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DISTRIBUTION OF CHEMICAL WOODPULP AND GROUNDWOOD THROUGH THE THICKNESS OF NEWSPRINT

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Introduction

A PAPERMAKING furnish may be regarded as potential paper. The extent to which this potential is exploited depends upon the design and operation of the papermachine. The degree of useful utilisation of the furnish is largely determined by the orientation and distribution of the fibres and fines or filler particles in the finished sheet, both across the sheet and through its thickness. However, the structure of paper is the result of an extremely complex interplay between the intrinsic properties of a pulp and the manner in which the formation process is conducted. Consequently, the way individual components of the furnish are put together in the finished sheet is only indirectly and by no means completely under the papermaker's control. In such a situation, analysis of the structure of paper, both on a microscopic and on a bulk level, provides the most direct link between the formation process and the characteristics of the finished paper.

Recently, the study of paper structure has taken a new turn. Theoretical approaches are being explored in an effort to relate a geometrically defined arrangement of fibres to the properties of the resultant sheet.[1,2] This approach is as yet in its infancy, but already promises to be a powerful one. The theoretical formulation of paper structure requires the use of an idealised model, however, in order that the problem can be set up in a manageable mathematical form. The choice of a model must depend on a knowledge of the structure of *real* paper. The analysis of the structure of commercially produced paper is therefore indispensable not only in its own right as an evaluation tool, but also as a complement to the theoretical studies.

The present investigation deals with the structure of newsprint. It was undertaken to obtain information on the manner and sequence in which the components of the newsprint furnish are deposited on the papermachine wire, also to establish the fibrous compositions of the top and wire side surfaces of newsprint. The work forms part of a general investigation of groundwood and newsprint evaluation, aimed at predicting the behaviour of a pulp on the papermachine wire in terms of parameters of the pulp that can be measured in the laboratory.

Most newsprint furnishes consist of a variety of particle sizes. The components of a typical North American newsprint furnish, for instance, range from softwood chemical pulp fibres (some of which may be 0·3–0·4 cm in length) to groundwood fines, many of which are so small that they cannot be resolved by optical microscopy.

During the formation process on the wire, the ability of particles to be entrained by the draining water and to move through the mat is governed to a large extent by the sizes of the particles relative to the available interstices through which flow can occur. In the initial stages of drainage on the papermachine wet end, the wire acts as a sieve and long fibres interact with it and are preferentially retained. As water is progressively removed from the suspension during the drainage process and the height of the suspension over the wire decreases, the longest fibres are the first to be anchored in the forming web. The deposited web then acts as a sieve of decreasing mesh size, allowing particles of ever-decreasing size to pass through it, until the whole mat finally becomes so compacted that very little further relative movement of particles can occur. Consequently, the composition of the fibrous material (and filler, if present) at different levels through the thickness of the sheet may vary considerably.

In papers that contain inorganic filler material, the distribution of filler through the thickness of paper can be determined by estimating the ash content of shavings or microtome sections at different levels. Techniques based on the ash content have been used effectively by Schilde[3] to study the effect of vacuum couch rolls, by Hansen[4] and Mack[5] to study principally the effect of dandy rolls and by Underhay[6] to study two-sidedness. In these studies, it was shown that the filler content was lower on the wire side than in the middle of the sheet and that this effect occurs before the web reaches the suction boxes. It was found, too, that the filler content in the top side was lower than in the middle of the sheet in papers made on machines without a dandy roll.

An uneven distribution of particles of different shapes and sizes in paper is obviously not confined to inorganic filler material. Treiber, Stenius and Rehnström[7] have shown that, when dyed fines were added to a chemical pulp furnish, the top side of the paper contained more fines than the wire side. Judt,[8] who introduced long, dyed fibres into a furnish, reported that about twice as many long fibres appeared on the wire side of the paper as on the top side.

All the studies quoted above were conducted on papers made at machine speeds below 1 000 ft/min. Information on the fibre distribution across the thickness of papers made on modern high-speed machines was largely lacking, although Wood,(9) who studied wire mark in newsprint by examining

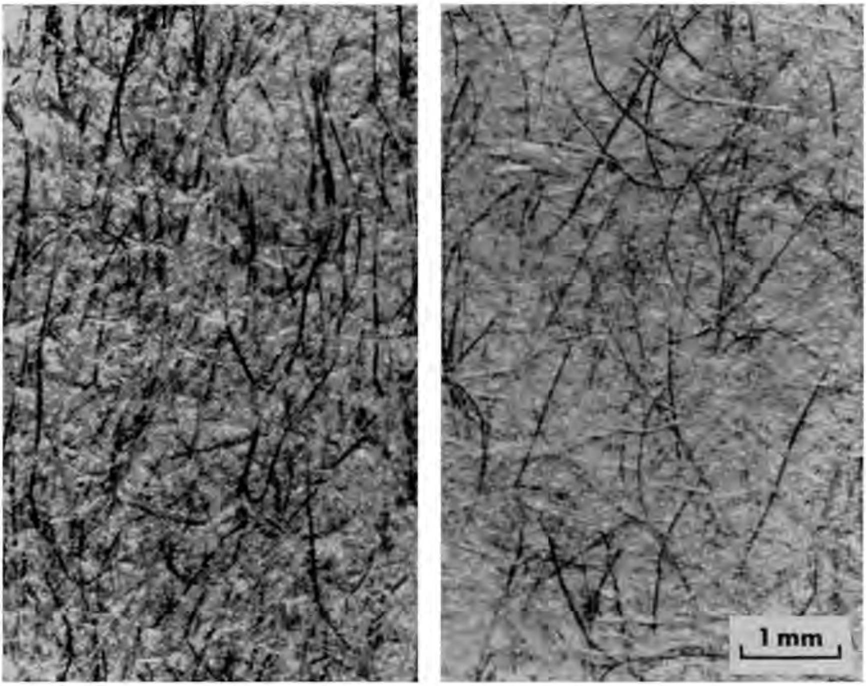

Fig. 1—Photomicrographs of the wire side (*left*) and the top side (*right*) of a newsprint sheet: the chemical pulp fibres have been stained black by soaking the paper in 10 per cent hydrochloric acid solution and drying at 105°C

Comparison of the two surfaces shows that the chemical pulp fibres are more abundant close to the wire side surface

microtome sections in the plane of the paper, pointed out a relatively high proportion of chemical pulp fibres close to the surface on the wire side. This effect can be illustrated by comparing the surfaces of newsprint in which the chemical pulp fibres have been stained preferentially (Fig. 1).

In the present study, the distribution of chemical pulp and groundwood through the thickness of various newsprint sheets was estimated quantitatively. The newsprint sheets were sectioned by means of a sliding microtome and the chemical pulp content of the sections was estimated on the basis of the different lignin content in chemical pulp and in groundwood. Laboratory handsheets prepared from a mixture of chemical and groundwood pulp were tested for comparison with the newsprint.

