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FUNDAMENTAL ASPECTS OF FILLER DISTRIBUTION IN PAPER

L. J. GROEN

CENTRAAL LABORATORIUM,
KONINKLIJKE PAPIERFABRIEKEN VAN GELDER ZONEN N.V., VELSEN, HOLLAND

Synopsis

An effective and simple method for sectioning paper was developed that enabled determination of the distribution of filler in a large number of papers. Attention was concentrated on papers made on Fourdrinier machines, but, to obtain a complete picture of filler distribution, handsheets and papers made on cylinder machines were also investigated. From the resulting filler distribution curves, it appeared that handsheets and cylinder-made papers have a comparable filler distribution, which is the reverse of that of Fourdrinier-made and handmade papers.

It is generally supposed that the filler in Fourdrinier-made papers is concentrated in the top layer, whilst much less filler is present on the wire side. This was confirmed in our investigations. It even turned out that the filler content of a 10 per cent wire side layer is almost constant and depends only in the degree of beating and to some extent on the total amount of filler in the paper. This suggests the filler capacity of the extreme wire side layer to be the determining factor.

Furthermore, the influence was investigated of filler retention, type of filler (particle size), fibre composition, filler content, machine speed, dandy roll and open table rolls on filler distribution. From this, some general rules about the distribution of filler in paper were derived: it is determined by machine speed, total filler content and filler capacity of the extreme wire side layer. The filler distribution in the top layers of a Fourdrinier-made paper is affected also by the dandy roll and probably by the retention of the filler.

This general picture of filler distribution, together with the results of laboratory and mill experiments, gave rise to a theory of the causes of the observed phenomena. This theory states that self-filtration (drainage) of the three-phase system water/fibre/filler results in a heterogeneous distribution of filler particles in the fibre mat, having the same character as in Fourdrinier-made paper. It is concluded, therefore, that the uneven distribution is already present in the first stage of drainage and is strongly intensified by the extreme drainage conditions.

Quelques aspects fondamentaux de la répartition de la charge dans le papier

L'auteur a mis au point une méthode simple et efficace pour délaminer le papier. Il a pu ainsi déterminer la répartition de la charge dans un grand nombre de papiers. La plupart étaient fabriqués sur machines à table plate, mais, pour compléter l'étude, des papiers faits sur formette et sur machines à forme ronde ont également été examinés.

D' après les graphiques de distribution de charge obtenus de cette étude, les feuilles faites sur formette et sur forme ronde révèlent des répartitions de charge semblables, qui sont l'inverse de celles trouvées dans les feuilles faites à la forme et sur table plate.

On suppose en général que la charge dans les papiers faits sur table plate se concentre dans la couche supérieure, tandis qu'il y en a beaucoup moins sur le côté toile. Les essais de l'auteur le prouvent. On a même trouvé que la teneur en charge d'une couche du côté toile représentant le dixième de l'épaisseur totale est presque constante et ne dépend que du degré de raffinage et, dans une certaine mesure, de la teneur totale en charge. Ceci laisse supposer que la capacité de rétention par la couche de surface du côté toile serait un facteur essentiel. De plus, l'auteur étudie l'influence sur la répartition de la charge, de la rétention de la charge, du type de charge et la dimension de ses particules, de la composition de la fibre, de la teneur en charge, de la vitesse de la machine, du rouleau égoutteur et des pontuseaux ouverts. Cette étude permet de déduire quelques règles générales sur la répartition de la charge dans le papier. Cette dernière dépend de la vitesse de la machine, de la teneur totale en charge et de la capacité de la couche du côté toile. Sur une machine à table plate, la répartition dans les premières couches du côté feutre, est modifiée par le rouleau égoutteur et probablement par la quantité de charge retenue.

Cette vue d'ensemble, ajoutée aux résultats d'essais tant à l'echelle industrielle qu'au laboratoire, ont permis d'établir une théorie de l'origine des effets observés. D'après cette théorie, la filtration naturelle d'un système triple eau/fibre/charge provoque une distribution hétérogène des particles de charge dans le matelas de fibres ayant le même caractère de la distribution dans un papier fait sur table plate. On peut donc en conclure que la répartition inégale existe dès le début de l'égouttage et se trouve fortement intensifiée par un égouttage forcé.

Einige fundamentale Betrachtungen über die Füllstoffverteilung im Papier

Mit Hilfe einer einfachen, wirkungsvollen Methode konnte die Füllstoffverteilung für eine grosse Anzahl von Papieren bestimmt werden, die auf dem Langsieb, auf dem Rundsieb und auf dem Blattbildner gefertigt worden waren. Die Füllstoffverteilungskurven waren für Laborblätter und Papier von Rundsiebmaschinen ähnlich und genau das Gegenteil von denen für Langsiebpapiere. Hier hat der Füllstoffgehalt in der obersten Schicht seine höchste Konzentration und ist wesentlich geringer auf der Siebseite, wobei jedoch die untersten 10% der Blattstärke fast konstante Werte aufweisen und der Füllstoffgehalt nur von Mahlgrad und Gesamtfüllstoffgehalt abhängt. Damit ist die Füllstoffaufnahme auf der äussersten Siebseite von grosser Bedeutung. Für diese Füllstoffaufnahmefähigkeit sowie für den Einfluss von Maschinengeschwindigkeit und gesamtem Füllstoffgehalt auf die Füllstoffverteilung konnten einige allgemeine Regeln aufgestellt und die Wirkung des Egoutteurs auf die Oberseite und wahrscheinlich auch auf die Füllstoffretention nachgewiesen werden. Danach ist die Selbstfiltration (Entwässerung) des 3-Phasen-Systems Wasser/Faser/Füllstoff die Folge einer heterogenen Verteilung der Füllstoffteilchen innerhalb des Faservlieses, so dass Schwankungen der Verteilung bereits während der ersten Entwässerungsphase auftreten und durch extreme Entwässerungsbedingungen wesentlich verstärkt werden.

Introduction

IT has been known for about 40 years that in loaded paper the filler particles are unevenly distributed throughout the sheet. It is generally assumed, particularly after the work of Schilde,[1] that the filler content on the top side of Fourdrinier-made paper is higher than on the wire side. As will be made clear in the next section, our knowledge of filler distribution in paper is limited, not about the existence of a definite uneven distribution, but about the factors causing this distribution. The phenomenon of uneven filler distribution is clearly visible in the case of highly filled, coloured papers and in paper containing a large amount of unbleached chemical and/or mechanical pulp. It is regarded as one of the causes of the so-called visible two-sidedness. White papers generally have only a small degree of visible two-sidedness, which however has no connection with a possible uneven filler distribution. We, therefore, felt it necessary to leave the conception of visible or measurable two-sidedness and to concentrate our efforts on the distribution of filler throughout a sheet. To make the scope of our investigations as broad as possible, it was decided to examine different grades of paper, produced on different machines and machine-types and to include handsheets.

