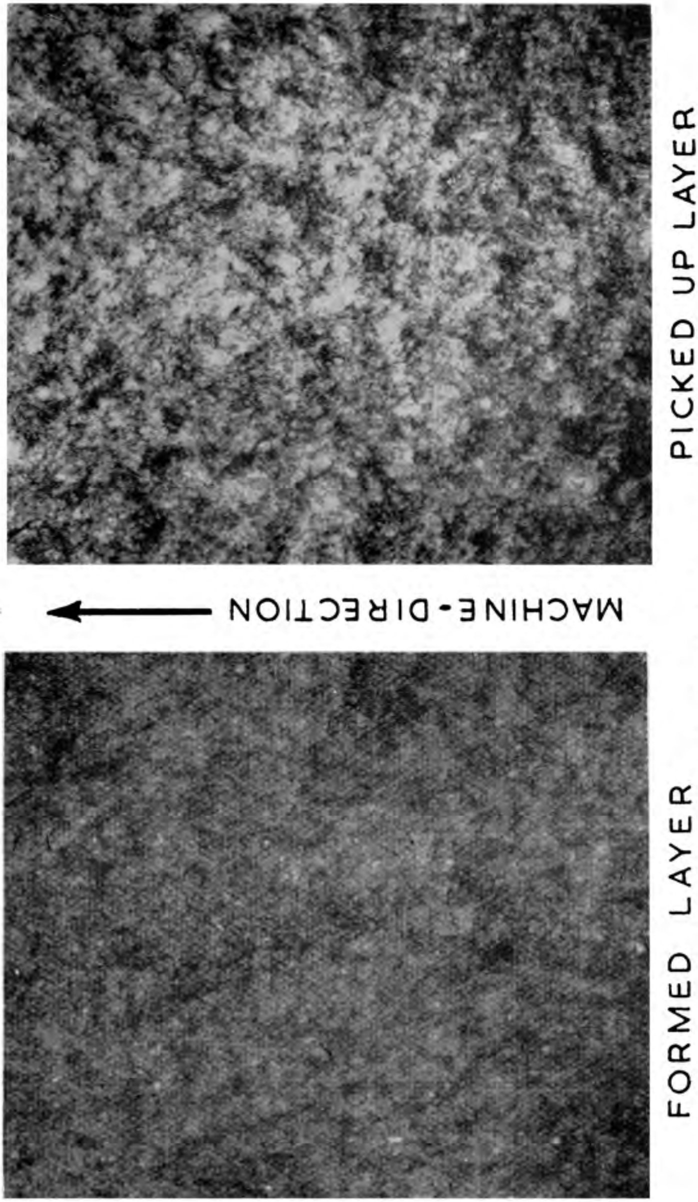

Fig. 3—Formed and picked up layers of a uniflow sheet (transmitted light × 1)

Emergence—A sheet formed in a vat has to be lifted from the pool of stock. In uniflow vats, such emergence results, as a rule, in a practically complete layer being dragged up with the formed sheet. The conditions favouring the pick-up are—high stock concentration and freeness of the fractionated stock at the back of the vat, gravity acting towards the interior of the mould at the point of emergence and the movement in the same direction of the mould and the stock. Fig. 3 illustrates the picked-up layer and the formed layer from a uniflow vat.

In a contraflow vat, conditions for pick-up are not as favourable, because the web is lifted from the inlet stock (that is, stock of lowest freeness and concentration) and because the mould moves in the opposite direction to the stock, although pick-up occurs under certain conditions. High inlet stock concentration on some slow machines produces it. On many machines, the contraflow principle does not apply to the region from which the sheet emerges. The inlet stock enters the vat at an appreciable distance from the mould and a 'roll' or a whirl of stock is created with the axis parallel to the mould axis. The roll moves in 'uniflow' with the mould.

Sheet structures typical of forming processes

THE understanding already gained of the relationship between constituent processes and sheet structure can be used to produce a composite picture of sheet structures typical of common forming processes. In Fig. 4, the typical structures are presented schematically.

The same pulp, beaten to the same freeness, is assumed to be used in all processes. Fibre loss is assumed to be zero, so that the incoming and outgoing quantities of fibres and fines are equal.