Finally, some observations on the nature of wire mark in newsprint are reported and are illustrated by means of scanning electron micrographs.

Materials

TEN newsprint samples were obtained from six Canadian mills. Samples of the component chemical pulp and deckered groundwood stock from which each sample of newsprint had been manufactured were also obtained. The newsprint samples chosen had been made on machines running at speeds 800–2 100 ft/min. None of the machines was fitted with a dandy roll.

Standard handsheets (basis weight 60 g/m^2), containing 28 per cent sulphite pulp and 72 per cent groundwood, were prepared and tested for comparison with the commercial newsprint.

Experimental

THE experimental technique adopted to determine the distributions of chemical pulp and groundwood through newsprint and handsheets consisted of two stages—firstly, the microtome-sectioning of the newsprint into sections parallel to the plane of the paper and, secondly, the chemical analysis of the sections.

Sectioning

The method used for preparing parallel sections of paper was based on that of Wood.[(9)]

A block of white pine with a cross-section of 4·0 cm × 1·7 cm was cut in a sliding microtome so that its surface was parallel to the microtome blade. The paper specimen was trimmed to the same size as the surface of the block and placed on the block. A few drops of a molten mixture of polythene (40 per cent) and microcrystalline wax (60 per cent) was placed on the surface of the paper. The mixture was kept molten by means of an infra-red lamp and allowed to impregnate the paper. After allowing some time for air bubbles to rise to the surface, the embedded paper was gently pressed to the block by means of a flat steel plate that had previously been heated to 105°C. The plate was removed and the specimen was allowed to cool to room temperature. Cooling was accelerated by means of a fan.

It was found that, with practice, sufficient adhesion between the block and the impregnated samples was obtained to render the use of an additional adhesive unnecessary. The microtome knife was then slid over the specimen and lowered in 2 μ increments until the surface of the paper was reached.

Three 25 μ sections were then cut. Since the caliper of newsprint is normally within 85–95 μ, this procedure left a section of 10–20 μ adhering to the block. This remaining section was rejected.

For each sample of paper tested, four pieces of paper were sectioned with the wire side of the paper upwards and four pieces with the top side upwards. Each specimen was cut into three sections, which were designated W_1, W_2, W_3 or T_1, T_2 and T_3, according to whether the sectioning was conducted from the wire side or the top side (as shown in Fig. 2).

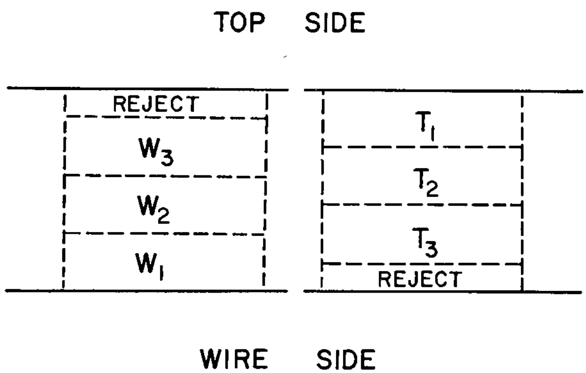

Fig. 2—Diagram showing the position designations of the microtome sections: W_1, W_2 and W_3 were cut from the wire side; T_1, T_2 and T_3 were cut from the top side

The caliper of the standard handsheets was about 165 μ. In sectioning the handsheets, it was therefore convenient to cut three 50 μ sections and to reject the 15 μ thickness remaining next to the block.

The embedding medium was completely removed from the sections by repeated washing with hot xylene and the xylene was removed by washing with acetone. Each section represented an area of 6·8 cm^2 and weighed about 10 mg, although the chemical analysis described below required a minimum dry sample weight of 15 mg. Since for each sample of paper four sections were cut from each position W_1, W_2, etc., the minimum weight requirement for the analysis could be met by conducting each analysis on a pair of sections with the same position designations. Each pair therefore represented an area of

TABLE 1

Sample No.	Average caliper, μ	Percentage	Section designations					
			W_1	T_3	W_2	T_2	W_3	T_1
1	90	Methoxyl	4·30	4·38	4·56	4·56	4·55	4·56
		Chemical pulp	17·5	15·5	11·0	11·0	11·2	11·0
2	88	Methoxyl	3·92	4·29	4·32	4·19	4·18	4·19
		Chemical pulp	28·0	19·6	18·5	21·5	22·0	21·5
3	88	Methoxyl	3·94	4·23	4·36	4·28	4·26	4·21
		Chemical pulp	29·4	22·0	18·7	20·8	21·2	22·5
4	94	Methoxyl	3·74	3·97	4·06	4·11	4·10	4·08
		Chemical pulp	32·5	26·8	25·0	23·5	23·7	24·0
5	86	Methoxyl	4·01	4·21	4·33	4·32	4·33	4·23
		Chemical pulp	29·4	24·4	21·5	21·7	21·5	23·8
6	90	Methoxyl	3·73	3·88	3·97	3·95	4·20	3·99
		Chemical pulp	26·1	22·2	20·0	20·4	17·8	19·4
7	84	Methoxyl	3·92	4·29	4·32	4·19	4·18	4·19
		Chemical pulp	28·0	24·0	18·5	21·5	22·0	21·5
8	90	Methoxyl	3·90	3·94	4·16	4·14	4·33	4·22
		Chemical pulp	33·6	32·5	26·3	29·7	24·3	27·4
9	80	Methoxyl	3·90	4·00	4·30	4·27	4·35	4·06
		Chemical pulp	27·0	25·0	18·0	19·5	17·8	23·8
10	86	Methoxyl	4·27	4·37	4·55	4·44	4·44	4·34
		Chemical pulp	19·5	17·3	12·5	15·2	15·2	17·8

newsprint or handsheet of 13·6 cm^2 and a volume of 34×10^{-3} cm^3 and 64×10^{-3} cm^3 for newsprint and handsheets, respectively.

It must be pointed out that, since newsprint is not a uniform material, some scatter in the thickness of the sections was inevitable. Serious errors in the section thickness were avoided by rejecting sections that were wedge-shaped or showed signs of severe deformation. Preliminary experiments indicated that 95 per cent confidence limits for the section thicknesses were ± 20 per cent, that is, 25 ± 5 μ for the newsprint sections. In the results presented below, the section volumes have been considered as constant. This approximation did not appreciably change the results obtained, but the scatter in section thicknesses and therefore in section volumes and weights should be borne in mind.

Analysis of sections

The principal chemical difference between chemical pulp and groundwood lies in the lignin content. A method for estimating the lignin content that could be used on a semi-microscale was therefore required. It was found that a semi-micromethod for methoxyl groups[(10)] was suitable, provided the weight of samples was over 10–15 mg.