The objects of the following study of the phenomena of filler distribution have been threefold —

1. To investigate the effect of machine conditions and stock and paper composition on the final distribution of the filler.

2. To derive general rules governing filler distribution.

3. To gain information about the behaviour of fine material during sheet formation.

To achieve these aims, the filler distribution in about 60 different papers was determined by a method that will be described later. Most of the samples studied were obtained from the normal production of nine Fourdrinier machines, ranging in speed 100–400 m/min and from two mould machines. In some cases, special runs were made to obtain samples of predetermined, but uncommon composition. Papers chosen were made from bleached and unbleached pulp and containing 0–70 per cent groundwood. The filler content varied 8–30 per cent. Different grades of china clay, talc and anhydrous gypsum were used as fillers. For comparative purposes, filled sheets from a standard sheetmachine and laboratory handmade paper were investigated. Paper from midget Fourdrinier machines also was investigated.

Of course, the use of samples of normal grades produced under normal conditions restricts the possible variations in machine conditions and in stock and paper composition. This, however, was not found to be objectionable and, on the contrary, had the advantage that all results have a direct practical meaning.

Previous investigations

THE distribution of filler in paper has been investigated since 1920, when Albrecht[2] determined the filler content in two halves of a paper for the first time. He found the highest filler concentration on the wire side. Between 1921 and 1930, several German investigators determined the filler contents in two sheet halves. Their results deviate from each other, some indicating a higher filler content on the felt side, some on the wire side. No general picture was obtained until 1930, when Schilde[1] determined, in about the same way, rough filler distribution for 76 grades of paper. He stated that, in nearly all cases, the wire side contained less filler than the felt side. By introducing a two-sidedness factor, being the quotient of the filler content on the felt side and that on the wire side, he converted his results into one figure for every grade of paper. Schilde concluded that the two-sidedness, as indicated by the two-sidedness factor, diminishes with increasing basis weight and sizing, but increases when groundwood content, filler content and speed are increased. The results of Schilde were confirmed later by Schütz.[3]

Very important work was done by Hansen,[4] who published complete filler distribution curves for the first time and investigated the effect of some machine and stock variables. The distribution curves are typically shaped and indicate a large difference in filler content between extreme top side and extreme wire side. The final distribution of the filler is not affected by filler retention and degree of beating. Increase of basis weight causes the horizontal middle part of the distribution curve to extend. The shape of the curve is changed somewhat when machine speed is altered or when consistency is increased. According to Hansen, the use of a dandy roll might result in an increase of the filler content on the top side. He finally concludes that an uneven filler distribution is present even in the first stages of sheet formation and thus indissolubly connected with the principle of papermaking on Fourdrinier machines.

Distribution curves are also published by Pritchard,[5] who observed that substance and degree of beating probably play a noteworthy rôle in the building up of the final filler distribution. From investigations of samples from different stages of a Fourdrinier machine, she concludes that the uneven distribution is imparted in the wet end.

The contribution of Mack[6] to the filler distribution phenomena is mainly related to the effect of the dandy roll. These results, obtained from a midget Fourdrinier machine and from low and medium speed production machines, fully confirm the results of Hansen in this respect. According to Mack, the suction boxes cause the filler content on the wire side to decrease.

From this survey of previous investigations, it turns out that the general aspects of the uneven distribution of filler have been well known since the time when techniques for obtaining complete filler distribution curves were developed. It might be clear without further explanation that the relation between filler content of an extreme felt side and filler content of an extreme wire side is insufficient to characterise the distribution of filler.

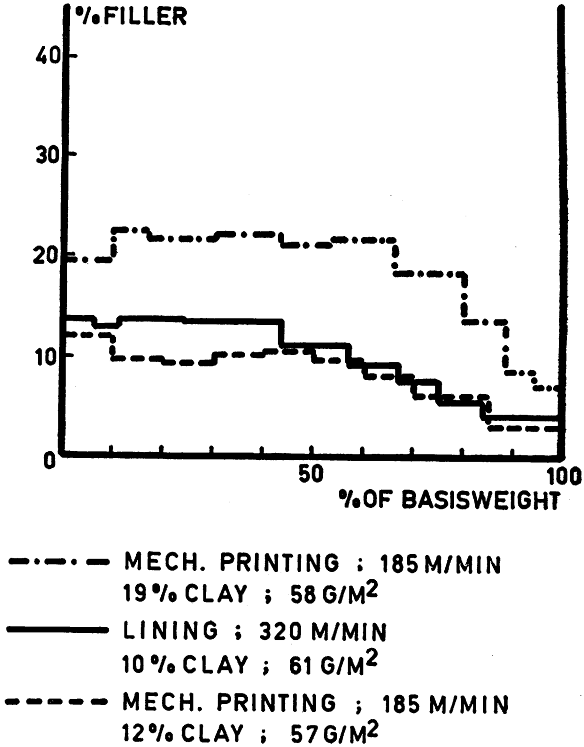


Fig. 1

The investigations performed hitherto have already partially disclosed the effect of some variables on the final filler distribution, but have not led to a complete picture of the influence of different factors operating in the papermaking process. An evaluation of these influences may enable us to give general characteristics of the phenomena of uneven filler distribution. The investigations described all resulted in the view that the distribution is imparted at the wet end of a Fourdrinier machine and is indissolubly connected with the papermaking process. As will be shown in the final section, different investigators do not agree about the real causes of the uneven distribution. An answer to this question might be of help in the study of sheet formation and drainage.

Determination of filler distribution curves

In order to obtain a filler distribution curve, it is necessary to divide a sheet of paper into a number of thin layers of definite weight or thickness.