Handsheet

Fibre orientation—Fibres are random.

Fibre dispersion—Very low stock concentration of 0.017 per cent results in an excellent fibre dispersion.

Distribution of fine material—Continuous drainage results in a fines distribution showing a maximum very close to the wire side of the sheet. The very surface of the wire side, obviously, contains practically no fines.

Fourdrinier machine

Fibre orientation—The wire side shows an appreciable degree of orientation, because stock velocity is kept as a rule below the wire velocity.

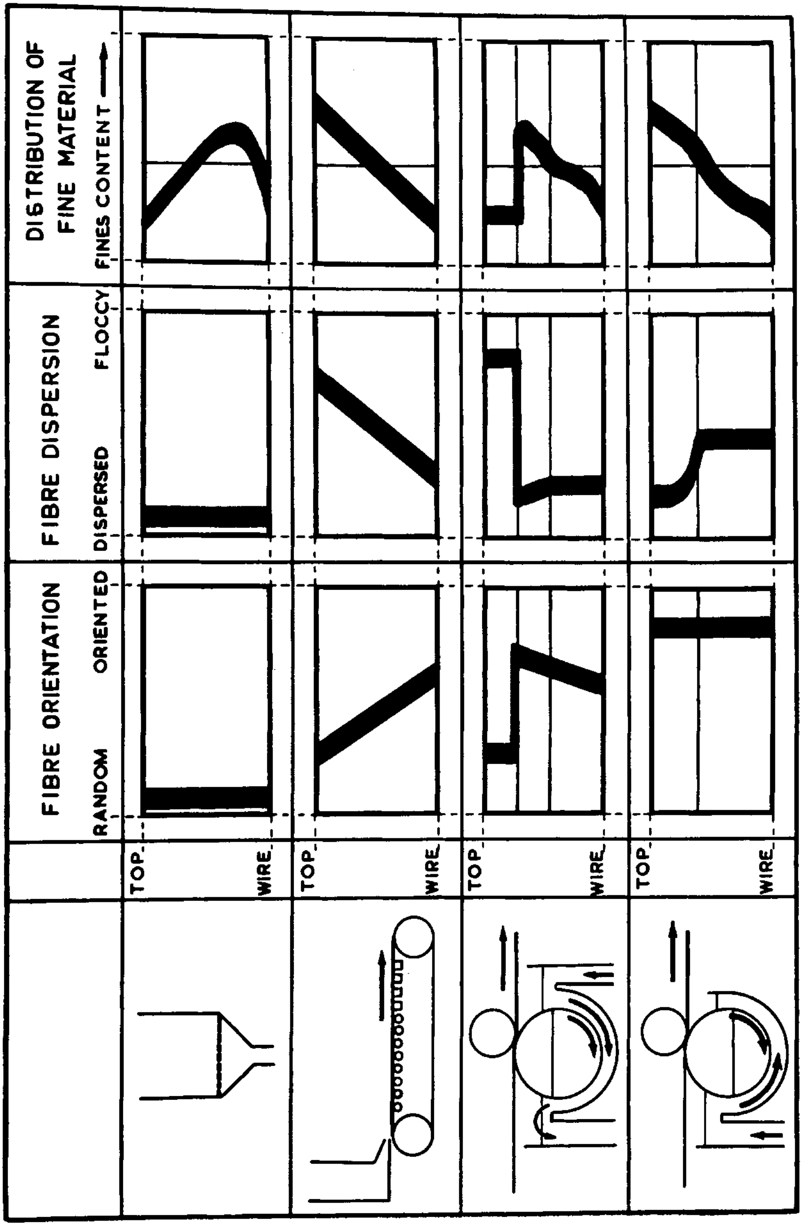

Fig. 4—Sheet structures typical of forming processes

Towards the top side, orientation decreases, because the stock gradually assumes the velocity of the wire. Wire shake increases fibre orientation, but does so in directions oscillating around the machine-direction, so that the resultant orientation in the machine-direction is reduced and normally a 'squarer' sheet is observed.[9]

Fibre dispersion—The wire side shows reasonably good dispersion, because no time is available for flocculation to occur. Wire shake on slower machines disperses some of the flocs. On faster machines, the violent action of the table rolls may help to keep the fibres well dispersed by repeatedly disrupting the mat. Towards the top side, flocculation increases appreciably.