Column A in Table 2 shows the methoxyl content expressed as a percentage of the sample weight for the ten chemical pulps, which include seven normal sulphite pulps, two sulphite/high-yield sulphite mixtures and one semi-bleached kraft. Column B shows the methoxyl contents of the corresponding groundwood pulps used to manufacture the newsprint, whose methoxyl content is given in column C.

TABLE 2

Sample No.	*Machine speed, ft/min*	*Percentage methoxyl content*			*Percentage chemical pulp*	
		Chemical pulp A	*Groundwood* B	*Whole newsprint* C	*From equation (1)* D	*Claimed by mill*
1	800	1·00	5·10	4·63	11·5	10·0
2	1 600	0·94	5·08	3·99	27·0	23·0
3	1 750	1·15	5·10	4·13	24·6	22·0
4	1 900	0·94	5·08	4·05	25·0	23·0
5	2 050	1·14	5·20	4·31	22·0	22·0
6	1 700	0·87	4·74	3·90	21·5	24·0
7	1 850	1·63[1]	5·23	3·89	26·9	24·0
8	2 000	1·53[1]	5·20	4·22	26·5	28·0
9	2 000	0·34[2]	5·22	4·13	22·3	21·0
10	2 050	1·10	5·04	4·29	19·0	17·0

[1] Normal sulphite/high yield sulphite mixture
[2] Semi-bleached kraft

All other chemical pulps were normal sulphite

The percent chemical pulp and groundwood in the whole newsprint or paper sections could then be calculated from the relationship—

$$\left.\begin{aligned}\text{Percentage chemical pulp} &= \frac{B-C}{B-A}\times 100 = D \\ \text{Percentage groundwood} &= 100-D\end{aligned}\right\} \quad . \quad . \quad . \quad (1)$$

The percentage chemical pulp calculated from equation (*1*) for the ten newsprint samples is given in column D of Table 2 and compared with the percentage chemical pulp claimed by the mills. It is shown that, with one exception, the analytical results agreed with the mill claims to ± 3 per cent.

The standard error of the section mean of two duplicate methoxyl

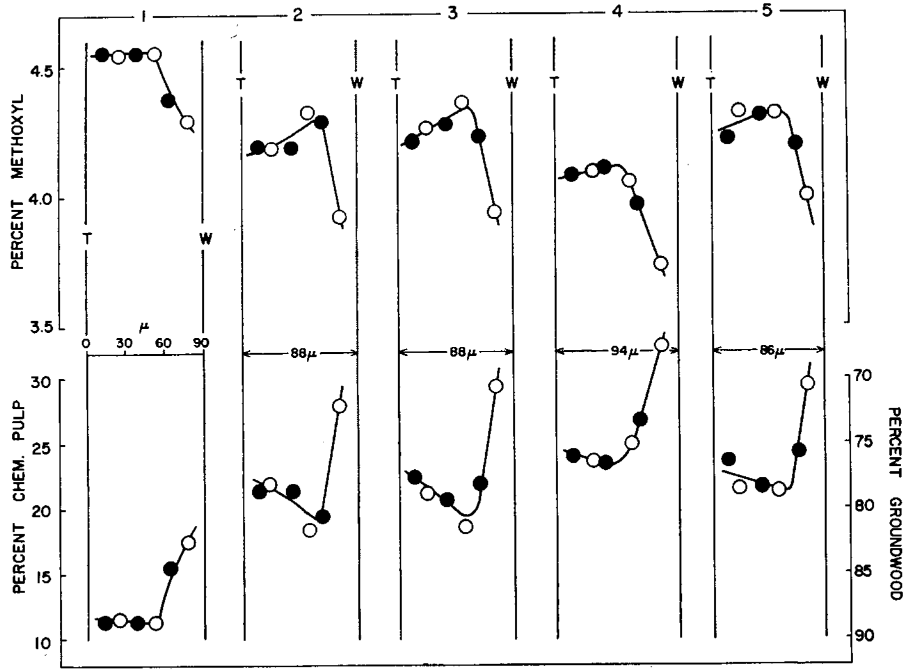

Fig. 3—Upper row: The distributions of the percentage methoxyl content per unit volume of the sections through the thickness of newsprint samples 1–5: the depth through the sheet is measured along the abscissa

The open points represent the methoxyl contents of 25 μ sections cut from the wire side, the solid points represent sections cut from the top side

Lower row: The distribution of percentage chemical pulp and groundwood per unit volume through the sheet, calculated by means of equation (*1*)

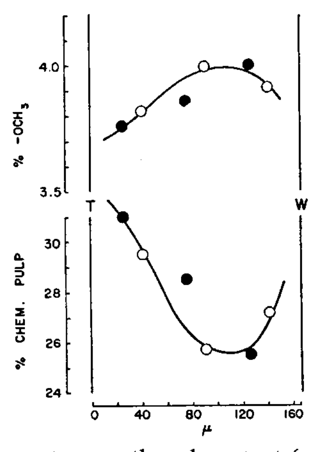

Fig. 4—Distribution of percentage methoxyl content (*upper graph*) and percentage chemical pulp (*lower graph*) across the thickness of a laboratory handsheet containing an average of 28 per cent chemical pulp

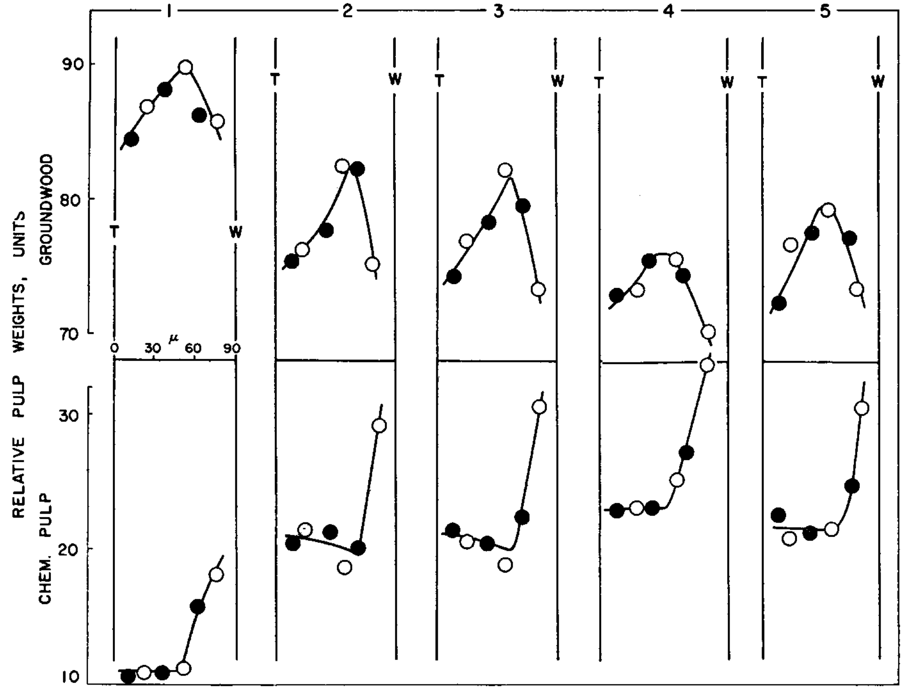

Fig. 5—Distributions of the groundwood content (*upper row*) and the chemical pulp content (*lower row*) per unit weight of the sections across newsprint samples 1–5: the groundwood and chemical pulp contents are presented in terms of arbitrary weight units and the values were calculated from the data of Fig. 3, assuming that the density decrease from the wire side to the top side is linear

