paper technology

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* IMPORTANT NOTICE ON PAGES **477** & **478** *

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SUMMARIES from foreign journals

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*

THE following are freely abridged versions of the original papers available in the original language through the Technical Section library—

Evaluation of various grades of paper with the FOGRA apparatus

F. Wultsch and K. Schubert
Das Papier, 1959, **13** (23/24), 600–607

IN this work, the operation of the FOGRA (German Printing Research Institute) printability tester was examined and the reproducibility of the results was critically evaluated. The influence of several variables on the results was studied and discussed in the light of present knowledge.

The FOGRA printability tester is constructed so that printing of test strips can be carried out under controlled conditions of ink application, pressure and printing speed. The printing forme is weighed on a semi-micro scale before ink is applied to it and is then reweighed with ink both before and after printing. In this way, the ink uptake ratio can be determined and ink distribution curves drawn.

The conclusions from the work were that the FOGRA apparatus can be used for the evaluation of the printability of paper and is specially suitable for measuring ink transfer and picking tendency. A complete evaluation cannot be made, however, with this apparatus, for printability is a complex expression and involves many other factors such as dimensional stability, sheet flatness and formation. As was evident from the ink distribution curves, the apparatus reacted well to changes in the furnish, to additives, to differences in the degree of finish (gloss) and to differences in caliper and amount of sizing. From curves, it was thus possible to forecast the effect of changes in any of these factors on the printability of the sheet.

The work also showed that there were no differences in the curves obtained for the same paper when tested at various time intervals and changes in the relative humidity were also without effect on the results. The apparatus can be used for constructing ink distribution curves for papers that give unsatisfactory results in printing and also for papers that can be printed successfully by a number of different processes. By using such standard curves for bad and good papers as reference curves, it is a simple matter to predict whether the ink uptake and pick resistance of an unknown paper will be up to the required standard. The adaptability of the machine operating conditions makes it possible to simulate the actual conditions in the printing shop and reproducibility of results in all these tests was found to be good.

Operation of a two-compartment suction couch roll

N. G. Nikol'ski and A. Yu. Golubev
Bumazh. Prom., 1960, **35** (1), 18–21

IN 1957–58, two Voith two-compartment suction couch rolls were installed in the Balakhninsk mill and suction was provided by vacuum pumps with a capacity of 65 cu. m./min. (2 295.5 cu. ft./min.), driven by a 110 kW. motor. It was found that some of the water removed from the sheet by the two suction compartments was held in the shell apertures by the opposing actions, on the one hand, of the vacuum force and, on the other, of the centrifugal and capillary forces. Under certain conditions, this water could spray out and rewet the sheet, causing breaks at the couch roll.

Another serious disadvantage of this design was that short fibres tended to accumulate and block up the suction apertures.

The suction couch rolls were modified and these drawbacks eliminated by reducing the width of the first suction compartment from 170 mm. (6.7 in.) to 135.5 mm. (5.3 in.) and the second from 122 mm. (4.8 in.) to 76.5 mm. (2.9 in.). As a result, the suction areas were reduced from 1.01 sq. m. (10.8 sq. ft.) to 0.797 sq. m. (8.5 sq. ft.) and from 0.715 sq. m. (7.8 sq. ft.) to 0.455 sq. m. (5.0 sq. ft.), respectively. This modification raised the vacuum in the suction compartments, in the first from 4.5 m. (14.8 ft.) to 5.5 m. (18.0 ft.) of water with one vacuum pump; in the second, from 5.5 m. (18.0 ft.) to 8.0 m. (26.2 ft.) of water with two similar vacuum pumps.

The increase in vacuum enabled the dry solids content of the sheet to be raised from 18 per cent. to 20 per cent., while the machine speed could be increased from 350 m./min. to 375 m./min. (1 148 ft./min. to 1 229 ft./min.) and the number of breaks between the couch roll and the first press was reduced.