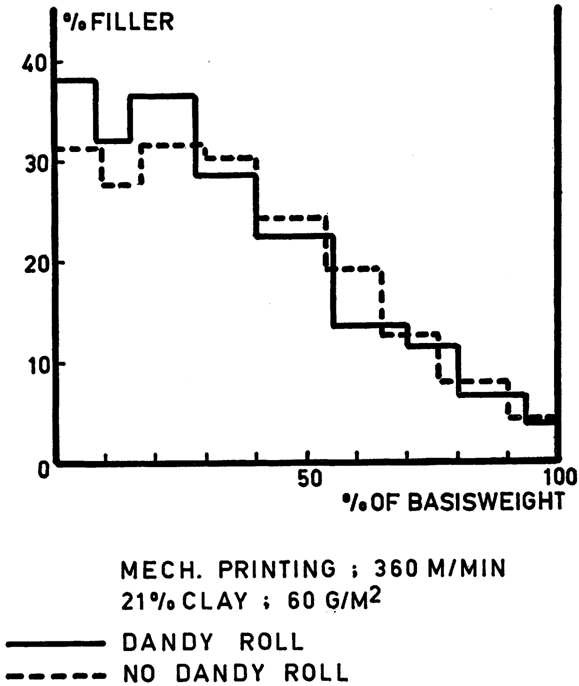


Fig. 2

The investigators previously mentioned have used several methods for this purpose. Schilde[1] scratched off layers with a razor blade. Schütz[3] and Hansen[4] made use of abrasive paper, whereas Pritchard[5] applied adhesive tape. Mack[6] and Browning and Isenberg[7] cut off very thin layers using a microtome.

In our experiments, a modification of Pritchard's method was used.

This enabled us to divide a sample of paper into 10–15 layers without disrupting their structure. Maintenance of such thin layers can be useful for other purposes such as structural investigations. The procedure can be described as follows.

A weighed sample of paper (70 mm × 400 mm), the larger dimension

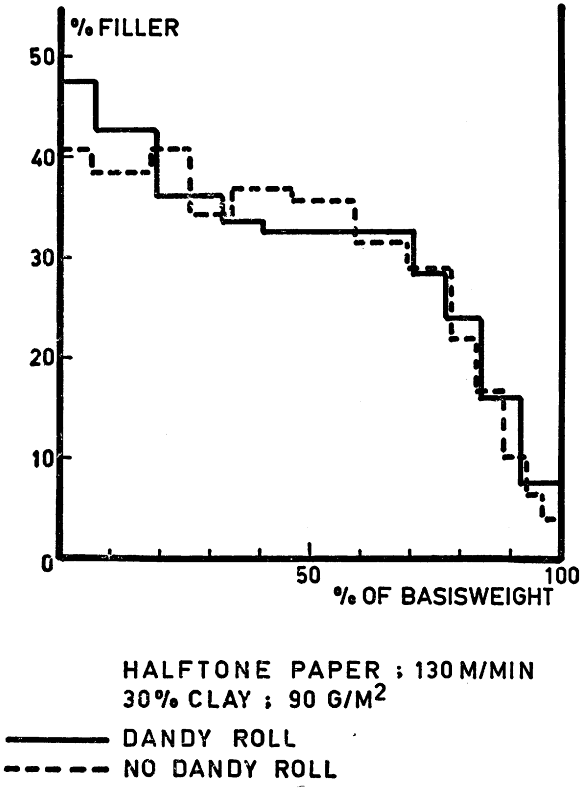
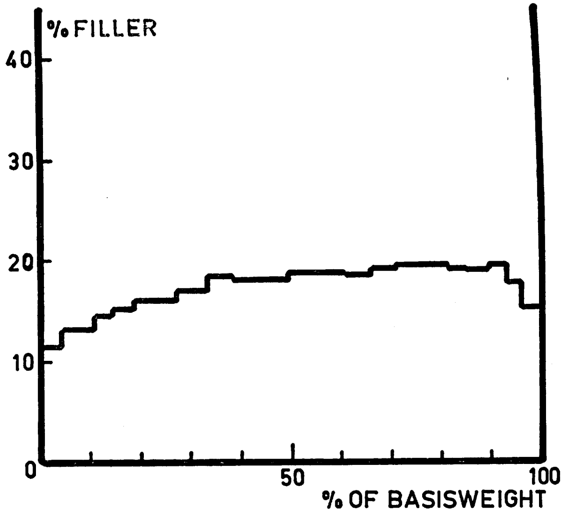


Fig. 3

being the machine-direction, is pressed on to a sheet of adhesive tape (75 mm × 600 mm). The combination of paper plus tape is weighed and a second sheet of adhesive tape is pressed on to the uncovered side of the paper. Care should be taken that there is very close contact between paper and tape.

The second sheet of tape is removed from the original paper + tape combination, which is mounted on a flat glass plate. A thin and even layer of fibres adheres to this second sheet of tape. After weighing the remaining paper + tape combination, the procedure is continued until one reaches the first sheet of adhesive tape.

The weight of each layer removed is known by difference and is expressed as a percentage of the weight of the original paper sample or as percentage basis weight of the paper investigated. A 15 per cent weight layer has to be



INTAGLIO PAPER
CYLINDER MOULD
18 % CLAY; 195 G/M^2

Fig. 4

regarded as a maximum. If a removed layer contains a higher weight percentage, this specific layer is treated as the original sample and subdivided.

The filler or ash content of each layer has to be determined by normal methods. The tape itself is a disturbing factor in a normal ash determination: therefore, each stripped layer is soaked in water. This separates fibres and adhesive from the tape body, which is then removed. Fibres and adhesive are filtered off on an ashless filter paper and ashed at 900°C. A correction has to be made for the ash content of the adhesive. The ash content of each layer is converted to filler content. The ash content of fibres and additives is neglected. Filler distribution curves are obtained by plotting filler content and percentage basis weight in a diagram, as shown in Fig. 1–9, in which the top side is on the left and the wire side on the right.

The use of percentage basis weight instead of percentage thickness may appear to be disadvantageous. If desired, the curves can be converted to

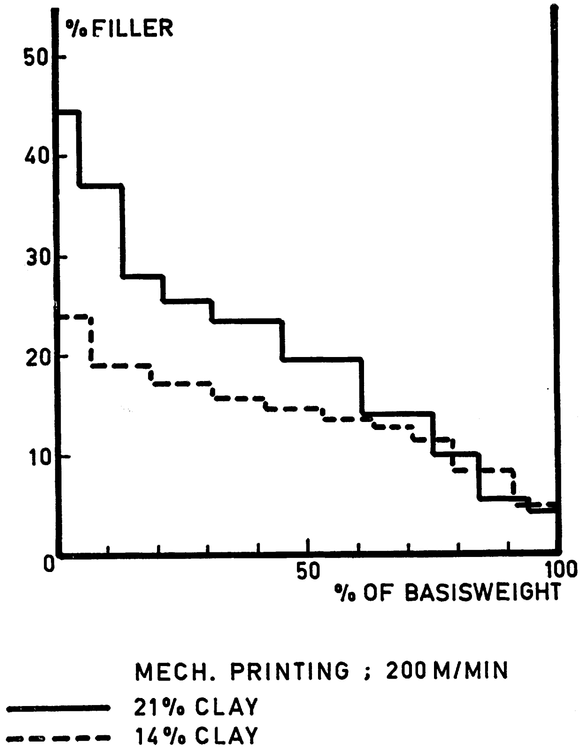


Fig. 5

a graph of percentage filler against percentage thickness by assuming that fillers do not contribute to thickness. Such a conversion is necessary, for instance, in the calculation of depth of penetration of coatings, but has no advantages at all if the filler distribution curves of papers of about equal filler contents have to be compared. Such a comparison is facilitated if the filler contents of layers of equal weight percentage are known. This can be achieved by a resetting of the distribution curves. The paper is regarded as being divided into ten layers of 10 per cent of the basis weight each. The corresponding percentage filler values can be calculated from the original values and compared with those of other graphs treated in the same way.