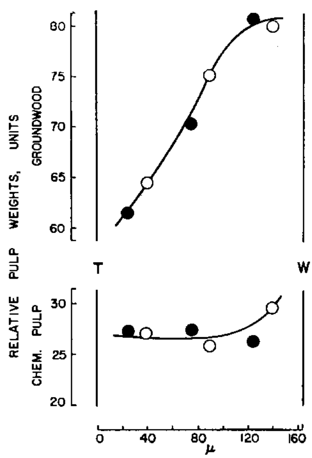

Fig. 6—Distributions of the groundwood content (*upper graph*) and the chemical pulp content (*lower graph*) per unit weight of the sections across the laboratory handsheet (as for the data in Fig. 5, a linear decrease in density from W_1 to T_1 was assumed)

determinations on newsprint sections was 0·073, corresponding to a chemical pulp content of 1·8 per cent. The 95 per cent confidence limit of the individual points in the lower graph of Fig. 4 is therefore approximately 3·6 per cent chemical pulp. The 95 per cent confidence limit of the individual points in the lower graphs of Fig. 5, in which each point is based on eight duplicate determinations, is equivalent to approximately $\pm 0{\cdot}7$ per cent chemical pulp.

It must be pointed out that the methoxyl content of groundwood 'fines' is usually slightly higher than that of groundwood 'fibres'. Preliminary experiments on sections of pure groundwood handsheets, however, showed that the difference in methoxyl content between the different groundwood fractions did not effect the validity of equation (*1*) significantly.

Results and discussion

THE upper row of graphs in Fig. 3 shows the results of methoxyl analyses of 25 μ microtome sections of the first five newsprint samples listed in Table 1. The percentage chemical pulp per unit volume through the sheets, calculated from the methoxyl data by means of equation (*1*), is shown in the lower row of graphs of Fig. 3. Each point is based on two methoxyl determinations.

Fig. 3 shows that, in each sample, the percentage of chemical pulp was about 1·4 times as high on the wire side as on the top side. The percentage chemical pulp decreased sharply over the first 30 μ from the wire side, reached a minimum near the centre of the sheet, then increased again to a slight, but nevertheless significant extent toward the top side. The analysis conducted on the additional five samples all yielded curves similar to those given in Fig. 3. This suggests that the distributions shown are characteristic of newsprint made on the Fourdrinier wet end over the speed range 800–2 100 ft/min. The complete set of results of the methoxyl analyses of the ten samples is given in the appendix.

Fig. 4 shows the average distributions of methoxyl content and percentage chemical pulp for eight standard laboratory handsheets. Again a significant increase in percentage chemical pulp towards the wire side was apparent, although this was considerably smaller than in newsprint. The increase in percentage chemical pulp towards the top side was much more pronounced however.

The results shown in Fig. 3 and 4 represent the distributions of the percentages of chemical pulp and groundwood on the basis of constant volume of the sections. In other words, they represent the ratio of chemical pulp to groundwood at different points through the sheet, but do not tell us the absolute weight distributions of the component pulps through the sheet.

In order to be able to estimate from these data the weight distributions of the constituent pulps, it is necessary to know the distributions of density through the sheets.

Although each pair of microtome sections submitted for methoxyl analysis was weighed, statistically significant density profiles could not be determined for individual samples, within the confidence limits imposed by the experimental scatter in weights.

Calculations of the average weights of sections of corresponding positions through the sheets for the ten newsprint samples and the eight handsheets, however, revealed that, both for newsprint and for handsheets, the density *decreased* significantly from the wire side towards the top side. For newsprint W_1 was about 8 per cent denser than T_1. In the laboratory handsheets, W_1 was 20 per cent denser than T_1. In the absence of precise information on how the density varied through the sheet between these two extremes, it seemed reasonable to assume as a first approximation that the decrease from wire side to top side was linear.

This approximation was then used to calculate the weight distributions of chemical pulp and groundwood. This was done for newsprint by multiplying the percentage chemical pulp in W_1 by 104/100, in T_1 by 96/100 and multiplying the values for W_2, W_3, T_2 and T_3 by intermediate fractions corresponding to their positions in the sheet. For the handsheets, W_1 was multiplied 110/100, T_1 by 90/100, etc.

The distributions of weights of groundwood and chemical pulp, represented in terms of arbitrary units of weight, are shown for the newsprint samples No. 1–5 in Fig. 5 and for the handsheets in Fig. 6.

In the newsprint, the groundwood content reached a maximum near the centre of the sheet and decreased towards both surfaces (upper row of graphs in Fig. 5). In the handsheets, however, the groundwood decreased continuously from the wire side towards the top side (upper graph, Fig. 6). Since groundwood contains about 50 per cent of 'fines' material (which will pass through a 100 mesh screen), it is reasonable to attribute the shortage of groundwood in the *wire* side of newsprint to the washing action of the table rolls on the papermachine: this does not occur on the sheetmachine.

Depletion of groundwood on the top side was apparent in both newsprint and handsheets. This result may be explained by the downward entrainment of fines by the draining water after the longer fibres in the web have been immobilised. This is, of course, common to both the sheetmachine and the Fourdrinier machine. The assumption that the shape of the groundwood distribution curve in newsprint is influenced dominantly by the removal of fines from the surface is supported by the similarity of these distribution curves and those obtained for filler content by Schilde,[3] Hansen,[4] Mack[5] and others for paper made without the use of dandy rolls.