Some theoretical and practical results of sizing paper in alkaline or neutral conditions

C. Simionescu and E. Poppel

Third International Conference of the Technical Association of the Paper and Printing Industries, Budapest, 1959

THE usual method of sizing paper with rosin in acid conditions has a number of disadvantages, the most important being the possibility of causing chemical degradation of the cellulose fibres, the production of paper with poor ageing properties, the impossibility of making paper with a neutral or weakly basic reaction, high consumption of size and alum and the danger of excessive corrosion of machine parts. The experiments described in this paper were begun in 1953 on a laboratory scale and were designed to discover the effect of sodium aluminate on the sizing process, also to investigate the other main factors affecting this process when rosin size is used as the sizing agent. A large number of laboratory experiments were carried out and the findings were verified by further experiments on an industrial scale. The main results of the work were as follows—

1. Both the laboratory and industrial work showed that a number of paper properties could be improved by using sodium aluminate and calcium chloride instead of alum. Paper made under certain conditions, such as insufficient water removal before drying or the use of too large amounts of sodium aluminate or calcium chloride, showed an undesirable property called 'dry diffusion' of ink, which appeared to be caused by high hygroscopicity of the sheet. This effect and the tendency to foam can be largely or completely eliminated by careful control of the process conditions and sizing can then be carried out successfully in alkaline conditions.

2. In order to develop a suitable process for neutral sizing, experiments were carried out to determine the optimum pH for sizing, the most favourable ratio of sodium aluminate to aluminium sulphate, the relationship between the amounts of sodium aluminate and size, the effect of the type of fibre suspension and the retention of size and fillers. All the main factors involved in neutral sizing were examined and it was concluded that this method has all the advantages of the basic method, but does not suffer from its disadvantages.

3. Both the alkaline process and the neutral process are important, since they make it possible to produce various grades of speciality papers, give economies in rosin size and aluminium salt consumption and reduce equipment corrosion.

4. Paper sized in alkaline or neutral conditions is much more resistant to ageing than is paper sized in the conventional way.

5. The coagulation of disperse size systems (Bewoid size and fully saponified rosin size) was studied in neutral conditions, using sodium aluminate and aluminium sulphate as coagulating electrolytes. The Tchaikovski electrophoresis apparatus was used to determine the swelling and coagulation ranges and, in a special case, the electrokinetic potential of the system at selected points.

6. The colloidal theory of sizing was used to explain the action of rosin size in neutral conditions and the effect of water hardness was studied in the laboratory.

7. Sizing degree under various conditions was evaluated by the linear method, Jayme's method and the electrical method; the latter method that uses the KBB apparatus being modified as a result of knowledge gained on the subject of moisture penetration through capillaries.

In general, it is concluded that alkaline or neutral sizing is an important and interesting process and requires more experimental work to be done on it.

Alteration in colloidal chemical properties of pulp fibres by high-frequency treatment

G. Jayme, H. Crönert and W. Neuhaus

Das Papier, 1959, **13** (23/24), 578–583; 1960, **14** (1), 5–11; (2), 58–66

IT was found that ultrasonic treatment has a specific effect on the colloidal chemical swelling of pulp fibres. This effect could be demonstrated both microscopically and quantitatively by the increase in the water retention value (WRV), with the drainage properties remaining good and the strength properties of test sheets high.

In this connection, there are interesting possibilities for the use of ultrasonic treatment under various conditions for theoretical research on the relationship between morphological changes in the fibre and colloidal chemical swelling behaviour or the properties controlled by this factor. Consequently, ultrasonics were used in experiments designed to investigate all possible relationships between the individual properties. The attainment of a high degree of swelling without a simultaneous increase in wetness (that is, without fibre shortening or formation of fines) is only one special case of ultrasonic treatment, although it is the most desired effect. In general, with low freeness and high consistencies, ultrasonic treatment resulted in very high tearing strength; with high stock wetness and low consistencies, the breaking length was increased in the finished paper.