Distribution of fine material—The stock supplied to the wire contains much more fine material than does the machine chest stock. The intermittent drainage washes out fines from the wire side, leaving it practically bare of fines. The top part is not subjected to this washing out and it shows a concentration of fines very close to that of the flow box stock.

Uniflow vat

The forming process in the uniflow vat is made up of continuous drainage, selective deposition and pick-up. Continuous drainage occurs during the whole submerged travel of the mould surface, whereas selective deposition sets in while formation is in progress. The initial phase, occurring before the beginning of selective deposition, can be called a phase of proportional deposition. As the name indicates, there is a strict proportionality between drainage and deposition. No such proportionality exists during the phase of selective deposition.

For the above reasons, the sheet in Fig. 4 has been divided into three parts—parts deposited during the phases of proportional deposition, of selective deposition and of pick-up.

Fibre orientation—As a rule, the sheet formed before the pick-up phase is reached shows a high degree of fibre orientation. This is caused by large relative movement between the stock and the mould. On slow machines, however, relative movement is small and only a low degree of fibre orientation is observed.

The picked-up layer is less oriented, because it is heavily flocculated, but the flocs are somewhat oriented, since they are dragged up from the pool of stock.

Fibre dispersion—During the phase of proportional deposition, dispersion is reasonably good. During the phase of selective deposition, it reaches an excellent level, because the nature of the process permits only single fibres and fines to be deposited. The picked-up layer is highly flocculated.

Distribution of fine material—The stock entering the vat is approximately of the same freeness as the machine chest stock, because the tendency of the whitewater to lower the freeness is countered by the high freeness of the overflow stock. During the phase of proportional deposition, the continuous drainage produces a distribution of fines similar to that of a handsheet, though even more uniform, because the retention is aided by fibre orientation.

With the onset of selective deposition, shorter fibres and fines are deposited, so that the proportion of fines increases, though the mat already deposited is still rather porous and the fines can partially penetrate towards the wire, thereby increasing the content of fines in the portion already deposited during proportional deposition. Towards the end of selective deposition, only very short fibres and fines are being accepted and a dense, impervious layer is being formed. The penetration of fines is more difficult and a pronounced maximum of concentration of fines occurs on top of this part of the sheet.

The picked-up layer, being composed of a very free stock, shows a very low content of fines; because it is not formed by drainage, a sharp boundary exists between the two parts of the sheet.

Contraflow vat

The contraflow vat differs from the uniflow in that the formation begins with fractionated stock at the back of the vat.

A picked-up layer is not shown in Fig. 4, because it is not typical of the contraflow sheet, although it occurs quite frequently. Another reason for its omission is that, if it is present, it does not represent such a dramatic change in the sheet structure as it does in the case of the uniflow sheet. It is composed of low-freeness inlet stock.

Fibre orientation—Rapid relative movement causes extreme orientation throughout the sheet thickness.

Fibre dispersion—Formation begins with a stock of high freeness and concentration, both increasing flocculation. Accordingly, during proportional deposition, a higher degree of flocculation is evident than in a uniflow vat. During selective deposition, the dispersion is excellent.

Distribution of fine material—The stock entering the vat contains more fines than does the machine chest stock, because of admixture of whitewater. The stock from which the first part of the sheet is formed, however, is the fractionated stock and contains very many fewer fines. In this part, formed during proportional deposition, what fines remain in the stock are distributed similarly to those in a handsheet. From the onset of selective deposition, the content of fines within the accepted stock increases and the fines tend to penetrate the mat. Towards the end of selective deposition, the shorter fibres and fines form a dense layer and the penetration is more difficult. A pronounced maximum of fine content occurs in the top portion of the sheet.

Unit processes

It has proved possible to account for typical sheet structures in terms of the characteristics of their forming processes. This has been done above by —

(*a*) Dividing each process into suitable constituents.

(*b*) Analysing the effect the constituents have on sheet structure.

(*c*) Combining these effects of the constituents according to the composition of each process.