The distribution of the weight of chemical pulp across both newsprint and handsheets showed a sharp increase in the 30 μ layer next to the wire side, but, unlike the distribution of *percentage* chemical pulp (Fig. 3), it *remained constant*, within the limitations of experimental error, across the rest of the sheets (lower curves, Fig. 5 and 6). Fig. 7 is a photomicrograph of a cross-

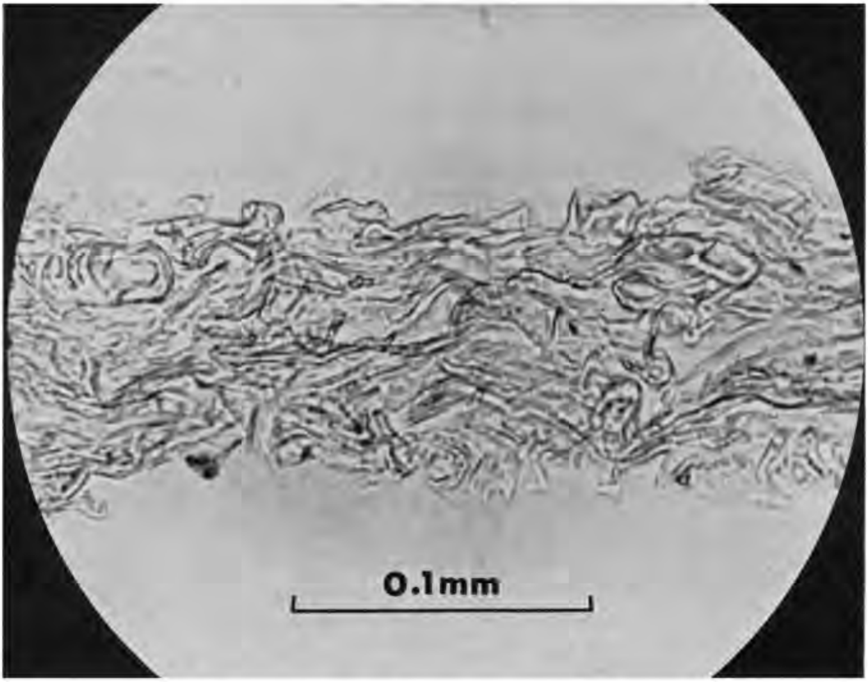

Fig. 7—Photomicrograph of a cross-section of newsprint

section of newsprint and shows that the newsprint sheet is 8–12 fibres thick. The data presented in Fig. 5 therefore suggest that preferred retention of chemical pulp fibres, that is, the long-fibre fraction in the furnish, occurred to a decreasing extent in approximately the first three layers of fibres that were deposited on the wire of the papermachine. After these first three layers had been deposited, the chemical pulp fibres remaining in the supernatant suspension were deposited in equal quantities throughout the subsequent drainage processes.

In the newsprint samples, the ratio of the weights of chemical pulp in W_1 to T_1 was about 1·4 compared with about 1·1 in the handsheets. These ratios were in fairly close agreement with ratios between the total fibre lengths of chemical fibres visible in the surfaces. Table 3 shows a comparison of the ratios W_1/T_1 obtained from the results shown in Fig. 5 with the ratios obtained by microscopic measurement(11) between the total length of stained chemical pulp fibres visible in the surfaces L_W/L_T.

TABLE 3

Sample No.	*Ratio of pulp weights* W_1/T_1	*Ratio* L_W/L_T
1	1·72	1·30
2	1·47	1·58
3	1·42	1·52
4	1·47	1·35
5	1·34	1·40
Handsheet	1·07	1·05

L_W = Total length of chemical pulp fibres per unit area in wire side surface
L_T = Total length of chemical pulp fibres per unit area in top side surface L_W and L_T were determined microscopically
W_1 and T_1 were taken from the data represented in Fig. 5 and 6

The most likely explanation of the difference in the ratios of weight of chemical pulp in the two surfaces of newsprint and handsheets is the difference in mesh sizes of the Fourdrinier wire (75 × 56 to 60 × 46) and of the sheet-machine (150). The greater the size of the spaces between the wires on the papermachine, the greater the selection of long fibres on the wire side surface. Further controlled experiments to establish the relationship between the wire mesh and the difference in long-fibre content on the wire and top sides are required. A theoretical basis for the mechanism of initial retention has recently been advanced(12) and it is believed that the present work forms a basis for the study of this problem under papermaking conditions.

Wire mark

It has been shown that the chemical pulp content of newsprint is enhanced in the 30 μ layer closest to the wire side. Wood(9) and Wrist(13) and the present authors have observed, however, that the raised portion of the wiremark pattern consists mainly of short groundwood fibres.

In the course of the present work, microscopic examination of newsprint surfaces in which the chemical fibres had been stained preferentially confirmed this observation. Furthermore, it was noticed that the long chemical pulp fibres that occur abundantly in the surface, span the wiremark pattern and tend to lie flat in the plane of the sheet.

The raised portion of the wire mark consisted mainly of short groundwood particles, which frequently stuck out through the long fibre layer.

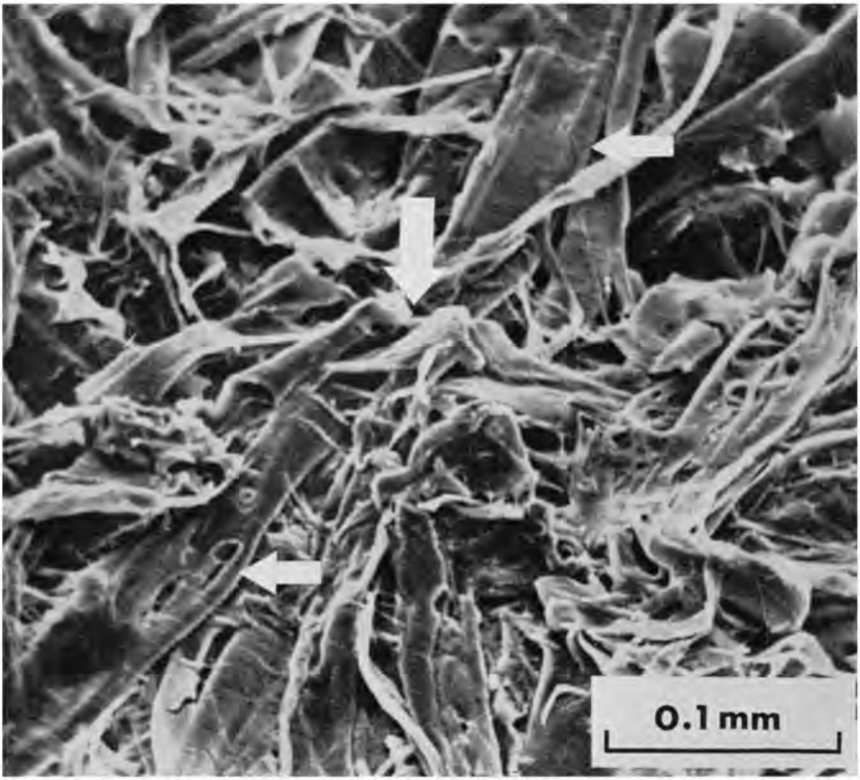

Fig. 8—Scanning electron micrograph of a newsprint surface: the centre of the field shows a raised portion of the wiremark pattern (large arrow), which consists mainly of short groundwood particles that accumulated in the wire openings on the machine wire and were later flattened by pressing and calendering

Notice the long fibre that appears to tunnel through the fibre mound (small arrows)

Fig. 8 is a scanning electron micrograph of a newsprint surface, which shows one of the raised portions of the wire mark in the centre of the field. Notice the long fibres, which tunnel through the raised spot. Fig. 9 is an electron micrograph of the surface of a pulp pad made of newsprint stock that had been drained under pressure in a sheetmachine fitted with a papermachine wire. An example of a raised portion of the wire mark in the unpressed surface is shown. A number of short groundwood fibres can be seen to protrude, forming an almost conical bundle.