Characteristics of filler distributions

As mentioned at the start, about 60 samples of paper were investigated for their filler distribution. In Fig. 1–9, 18 of these distribution graphs are

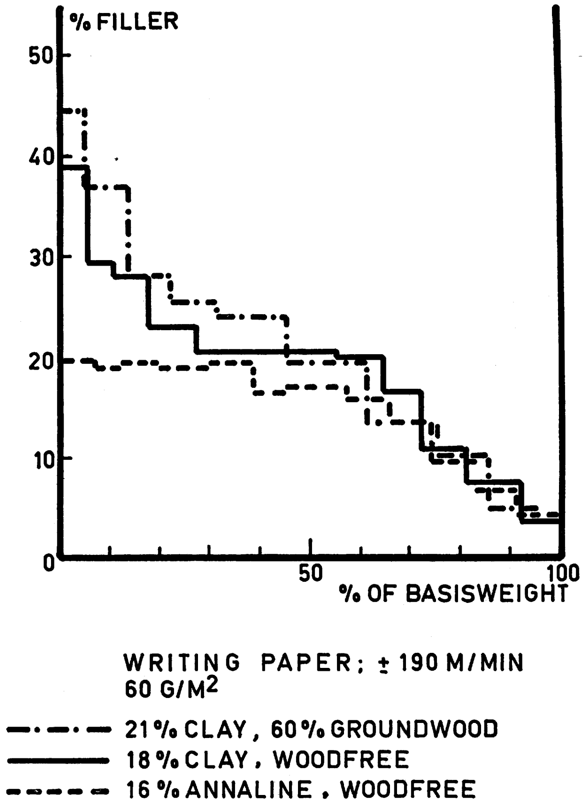


Fig. 6

presented. Those in Fig. 1–3, 5–7 were obtained from Fourdrinier-made papers, whereas Fig. 4 is a typical example of the distribution graph of cylinder mould papers.

A first glance at the filler distribution curves gives rise to the following general characterisation.

Fourdrinier-made paper

The filler content on the top side is always higher than that on the wire side. Often the curve shows a horizontal part, with a fairly rapid decrease in

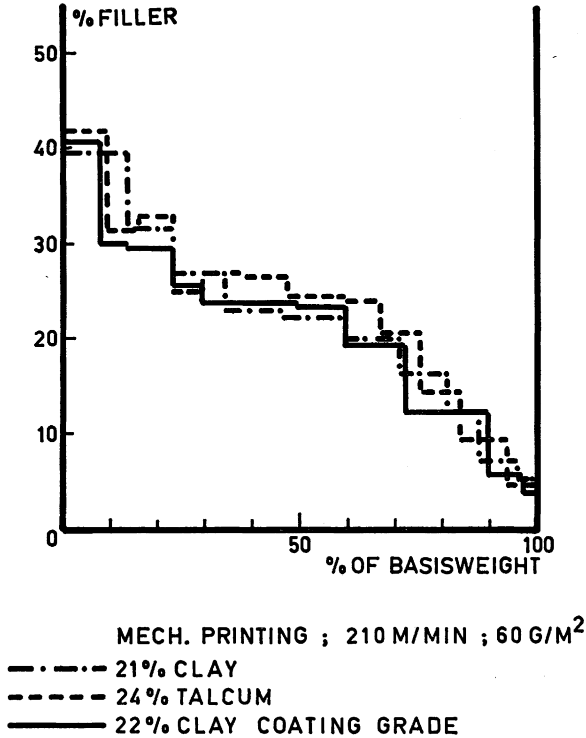


Fig. 7

filler content towards the wire side and in some cases even a big increase towards the top side.

Cylinder mould paper

The filler content on the top side is always less than that on the wire side. Starting from the top side, a gradual increase in filler content is noticeable, followed by a horizontal part of the curve and a slight, but definite, decrease near the wire side.

A further survey of the distribution graphs of Fourdrinier papers indicates that between 50 and 100 per cent basis weight all curves have the same shape and are more or less identical for papers containing the same amount of filler. Furthermore, the filler content in the extreme wire side layer proves to be equal for nearly all papers, regardless of total filler content (10–30 per cent), machine speed (100–400 m/min), filler (clay, talc, annaline, coating clay) or stock composition (0–70 per cent groundwood). The extreme 10 per cent layer on the wire side contains between 2.5 and 7.5 per cent filler. Taking into account the accuracy of distribution curve determination and the reproducibility in some well-investigated cases, one may conclude that the extreme wire side layer contains on the average 5 per cent of filler, regardless of the above-mentioned variables.

There are two exceptions to this '5 per cent rule', however; in some cases (for instance, Fig. 8), this extreme wire side layer contains $\pm$ 10 per cent filler. It turned out that such high values are obtained, in the case of wood-free papers, with a degree of beating exceeding 40° S.R. The other exception is paper with an extremely low ($<$ 8 per cent) filler content. Probably, papers with an extremely high filler content ($>$ 40 per cent) will not obey the '5 per cent rule' also.

The different curves show great differences between 0 and 50 per cent basis weight. The filler content in the extreme 10 per cent top side layer varies 10–50 per cent. As will be pointed out later, this variation is attributable to different causes. The reproducibility, which is fair to extremely good for the wire side, is sometimes very poor. It seems that the process on the wire side is much better defined than that on the top side.

Effect of composition

THE question may arise to what extent the filler distribution curves are affected by the composition of the final paper (or the composition of the stock). Therefore, the influences of the loading material, fibre composition and filler content were investigated. No special attention was paid to sizing or to addition of starch or other additives, except animal glue (see later). The experiments were carried out on two Fourdrinier machines with a speed of about 200 m/min, under controlled conditions.