An important feature of the proceeding was that a relatively small number of constituents had to be considered. It appears that the constituents can become a very useful tool in analysing a forming process and synthesising the resultant sheet structure and properties. For want of a better name, it is suggested that they be called *unit processes* of formation. Further work is needed to define the various unit processes more clearly, but the following list has been derived. The unit processes and their effect on structure are —

Orienting—Relative movement between stock and wire causes fibre orientation.

Continuous draining, resulting in concentration of fine material in the vicinity of the surface towards which the drainage takes place.

Intermittent draining—Table roll action is responsible for washing out of fines from the side of the sheet towards which the drainage is occurring.

Selective depositing, occurring when formation takes place from a pool being traversed by the forming surface and causing preferential deposition of the finer fraction of the stock.

Emerging of the formed sheet from a pool of stock, resulting in a pick-up of a layer of rather poor formation.

Flocculating of stock, causing uneven sheet structure.

In Fig. 5, the key to composing a sheet structure by means of unit processes is given. The significance of each unit process is denoted by the number of crosses.

	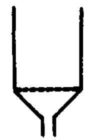	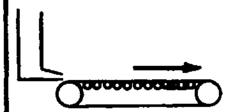	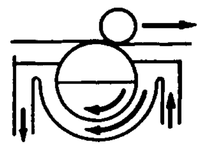	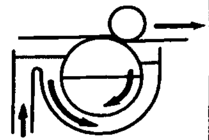
DRAGGING	−	+	++	+++
CONTINOUS DRAINING	+++	−	++	+++
INTERMITTENT DRAINING	−	+++	−	−
SELECTIVE DEPOSITING	−	−	++	++
EMERGING	−	−	++	+
FLOCCULATING	−	+++	++	++

Fig. 5—Unit processes—key to sheet structure

Conclusion

A PICTURE has been obtained of sheet structures that are typical of some forming processes. It is a crude picture and it can be improved in many ways, although the study of structure should not be an objective in itself. It is only a link—a link essential to a fuller understanding of the process of obtaining certain sheet properties from a stock. The accent, therefore, should be put on the relationships existing between various aspects of the entire process as a whole. A complete understanding of structure for its own sake is only of limited value, until it is known how it came about and what it is good for.

This paper has discussed the relationship between forming process and sheet structure, without dealing with that between sheet structure and physical properties. It shows a diversity of structure and aims to define what structural features are produced by certain process features. These process features are described as unit processes. There is a need to express the entire process in terms of unit processes. The remaining step is to relate the unit processes to the physical properties of the sheet.

The road back may then be taken, expressing the desired sheet properties in terms of structure and post-forming treatment and these, in their turn, in terms of unit processes. It will be left to the designer of machines to give engineering shape to the required combination of unit processes.

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Appendix

Distribution of fine material in handsheets

To determine two-sidedness in a handsheet, an attempt was made to split the wet web for the purpose of reslushing for freeness determination of the two halves. Splitting proved very difficult and unsatisfactory.