It appears therefore that the long fibres that are laid down on the wire first do not contribute greatly to the wire mark, but tend to span the wire

Fig. 9—Raised mound of fibres on the wire side of an unpressed pulp pad made on a sheetmachine fitted with a Fourdrinier wire

mesh. After the initial layer of long fibres has formed, short stiff particles consisting mainly of groundwood are drawn end first into the spaces between the wire strands and are wedged there, in conical or ridge-shaped bundles. During pressing and calendering, these bundles tend to be flattened out, until they appear as a series of small mounds or ridges like the one shown in Fig. 8.

Summary

It has been shown that the percentage of chemical pulp per unit volume through the thickness of newsprint sheets made in the speed range 800–2 100 ft/min is highest close to the wire side, decreases sharply towards the centre of the sheet, then increases again slightly towards the top side. These trends were similar for the ten newsprint samples tested.

The chemical pulp content per unit weight through the newsprint, calculated by assuming a linear decrease in density from the wire to the top side, was significantly higher in the 30 μ layer next to the wire side than in the rest of the sheet, in which it was approximately constant. The higher chemical pulp content on the wire side, which occurred in the first three layers of fibres formed on the wire, was attributed to the preferred initial retention of long fibres. The groundwood content through the thickness of newsprint was at a maximum near the centre of the sheet and decreased towards the wire side and towards the top side. This distribution was attributed to the removal of fines by respectively (*1*) the washing out of fines material from the wire side of the mat during the passage of the wire over the table rolls and (*2*) the entrainment of fines by water draining downwards after the long fibres in the furnish had been immobilised. In laboratory handsheets made of mixed stock, the chemical pulp content also was enhanced on the wire side, but to a lesser extent than in newsprint. It is postulated that the wire mesh size plays an important role in determining the relative increase in the quantity of long fibres on the wire side. The handsheets showed a continuous decrease in groundwood content from the wire to the top side, which may again be attributed to the downward entrainment of fines material.

It was observed that the raised portion of the wiremark pattern in newsprint consisted chiefly of short groundwood fibres, which had been drawn through the initial layer of long fibres and had wedged there. Electron micrographs to illustrate this effect are presented.

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13. Wrist, P. E., this vol., 839

Appendix

SUMMARY of methoxyl determinations and the percentage chemical pulp in 25 μ sections for ten samples of newsprint.

The percentage chemical pulp was derived from the methoxyl contents of the individual sections and of the constituent pulps (*see* Table 2) by means of equation (*1*).

DISCUSSION

MR. G. F. UNDERHAY: You have said that the theory of water washing by table rolls has been disproved, but I feel that, having omitted the investigation of low speeds, which you say you could not get on your papermachine, you have overlooked important evidence. A speed of 80 ft/min, for example, on a Fourdrinier machine with plain table rolls will provide a sheet of paper that is practically non-two-sided, even if it contains 5–10 per cent of china clay loading. The total losses through the wire in these circumstances are 10–15 per cent. On the other hand, a modern machine operating at speeds well over 2 000 ft/min such as one recently investigated at our Tennessee mills, equipped substantially with plain table rolls and with no loading, normally loses 55–60 per cent and composition two-sidedness is in evidence. The same machine, when completely equipped experimentally with scrapers (foils), gave total losses of only 20 per cent and composition two-sidedness was no longer evident. The improvement, in my opinion, was due to the absence of the washing of the under side of the sheet.

I would like to congratulate you on being able to divide your sheet into 15 thicknesses. You must have developed an excellent technique to enable such a degree of subdivision to be possible.

DR. L. J. GROEN: I would refer you to Fig. 8. Below 100 m/min, the filler capacity of the extreme wire side layer increases and the '5 per cent rule' is obviously no longer obeyed.

THE CHAIRMAN: Before going on to other aspects of what Dr. Groen has said, would anyone like to talk directly on this controversial question of washing up from the bottom or draining from the top?

MR. P. E. WRIST: We have gathered quite a considerable amount of experimental evidence on this subject and the results confirm that the profiles on machines with foils remain the same, although the filler retention may improve by up to 50 per cent.

DR. O. J. KALLMES: As this symposium is on the structure of paper, have you made any attempt to determine the effect of density on the sheet?

DR. GROEN: No. We have investigated samples of all possible fibre composition. All densities will have been present and such differences seem to have had no effect.

THE CHAIRMAN: In that connection, we will hear a special contribution later this afternoon that will deal with changes in fibre composition of a mixture going from top to wire side.

MR. P. G. SUSSMAN: I have carried out some experiments on the question of loss of filler during drainage that may be of interest. Sheets were made from newsprint breastbox stock of 0·8 per cent consistency, forcibly draining the sheet at high speed. This stock was completely enclosed in a cylindrical cell, 9 cm diameter, closed at one end by a tightly sealed, movable piston, the other end consisting of a normal 60×48 mesh newsprint wire, strongly supported by a drilled brass plate.

The piston was 1 cm distance from the wire. When the piston was pushed down in a measured time of 0·06 sec, the ash of the sheet made in this manner was 14 per cent, while the ash of the newsprint made on the Fourdrinier machine at 1 800 ft/min was 7·5 per cent.

MR. J. MARDON: In the past, I have operated model equipment making paper at high speeds without any table rolls. It is very clear that the washing action from table rolls is present, because it keeps the water to the top of the paper and the dry line exists at the flatboxes when table rolls are used, whereas 18 in is enough for the dry line to appear, without using table rolls. I would concur with Mr. Underhay's figure that, with newsprint running at 2 300 ft/min, the amount going through the wire would be 45 or 50 per cent on an ordinary machine. I can say that, on a special piece of equipment, it can be brought down to around 12 per cent.

DR. GROEN: I should like to point out that there is no relation between retention and the distribution in the final sheet. To talk about retention is different from talking about any final distribution or any final filler content on any side of the sheet whatsoever. As we proved in many cases, a change in retention will not cause a change in distribution, although papermakers usually expect the contrary.

DR. J. GRANT: Was there complete backwater circulation in these experiments?

DR. GROEN: We have investigated about 15 machines, most of which had complete backwater circulation.

MR. UNDERHAY: May I go back to one point and ask whether you have managed to reproduce in the laboratory the sort of two-sidedness that occurs on fast papermachines by using suction alone? In the work with which I was concerned some years ago, it was because of our inability to make, on an ordinary sheetmachine, paper having anything like the same degree of two-sidedness as that which occurs on a commercial newsprint machine, despite the application of additional vacuum of up to 25 in mercury, that we concluded some mechanical or hydraulic effect from the table rolls must be responsible for the exceptional losses of fines on the under side. I think the observations that Mr. Sussman has just made confirm my views in this regard; incidentally, I must make it clear that, in the experiments I am talking about, the sheets were examined by subdividing them into four layers, not into the 15 or so that were mentioned.