Fibre composition

No difference in filler distribution was found between wood-free paper and paper containing up to 70 per cent groundwood. Examples of the distributions obtained are given in Fig. 6. The diagrams are totally identical provided all other conditions (percentage filler, etc.) are equal.

Loading material

No difference in filler distribution was noticeable when using clay, talc or coating clay as filler (Fig. 7). The presence of annaline (anhydrous

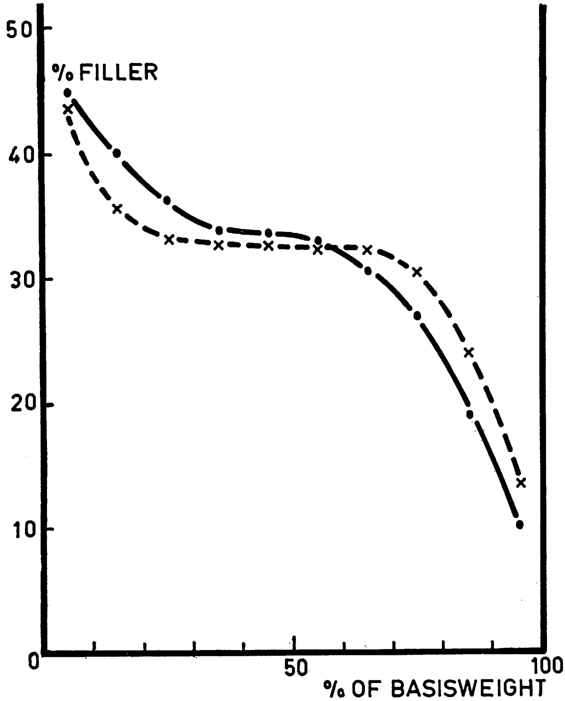


FIG. 8.

HALFTONE PAPER; ± 130 M/MIN
± 30 % CLAY ; 90 G/M²

•——• SOLID TABLE ROLLS
×- - -× OPEN TABLE ROLLS

Fig. 8

gypsum), however, changed the filler distribution considerably with respect to the top side (Fig. 6). The specific gravities of the fillers mentioned are all about equal. Of all fillers used, annaline has the highest average particle size (25 μ). In addition, the average particle sizes of normal grade clay and coating grade clay differ considerably (1 μ and 10 μ, respectively), but this seems to have no effect at all. Under the acid conditions (pH 4.5) of all experiments described, however, the primary particle size is of no importance, since coagulation and agglomeration control the behaviour of filler particles. If particle size played a dominant role, one should expect even an increase on the top side by using larger particles instead of a decrease (see later section on theoretical considerations). Consequently, the reasons for the behaviour of annaline are not at all clear. An explanation may however be found in the section in which the action of the dandy roll is discussed.

Total filler content

Since distribution curve shape and percentage filler in the extreme wire side layer are given, it is possible to predict the effect of an increase or decrease

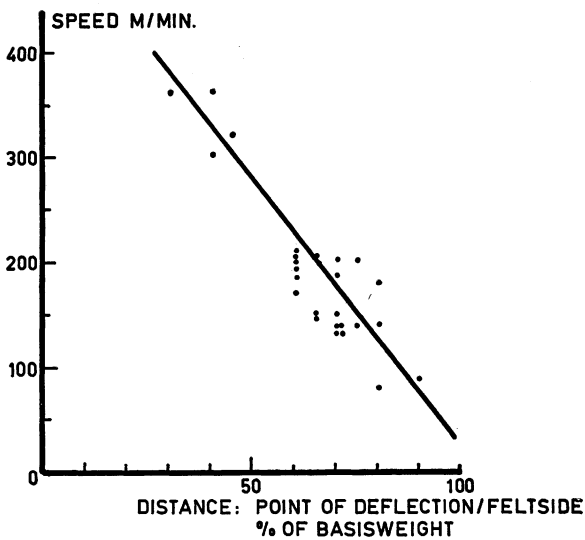


Fig. 9

in the total filler content. An increase in the percentage filler results in an increase of the filler content in the top side layers; a decrease will result in a less steep curve on the top side. An example of the practical results is given in Fig. 5. All other distribution graphs of low and high filler content paper are governed by the same rule (for example, Fig. 1).

Extremely low filler percentages were not investigated, as the distribution curve becomes very inaccurate. Papers of an extremely high filler content were not available.

Effect of machine conditions

THERE are several reasons for expecting an influence of machine speed on filler distribution. It is known from papermaking practice that an increase in machine speed results in a more markedly visible two-sidedness. It is also stated that two-sidedness has become a serious defect since high-speed machines were introduced. It was interesting therefore to trace the effect of speed on the shape of filler distribution curves.

Both Hansen(4) and Mack(6) investigated the effect of the action of a dandy roll on the final filler distribution and made clear that this action results in an increase in filler content on the felt side. In order to control this action under known conditions, two cases were tested, either with or without using the dandy roll.

The third machine condition investigated concerned the drainage conditions in the table roll section. As stated by Fergus Smith(8) and Underhay,(9) two-sidedness of a loaded paper will be less if solid table rolls are replaced by open table rolls with a dandy roll structure (see theoretical section). During the investigation period, such replacement was carried out on one of the best investigated machines and a number of distribution curves under both conditions could be obtained.

No effort was made to investigate the effect of other possible machine variables separately. Comparison of the distribution curves of several grades of paper, manufactured on different machines, showed no influence of number of table rolls, vacuum at suction boxes, construction of wire part and initial draining conditions whatsoever. Consequently, only those variables that could possibly affect the final filler distribution were taken into account—machine speed, dandy roll and drainage conditions in the table roll section as outlined above.