The great effect of fines on air resistance of a sheet was used in another

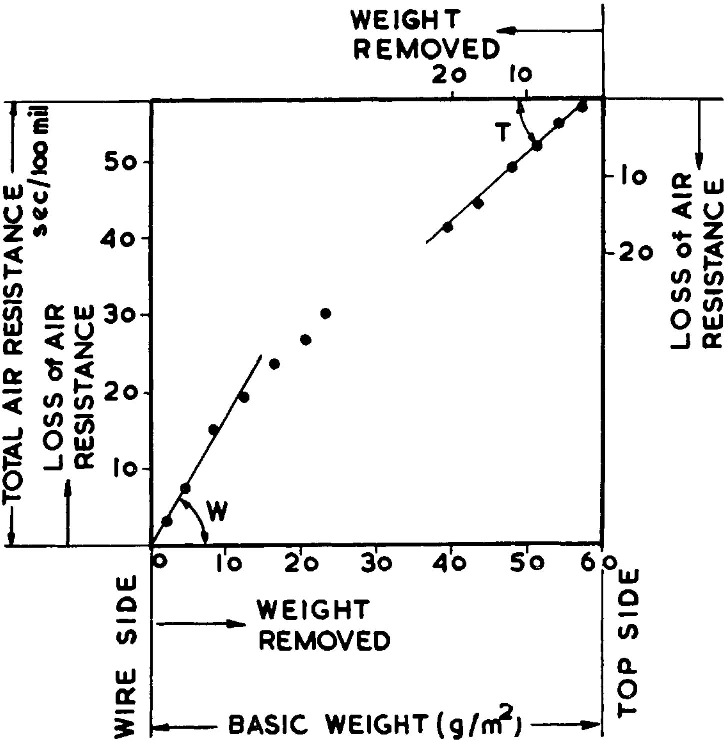

Fig. 6—Two-sidedness of a handsheet

Loss of air resistance due to peeling
Two-sidedness = tan *W*/tan *T*

approach to the problem. Variation of fines content through the sheet thickness should result in different contributions of various layers to the total air resistance.

The following procedure was adopted. On one part of the sheet, starting from the wire side, a routine of weighing, measuring the air resistance and peeling with adhesive tape was followed till imperfections of peeling produced small holes and further testing was rendered meaningless. On another part of the same sheet the same routine was carried out from the top side. The results are presented in Fig. 6.

The total height of the graph (Fig. 6) represents the total air resistance of the sheet and the total width of it represents the basis weight of the sample. For peeling from the wire side (bottom left corner), the decrease of air resistance is plotted as a function of decrease in weight. For peeling from the top side, a similar function is plotted from the top right corner. The initial slopes, starting from either side, can be determined. The ratio of the initial slope of the wire portion to that of the top portion can be used as a measure of two-sidedness of the sheet—that is, two-sidedness = tan $W/\tan T$.

Effect of fines quantity on two-sidedness

The effect of increasing or reducing the proportion of fines was the subject of a further experiment on two-sidedness. A sample of hardwood pulp, beaten to a freeness of 300 CSF, was made into handsheets and tested as described above. The two-sidedness of 2.0 was observed. The test was repeated after beating to a freeness of 145 CSF, two-sidedness increasing sharply to the value of 6.5. This well-beaten stock was then screened to remove all fines. The handsheets were found to have no two-sidedness.

The results of this experiment provide support for the concept of uniform structure of fibres within a handsheet and also show that fines, when present, become concentrated towards the wire side of a sheet formed under conditions of continuous drainage.

Transcription of Discussion

DISCUSSION

DR. F. L. HUDSON: The results in the appendix are of considerable interest to us at the Manchester College of Technology, as they are closely related to some unpublished work on colour two-sidedness done by M. Farrington in our laboratories.

The following experiment is particularly relevant. Some unbeaten bleached sulphite pulp was fractionated (with a Somerville fractionator) into four fractions and the finest fractions were dyed with Direct Sky Blue GS. Sheets containing 90 per cent long white fibres and 10 per cent dyed fines were made on the standard sheetmachine under the following four conditions—

Sheet	*Drainage procedure*	*Most colour on*
1	Normal (10 sec)	Wire side
2	¼ drain with long fibres only, mix very carefully and drain	Wire side
3	Slowly over 1½ min	Top side (slightly)
4	Stood 6½ min, then rapid drainage (10 sec)	Top side

These results can be explained only by assuming that the fines are washed most of the way through the network of long fibres and they confirm the data in the appendix. It is interesting to see that sheets 1 and 2 give the effects expected with a slow-running papermachine, but the very slowly drained sheets (in which the long fibres have had a chance to make a tighter mat) show the results to be expected on a fast-running machine, though for quite different reasons.

MR. Z. J. MAJEWSKI: I have neglected flotation and sedimentation as being insignificant in the process described. When they occur, as they do at very low rates of drainage, they lead to partial fractionation of the suspension and, subsequently, to a quite different picture of two-sidedness.

DR. S. G. MASON: In Fig. 4, you give a very systematic series of pictures of the variation in various properties through the sheet. Are these drawings based on actual experimental data or merely hypothetical?

MR. MAJEWSKI: This picture has been obtained by a combination of experiment and thought. In analysing the sheet structure of a commercially made paper, one deals with a combination of factors, each affecting the structure in its specific way. To disentangle the combination, the approach of unit processes was adopted. The effect of each unit process has been determined experimentally. Fig. 4 was obtained by combining the effects of unit processes according to their participation in a given forming process.