DR. GROEN: Of course, I have studied Underhay's work. I have not tried to compete with his investigations in the laboratory, because they were done excellently. We merely tried some experiments in the laboratory that provided us with the results in Fig. 10.

PROF. B. STEENBERG: The fines content in a sheet formed by a continuous or an intermittent drainage process should be different. The intermittent drainage process produces a sheet with fewer fines in the wire side for the following reasons.

The viscous drag on the pulp mat during drainage compresses the mat elastically. Fines are trapped in this compressed sheet, but are released when there is no pressure drop over the sheet. At the start of another drainage cycle, some of these fines will pass into the whitewater. This release of fines from a sheet at the start of intermittent drainage cycles can easily be observed in transparent sheetmachines, provided the pressure drop over the sheet during drainage is sufficiently high. Washing of the wire side by table roll water may therefore not be the only reason for two-sidedness.

THE CHAIRMAN: Do you object to that?

MR. UNDERHAY: No, I will think about it.

MR. C. R. G. MAYNARD: Can you say anything about the effect of pressing on filler distribution and structure in paper? Straight pressing reduces the oil permeability of the wire side to top side more than from the top side to the wire side. It appears that pressing may alter the distribution of filler or fines or the basic sheet structure.

DR. GROEN: I think there is no redistribution of material after the paper web leaves the wire—not to a measurable extent, anyhow. It is true that printing on the top side gives a quite different result in oil penetration from that on the wire side.

MR. L. NORDMAN: We have carried out laboratory experiments on the effect of suction on the two-sidedness as judged by fines content on both sides of the paper and by oil penetration tests, but we found no great effect by the suction when the dry solids content of the sheet subjected to suction was about 7 per cent.

PROF. J. D'A. CLARK: The distribution of filler is probably caused by the relatively greater flow of water vertically through the under side while the fibres are in motion.

MR. D. ATTWOOD: Beta-ray photographs show that variation in basis weight corresponding to the wire mark amounts to some ± 20 per cent, so that in a 50 g/m^2 sheet the substance caries 40–60 g/m^2 on wire mark scale. Random variations are of the same magnitude so that it is not possible to think of paper as a flatsided sheet when considering drainage. Could it not be that in your splitting technique, especially in the calendering process, your first application of adhesive tape picks up fibre from the hollows of the paper, which is in fact the middle of the sheet? This could lead to an error in what you attribute to the wire side layer.

DR. GROEN: Supercalendered paper strips more easily and wire mark can often be seen 30 or 40 per cent within the sheet, though no fibres were removed from the middle of the sheet by the adhesive tape technique. No difference was found with a variety of papers.

One per cent layers probably do not contain any filler at all; however, it is necessary to have a final wire side layer of about 5 per cent.

MR. WRIST: I can confirm that, when you strip the wire side of uncalendered paper, the first two or three layers peeled off are just wire marks—it is like a lace curtain—nothing is picked out from the bottom. I agree that the same kind of distribution exists in calendered and uncalendered paper.

I suggest that this value of 5 per cent on the wire side is probably influenced by the wire mesh being used. Work has shown the initial retention to be the function of the ratio of the fibre size to the opening in the grid. Fine paper makers use this fact when they want high retention and less two-sidedness.

Another technique also is used, not so far mentioned. In certain cases, the filler is deliberately precipitated with adhesive systems on to the fibre before reaching the wire to give much higher retentions. Such papers reach 80 per cent ash content. They are usually made on very slow machines.

THE CHAIRMAN: Before proceeding with a general discussion of this paper, we will hear a contribution by Forgacs and Atack.

DR. A. B. TRUMAN: It is well known that the presence of chemical pulp fibres on the surface of newsprint is detrimental to the printability of the sheet. Has Forgacs thought of correlating his results with the amount of ink picked up by the paper?

DR. O. L. FORGACS: We have not, so far, attempted to relate the chemical pulp content in the surfaces of newsprint with printability. No doubt the method I have described could be of use in seeking this relationship. However, many variables influence the printability of newsprint.

It seems unlikely that one could isolate the effect on the fibrous composition of the surface, unless the papers to be studied are made under carefully controlled conditions. It would be of great value to have a laboratory instrument capable of making paper of the same structure as high speed newsprint. Obviously, the standard sheetmachine is not good enough for this purpose. We are therefore using the data on newsprint structure as a guide towards the design of a method of making more realistic paper sheets in the laboratory.

MR. J. G. MACNAUGHTON: This contribution is concerned with the possible interpretation of data collected during experiments on loading retention at the Research Association laboratories, Kenley. The retention of loading was investigated when sheets of different basis weight were formed. These sheets were formed also from different pulp consistencies. The retention per unit fibre weight was calculated for each sheet formed and an increase found with basis weight increment and lower formation consistency. This effect was more closely studied by calculating the ratio of incremental ash to incremental fibre weight and plotting this against fibre weight as in Fig. D16. In this way, an apparent loading distribution is shown that indicates higher levels of retention at the top side. This apparent distribution is more marked at lower formation consistencies.

Fig. D17 illustrates the volumetric flow rates during the laying down of the several increments of fibre weight and shows that the occurrence of high ash to fibre incremental ratio is related to lower volumetric flow rate. There is also a time effect, since a longer drainage time is necessary at different con-

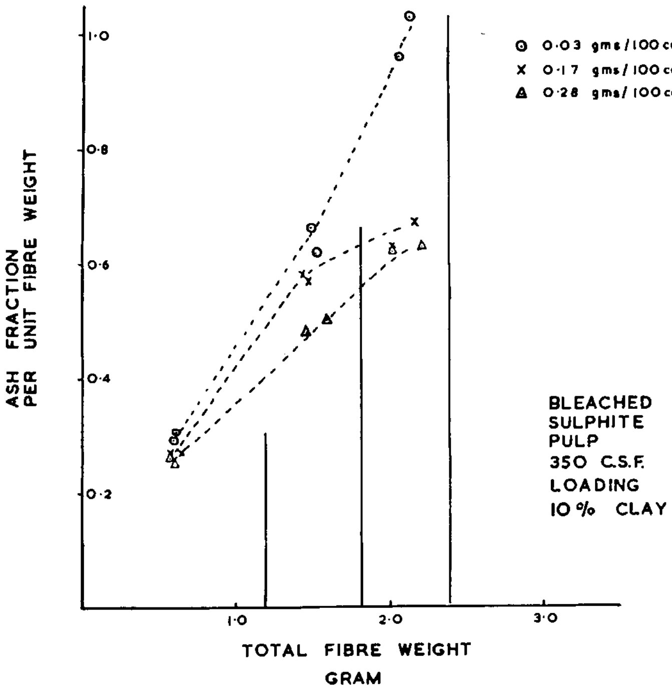

Fig. D16—Loading distribution at different formation consistency

sistencies to lay down the same fibre weight. Hence, sheets formed at a lower consistency could be more compacted through longer subjection to filtration pressure. It is possible, too, that the original dispersion at lower consistencies would be less flocculated, but that during the drainage time flocculation would develop and lead to a less compact structure on the top side of the forming sheet.