Machine speed

As described earlier, filler distribution curves possess a typical shape, which is more or less well-defined for the wire side. In surveying the distribution curves obtained, attention was drawn to the fact that there seemed to be a relationship between machine speed and the location of the so-called *point of deflection* on the curve. By this is meant the point on the distribution curve where the decrease of the filler content towards the wire side commences. It may be defined also as the point of intersection between the horizontal or less steep part of the curve and the straight line representing the decrease in filler content towards the wire side. This definition is not clear cut and the location of the point of deflection is in many cases not exactly indicated. In Fig. 1, for instance, the points of deflection are located at about 70 per cent, 40 per cent and 60 per cent of basis

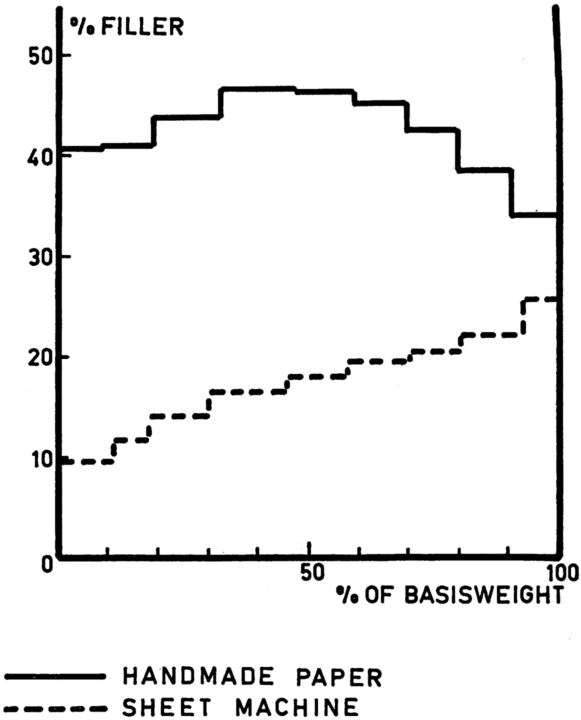


Fig. 10

weight, respectively; in Fig. 2, at 35 per cent of basis weight; in Fig. 3, at 60 per cent; in Fig. 5, at 50 and 60 per cent of basis weight, respectively.

The relationship between location of the point of deflection and the machine speed is plotted in Fig. 10. The clustering of points in the middle of the graph is because many of the machines investigated had a speed between 130 and 200 m/min. Unfortunately, we could not obtain samples of paper made on the same machine at different speeds. Taking the inaccuracy in the determination of the point of deflection into account, however, it may be concluded that the resulting graph gives a reasonable idea of the effect of machine speed on the filler distribution. In a later section, we will see how this graph can be used in predicting the distribution of loading material in a given grade of paper.

Dandy roll

On two machines normally provided with a dandy roll, short intermediate runs were made without dandy roll: the resulting distribution graphs are shown in Fig. 2 and 3. The effect of the dandy roll on the distribution of the filler is remarkable and in accordance with the observations of Hansen[4] and Mack.[6] Its action results in an increase in filler content on the felt side at the cost of the filler content in the next layers.

In other cases, too (Fig. 5 and 7), the same action is responsible for the sudden increase in filler content on the top side. The action of the dandy roll even results in a one-pass retention of the filler in the extreme top side layer of over 100 per cent—the filler content of this layer is higher than in the stock leaving the head box.

Using annaline as a filler seems to minimise the dandy roll action (Fig. 6). As was stated by Mack,[6] this action is merely a compression of the fibre mat, thus forming an aqueous suspension of filler particles on top of the top side. This enriches the top side with filler particles after subsequent drainage. We have to conclude therefore that annaline is not as easily removed from the fibre mat as clay, which might be due to the relatively large particle size of this particular loading material.

There are also cases (for instance, top line Fig. 1) in which no effect of the dandy roll is observed. As already stated by Hansen,[4] this will be noticed when the dandy roll runs dry, although we have met a few examples of a wet running dandy roll without much top side enrichment. This seemed to be related to low filler retention (see next section). As will be explained in the last section, such a relationship is within the theoretical possibilities.

Open table rolls

In recent years, it has become general practice to provide the table roll section of high-speed machines with a number of grooved table rolls or with a few open table rolls of dandy roll type as well. The object of the application of such rolls is to achieve less violent drainage during the first stages of formation. Sometimes it is advisable to use these non-solid table rolls over the whole table roll section.

One of the machines investigated is equipped normally with three open table rolls of dandy roll type directly after the breast roll and ten solid table rolls. For various reasons, the number of open table rolls was increased to ten, leaving three solid rolls preceding the suction boxes. From each situation, five samples were investigated for their filler distribution. The resulting average distribution curves, converted to ten layers of 10 per cent basis weight each, are plotted in Fig. 8. It can be calculated (and might also be deduced from Fig. 8) that the use of open table rolls exerts a slight, but definite, influence on the filler distribution on both top side and wire side. The increase in filler content on the wire side is about 20 per cent and the horizontal part of the distribution curve is extended in both directions. The consequences of this final result will be discussed in the final section of the paper.

Effect of filler retention

SINCE filler retention is the result of interaction between the filler particles and the fibres (or the fibre mat), it may be supposed that filler distribution and filler retention are related.

It is well known that the usual addition of alum increases the filler retention. Quite often, retention aids are applied, especially in making heavily loaded papers. One of the most common retention aids is Sveen glue or animal glue as described, for instance, by Brecht and Rausch(10) and many other investigators. In recent years, new retention aids have been developed, some of which are based on polyacrylamide.(11) A survey of different retention aids is given by McInnes.(12)

Generally, it is assumed that increased retention is brought about by flocculation or aggregation of filler particles by a flocculating agent. Michaels(13) describes some experiments on the aggregation of suspensions by polyelectrolytes. It is supposed that aggregates of filler particles, formed by the influence of alum, animal glue or polyelectrolytes, are trapped by the fibre mat and that larger aggregates are retained better. It is sometimes stated that this leads to less of two-sidedness and thus should influence the filler distribution.

Filler retentions can be calculated in many ways. We prefer calculating the one-pass filler retention R from an analysis of the head box stock and the paper, without taking fibre losses into account —

$$R = \frac{FP\ (100-FS)}{FS\ (100-FP)} \times 100$$

where FP = percentage filler in oven-dry paper and
FS = percentage filler in oven-dry head box stock.

The machines investigated showed quite different values for *R*, since all possibilities—no alum, alum, animal glue, polyelectrolyte—were studied. Filler retention ranged 18–63 per cent. In one case, special trials were made to obtain different levels of retention. From the resulting filler distribution curves, it could be deduced that filler retention has no influence on filler distribution on the wire side of the paper. There are indications, however, that a low filler retention causes a decrease in filler content in the top side layers (see dandy roll section). The absence of a relationship between filler retention and filler distribution will be discussed in the final section.

Factors governing filler distribution

FROM the conclusions reached in the previous four sections, a general picture of filler distribution and rules concerning the effect of normal variables on filler distribution can be derived. It has been shown clearly that the uneven distribution of filler particles in a sheet of paper is a given fact, closely connected with the papermaking process on Fourdrinier machines.