As an example, successive peeling, weighing and measurement of the air resistance gave results consistent with the physical nature of the process of forming a handsheet. This is described in the appendix and the same technique produced unsatisfactory results when it was applied to Fourdrinier sheets. A high degree of fibre orientation on the wire side tends to increase the air resistance there. The result is inconsistent with the described differences in freeness between the top and wire sides of the sheet. Distribution of fine material in a Fourdrinier sheet is therefore based on the rather crudely observed differences of freeness and on a critical appraisal of the process conditions. The work done by Underhay and Groen on filler distribution does not contradict the picture.

DR. O. L. FORGACS: Majewski has attempted to summarise the filler distribution across the thickness of papers made by different forming processes. In his Fig. 4, he has represented the filler content of paper made on a Fourdrinier wet end as decreasing from the top side to the wire side. It has been shown repeatedly, however, that the fines content is at a maximum on the top side of the sheet only when a dandy roll is used. In the absence of a dandy roll, the maximum filler content occurs in the body of the sheet and the filler content either remains level or, indeed, decreases towards the top side. This was clearly illustrated by Schilde,[1] Hansen[4] and more recently by Mack.[6] The results obtained by Atack and myself, which I reported yesterday, also indicated rather clearly that the top side of high speed newsprint had a lower fines content than has the middle of the sheet. I would therefore submit that the use of the word 'typical' in the description of this Fig. 4 would be justified only if a dandy roll were included in his sketch of the Fourdrinier wet end.

MR. MAJEWSKI: I referred to your work because your slides show a tendency for fibre fractions to penetrate the mat of fibres. Distribution of fines in a Fourdrinier sheet is greatly simplified in Fig. 4 in order to avoid a lengthy discussion of specific differences between machines. It represents only a trend typical of Fourdrinier machines. The maximum concentration at the top surface is definitely characteristic of the dandy roll effect that Groen discussed. In the context of my paper, dandy roll action should be considered as a unit process in its own rights.

MR. J. D. PARKER: We made some experiments similar to Hudson's, in which we formed handsheets at various rates of drainage and found a marked effect of the rate of drainage on sheet formation or large scale flocculation in the sheet. As we increased the drainage velocity from 1 in/sec to 14 in/sec, the flocs in the sheet were reduced to much smaller and more sharply defined areas. I wonder if Dr. Hudson has noticed this same effect in his experiments?

DR. HUDSON: This is a very useful suggestion and I will refer it to Farrington, from whose thesis I was quoting.

MR. W. J. WILLEMS: When a cylinder mould machine is started up with fresh pulp and fresh water, there are very few fines in the stock and the fines content then gradually increases because of the internal vat recirculation. Every cylinder mould machine operator observes that the machine runs beautifully on Monday morning for a couple of hours, then the whitewater starts coming back through the beater system and the formation suddenly deteriorates. Can you explain this, please?

What is happening when the fines reach saturation point and suddenly make their presence evident in the formation of the sheet?—and what will be the result on the sheet properties?

MR. MAJEWSKI: More fines within the stock slow down the drainage. Relatively, the load on the vats increases. At a prevailing mould head, less water will drain through the forming surface and less fibre will be deposited; more water and fibre will remain within the vat circle. In vats without overflow, this excess leads to a rapid increase of the stock levels outside the mould. This leads, on the one hand, to increased weight of the picked-up layer and, on the other hand, the weight of the formed layer increases from the temporarily reduced weight. The weight ratio of the two layers shows an increase of the picked-up layer and, because this layer is always poorly formed, the general formation is worse.

In vats with overflow, the final result is to a first approximation about the same, though the degree of deterioration and the mechanism are different. A prolonged period of reduced substance is typical of these vats. An overflow weir does not allow a rapid and substantial increase of the stock levels. The lower sheet weight temporarily produced amounts to an increase of fibre content within the overflow volume. Stock concentration within the vat system increases to increase at the new equilibrium both the weight of the picked-up layer and the flocculation throughout the sheet.

In a contraflow vat, equipped with overflow, formation does not deteriorate so much as in a uniflow vat. Probably, more effective deflocculation by the greater relative movement is the reason.