A mechanism that links this study of apparent retention effect to the found loading distribution type of curve must consider transport of loading through the forming sheet. The initial building up of a fibre mat leads to the progressive reduction in pore size and a more complex porous path through the sheet. Both these factors reduce the probability of filler loss through the wire side, but the delivery of filler from the upper layers is not decreased, hence a build-up of filler in the interior of the forming sheet could be postulated. This should be greater for the lower consistency pulps, for which fibre

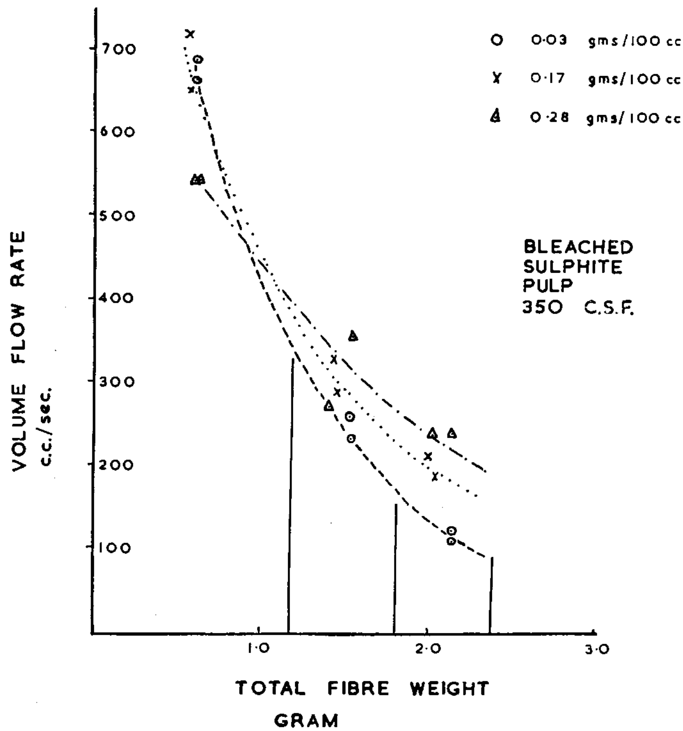

Fig. D17—Variation of flow rate during sheet formation

structure would be more compact than the more flocculated higher consistency pulps and increasing pulp flocculation would allow more transport from the upper layers. It will be interesting to check these thoughts experimentally.

The possibility of filler/fibre adsorption cannot be completely discounted, since it could account for an even distribution throughout the sheet with the transport of unadsorbed filler causing the filler distribution curve. The degree of curvature of the distribution would then be independent of the fibre/filler adsorption, hence only a general increase in level of retention would occur with additives present as has been previously found.

DR. GROEN: My first remark is that I have learned to reject any experiment that tries to relate sheetmachine results to filler distribution as found in practice, because sheetmachine experiments give no information of what happens on the majority of machines. I once tried to predict the distribution in a thick sheetmachine sheet by adding the amounts of loading in different layers formed separately on a sheetmachine, but the final distribution was completely different from the 'theoretical' one.

I regard as proof of transport the occurrence of a maximum amount of filler in the middle of the paper and the relatively low filler content of the top side of uniflow mould paper. Since the filler concentration at the outlet is higher than at the inlet, one would expect a different result if no transport occurred.

DR. GRANT: The removal of water from both sides of the sheet at once already exists in the Inverform process.

MR. ATTWOOD: What is Forgacs' definition of density? As I pointed out in discussing Groen's paper, when referring to drainage, the sheet must be considered as a three-dimensional structure, not two-dimensional.

DR. FORGACS: The density profile we considered was based on about 20 microtome sections corresponding to each position in the sheet. This covers an area of about 140 cm^2. Local fluctuations in basis weight because of wire mark are therefore averaged out.

DR. KALLMES: Do you know if there is a relationship between the number of layers peeled off and the number of table rolls on the papermachine?

DR. GROEN: I do not think so. We start mostly at the top side and the first layer peeled off is within 10–40 per cent of the basis weight.

PROF. CLARK: Do I understand that you split the first strip again and again to get it thin enough?

DR. GROEN: Yes.

DR. TRUMAN: Have you paid attention to the angle at which the adhesive tape was peeled from the surface? If the angle was allowed to vary, particularly during one peeling operation, the thicknesses of fibres removed would not be constant.

DR. GROEN: The angle was within 10°–30°.

DR. J. F. SMITH: Do you consider that your theory of sedimentation fits the following facts—

1. Analysis of whitewater from table rolls next to suction boxes shows a higher ratio of clay to fibre than do whitewater samples from the other rolls.

2. The wire side of a newsprint sheet shows a relatively high ratio of chemical to mechanical fibres?

DR. GROEN: So far as I know, the amount of clay is constant in the backwater coming from different table rolls. Figures for fibre/filler ratios are given in the literature.[1] The theory as put forward in my paper does not attempt to explain this.

PROF. A. H. NISSAN: May I make a general concluding comment? I wish to announce a new natural law, *The evolutionary pattern of theories.* When a new theory comes out, the criticism is made that no one has said it before, therefore it cannot be true. This is stage 1. The author then accumulates evidence that cannot be contraverted and people say, 'This is luck.' This is stage 2. Then the poor author works harder and produces more and more evidence until there is no way out, you have to believe it. People say, 'A hundred years ago, so-and-so said it.' This is stage 3.

I congratulate friend Steenberg on his performance. It took the hydrogen bond six years to reach stage 2, it took him six seconds to reach stage 3. Now you are telling him the theory must be right, because you told him as soon as he announced it that someone had said it before. This, to me, is clear evidence that the theory must have grounds for some probability of being correct, as everybody has agreed that it has honourable lineage.

[1] Bennett, W. E., *Tappi*, 1954, **37** (11), 534–541

Written contribution

DR. J. F. SMITH: Drainage on a laboratory sheetmachine results in the wire side of the sheet containing more clay than the top side, owing in all probability to the faster rate of drainage of the denser clay particles. This distribution cannot be altered by applying a vacuum of any degree, but the clay and fine fibres can be removed from the wire side by 'hosing' the wire gently from below, giving a two-sided effect comparable to a mill-made sheet.

This normal distribution would happen also on a papermachine, if the clay and fine fibres were not washed out by the table roll action almost as soon as they were laid down.

The effect is increased, of course, as the machine speed is increased, owing to larger volumes of whitewater entering the nip, accompanied by higher vacuums applied to the wire immediately following this.