The two principal factors governing filler distribution are filler content and machine speed. Dandy rolls, nature of loading material, degree of beating and retention play a rôle under certain conditions. The influence of basis weight has not been treated in the foregoing sections, because, in the main, basis weights between 60 and 80 g/m^2 were chosen. It is clear, however, that increase in basis weight results in an extension of the horizontal part of the filler distribution curve, leaving top side and wire side phenomena unaffected: this was already shown by Hansen.[(4)] In summarising the different effects, it is practical to deal with top half and wire half of the distribution separately.

Wire half

The filler distribution curve is governed by machine speed, filler content of the paper and filler capacity of the extreme wire side layer. This filler capacity generally turns out to be 5 per cent, increasing with increasing degree of beating and decreasing somewhat when the average filler content of the paper falls below 10 per cent. An increase in machine speed decreases the slope of the curve representing the filler distribution near the wire side. An increase in average filler content has an opposite effect. Nature of filler, fibre composition and level of filler retention have no effect.

Top half

The filler distribution curve depends on machine speed, average filler content and a combination of dandy roll action, filler retention and, to some extent, nature of filler. Increased machine speed and increased filler content both result in an enrichment of the extreme top side layers. The use of a dandy roll increases the filler content in the extreme top side layers or has no effect at all.

A low filler retention probably reduces the filler content in the extreme top side layers. Finally, annaline does not give such high filler percentages on the top side as do talc and clay grades.

With the aid of Fig. 10 and keeping the '5 per cent rule' in mind, it is now possible to predict the filler distribution of a certain grade of paper, provided percentage filler and machine speed are known. This procedure is not limited to a certain group of machines, but can be carried out for each Fourdrinier machine and, consequently, is generally applicable.

Theoretical considerations

THE rules of filler distribution having been established, the question arises what causes such location of filler particles? It is generally supposed that the table rolls play a dominant role and that the effect of suction boxes and wet presses is negligible. This has been established by Hansen,(4) Pritchard,(5) Mack(6) and Underhay.(9) These authors more or less agree that uneven distribution of small particles in paper is imparted in the table roll section, but are not unanimous in their opinion about the exact causes.

Both Hansen(4) and Mack(6) investigated samples of paper taken directly after the breast roll under conditions of free drainage after a sudden shutdown of the machine. They both found the final filler distribution already present to a certain extent in these samples and concluded that uneven filler distribution is caused partly by normal drainage effects such as filtration. On the other hand, Underhay(9) stated that the uneven distribution is because of the water that, adhering to the table rolls and advancing under the wire, is wedged into the nip between the rolls and the wire. This water is pushed through the underside of the wire, disturbs the wire side of the sheet and loosens and resuspends loading material. According to this view, the filler is washed out of the wire layers, thus leading to a decrease in filler content on the wire side.

The work of Underhay(9) is partly based on that of Fergus Smith,(8) who recommends the substitution of open table rolls for solid table rolls. The amount of water adhering to open rolls is far less than that adhering to solid rolls and thus the washing-out effect will be greatly reduced. As has already been shown, however, the effect of open table rolls is comparable with that of solid rolls and does not support the washing-out theory.

Considering the system water/fibre/filler—and assuming no interaction among these three components in suspension—we may regard the paper-making process primarily as the separation of a three-phase system into two solid phases and one liquid phase. This leads to the conception of self-filtration during the drainage period on the wire section of a Fourdrinier machine as suggested, for instance, by Wrist.[14]

The self-filtration of this three-phase system, containing two solid phases of entirely different size and shape, will at any rate result in an uneven final distribution. In the first stage of drainage, the filter mat is formed only by the wire, with coarse openings compared with the particle size of the solid phases and especially with that of the loading material. Consequently, the first hypothetical layer will be relatively poor in filler particles. The next layer contains somewhat more filler, because now an open layer of fibres takes the place of the wire as filter medium. During continued drainage, subsequent layers will be built up, steadily increasing in filler content. The loading material itself acts as a filter aid in plugging the pores, as do small particles when filtering on filter paper. The top layer will contain less loading, however, because the filler particles are retained not by this layer, but by the next one.

The resulting theoretical filler distribution will show a maximum with a decrease towards the top side and a somewhat larger decrease towards the wire side. Such distributions were found by Mack,[6] who used a midget Fourdrinier machine at a speed of 1.5 m/min. In these conditions, no serious washing effect has to be considered. The same type of distribution curve is obtained from handmade paper prepared in the laboratory, working with a 0.6 per cent fibre consistency (Fig. 9). These experimental distribution curves are very much like those in Fig. 1 and, consequently, in principle, they do not deviate from those of Fourdrinier-made paper. This leads us to the conclusion that the papermaking process may be regarded as a filtration process. The uneven filler distribution is a result of the self-filtration of a three-phase system.

As may be seen from Fig. 9, somewhat different rules seem to govern the filler distribution of handsheets, made in a standard sheetmachine at fibre consistencies of 0.06 per cent. It was pointed out by Pritchard[5] and confirmed by our own experiments that the degree of beating exerts an appreciable influence on the filler distribution in this type of laboratory-made paper, high degrees of beating resulting in a filler decrease towards the wire side. This phenomenon was not studied thoroughly: the only observation made was that there is the same striking resemblance between the filler distribution of sheetmachine samples and cylinder mould samples (Fig. 4) as there is between their methods of manufacture. It is thought that the large amount of water causes a displacement of the filler particles to subsequent layers. This holds particularly for cylinder moulds, on which, according to Steenberg *et al.*[15] and our own investigations, thickening takes place.

Having demonstrated how filtration leads to uneven filler distribution, we now return to papermaking practice. The shape of the filler distribution curve of a Fourdrinier paper has been explained, but not its level. From the study of filler distributions, we learnt that, as a rule, the extreme wire side layer contains 5 per cent filler.

This suggests a constant filler capacity of the extreme wire layer, which depends only on the degree of beating. Other stock conditions being of no effect, it may be supposed that the filler capacity is determined by such external factors as drainage conditions. Referring to the work of Burkhard and Wrist[16] on the suction exerted by table rolls and to the investigations of Scott[17] and Bennett[18] on the amount of water withdrawn in the different stages of the wire part, it can be calculated that the time of drainage in the table roll section is about 0.2 sec, fairly independently of machine speed. Thus, the filtration takes place exceedingly rapidly and results in a violent washing of the extreme wire side layers, not by water adhering to wire or table rolls, but by the drainage water. This violent action leaves only the minimum amount of filler in the wire side layer. It is probable that in these conditions a higher degree of beating increases the filler capacity. The drainage on Fourdrinier wires proceeds further as outlined in the description of the filtration phenomena, modified according to the dynamic conditions. The compression of the fibre mat (Ingmanson[19]) has certainly to be considered. The compressed, denser structure will increase filtration capacity as drainage proceeds.

The use of retention aids has to be discussed separately, because it might appear that the filtration theory changes appreciably when coarse agglomerates are concerned. In fact, it is known that vigorous agitation sometimes results in irreversible destruction of filler agglomerates: this is supposed to occur during the extremely rapid drainage. Consequently, no influence on the filler distribution in the wire half is to be expected. The extreme top side layer probably retains the coarse agglomerates, giving rise to a relationship between retention and top side filler distribution (as discussed earlier).

The filler distribution in cylinder mould paper can be explained partially by taking into consideration a drainage time of about 5 sec and the displacement effect. In this case, the filler capacity of the wire side layer is probably determined by the stock conditions and not by drainage conditions.

From the foregoing exposition, it may be concluded that the uneven or heterogeneous distribution of fillers in Fourdrinier-made papers is present even in the first stage of drainage and is strongly intensified by extreme draining conditions. The theory just outlined, based on practical data and experiences, deals only with the behaviour of filler particles during paper-making. The idea is that some of the results may be applicable to the structure of paper and the behaviour of fibres of different dimensions.

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REFERENCES

1. Schilde, H., *Papierfabr.*, 1930, (28), 409–415; (26), 423–477; (27), 439–444
2. Albrecht, E., *Wochbl. Papierfabr.*, 1921, **52** (42), 3 864–3 865
3. Schütz, F., *Papierfabr.*, 1937, **35** (51/52), 516–518
4. Hansen, E., *Tappi*, 1951, **34** (4), 180–185
5. Pritchard, E. J., *Proc. Tech. Sect. B.P. & B.M.A.*, 1957, **38** (2), 426–438
6. Mack, H., *Das Papier*, 1959, **13** (19/20), 459–469
7. Browning, B. L. and Isenberg, J. H., *Tappi*, 1955, **38** (10), 602–603
8. Fergus Smith, J., *Paper Trade J.*, 1949, **129** (21), 29–31
9. Underhay, G. F., *Tappi*, 1954, **37** (11), 547–553
10. Brecht, W. and Rausch, R., *Papierfabr.*, 1937, **35** (48), 449–453
11. Reynolds, J. F. and Ryan, R. F., *Tappi*, 1957, **40** (11), 918–920
12. McInnes, J. S., Mills, R. H. and Collins, T. T., *Paper Trade J.*, 1958, **142** (29), 26–34
13. Michaels A. S. *Ind. Eng. Chem.*, 1954, **46** (7), 1 486–1 490
14. Wrist, P. E., *Pulp & Paper Mag. Can.*, 1954, **55** (6), 115–119
15. Steenberg, B., Bergström, J. and Kjensjard, R. I., *Tappi*, 1954, **37** (11), 512–521
16. Burkhard, G. and Wrist, P. E., *Pulp & Paper Mag. Can.*, 1956, **57** (3), 100–118
17. Scott, A. A., *Pulp & Paper Mag. Can.*, 1937, **38** (2), 172–178
18. Bennett, W. E., *Tappi*, 1954, **37** (11), 535–541
19. Ingmanson, W. L., *Tappi*, 1959, **42** (6), 449–454

Transcription of Discussion

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-

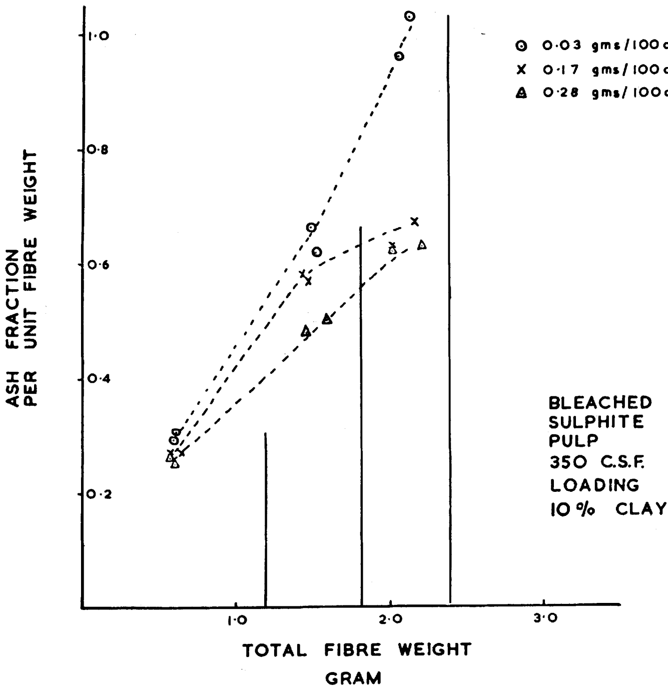

Fig. D16—Loading distribution at different formation consistency

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

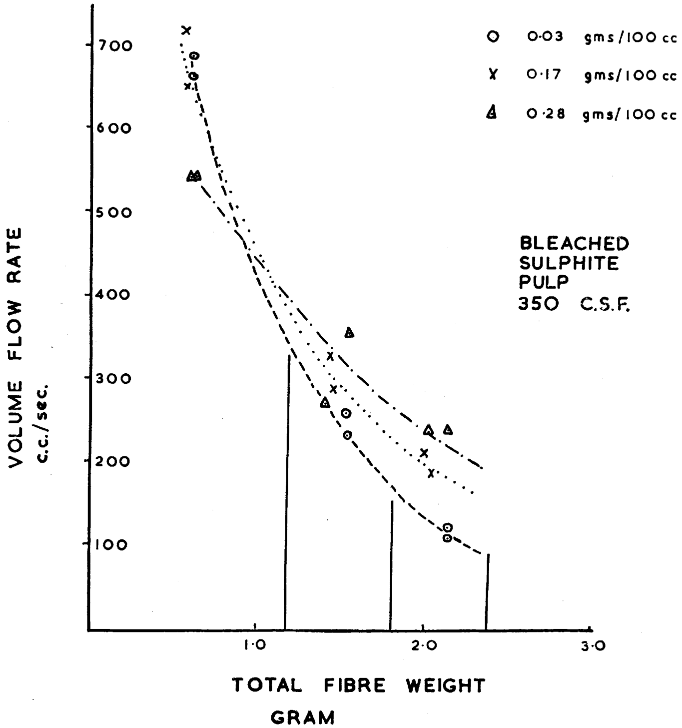

Fig. D17—Variation of flow rate during sheet formation

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.