Under suitable conditions, ultrasonic treatment can suitably alter pulp properties for such processes as the preparation of viscose cellulose and bleaching by breaking microfibril bonds and dissolving cell walls, thus increasing reactivity without altering the fibre structure in any other way.

There is little hope for industrial application of ultrasonic treatment, for the power demand is extremely high, quite apart from the expensive and sensitive apparatus required. Moreover, maximum effects are achieved only by working at very low consistencies and this, too, is a disadvantage from the point of view of economy.

Further experiments showed that several desirable effects could be achieved by a mechanical high-frequency treatment, these being—

(*a*) Improved beating of the fibres, without affecting fibre length and resulting in marked improvements in tearing strength and folding endurance.

(*b*) An alteration in the morphological/structural properties of the fibre, leading to increased reactivity, without excessive degradation of the fibre.

The mechanical high-frequency treatment is used in a different way from the ultrasonic treatment. There is a high degree of similarity, however, between the results achieved with low frequency ultrasonic treatment at higher consistencies (22 kHz., 1 per cent. pulp consistency) and the results of mechanical high-frequency treatment at high consistencies (up to 7 per cent.) with a maximum mechanical frequency of 72 000 per sec.

Mechanical high-frequency treatment improved the properties of the fibres and so developed the strength properties that the pulp did not need to be beaten so much in the later stages.

A direct comparison of ultrasonic treatment, beating in a Jokro mill and mechanical high-frequency treatment at low and high consistencies showed that the Jokro mill had the greatest cutting and fibre-shortening effect, while mechanical high-frequency treatment at high consistency gave the highest tearing strength and folding endurance.

Measurements made on the laboratory scale showed that the power requirements for successful mechanical high-frequency treatment are within economic range, so long as the highest possible pulp consistencies are used.

It was shown that mechanical high-frequency treatment had a favourable effect on the reactive capacity of various pulps that were to be subjected to a final emulsion xanthogenation, alkaline oxidative attack or three-stage bleaching and, in this respect, no differences could be detected between pulps treated by the mechanical high-frequency method and those treated ultrasonically.

As an example of this, high-frequency treatment of unbleached pulp resulted in a 5 per cent. saving of bleaching agent in the chlorination stage and a 6 per cent. saving in the hypochlorite stage.

It would appear that this new form of treatment has many possible applications and should be further developed.

The problem of paper curl with special reference to wallpaper

L. Pálffy

Das Papier, 1960, **5** (14), 192–198

CURLING of paper is a common problem and is particularly important when paper is wetted on only one side, such as is the case with wallpaper. Curl makes printing extremely difficult and it is important therefore to have a practical method of measuring it.

The absolute curl value is equal to the curvature of the arc formed by a test piece when it is wetted on one side —

$$\text{radius} = \text{curl value} = K = \frac{1}{r}\ \text{cm.}^{-1}$$

where r = radius of the arc (cm.).

When a test piece is wetted, the water penetrates the paper at a certain rate and, when penetration has proceeded to a certain depth, curling stops. Up to this limit, the absorbed water releases tensions that tend to curl the sheet; after penetration to this depth, opposing forces come into operation and the test piece begins to straighten out. In investigations on the curl tendency of papers, it is essential to know the maximum curl value and, hence, sufficient water must be applied to the test piece to saturate it as far as the limiting depth.

It is a simple matter to measure curl. The radius of curvature of the arc can be expressed by the equation —

$$r = \frac{180\ s}{2\ \pi a^\circ}\ \text{cm.}$$

where s = arc length (cm.)
a° = angle between chord and tangent of the arc

Curvature (curl value) can be expressed —

$$K = \frac{1}{r} = \frac{2\pi a^\circ}{180\,s}\ \text{cm.}^{-1}$$

Curl is thus proportional to the angle a°. In round figures, arc length can be taken as —

$$s = 2\pi\ \ 100/180 = 3.488\ \text{cm. (approx. 3.5 cm.)}.$$

If a test piece 3.5 cm. long is taken as standard, curl can be expressed by the simple formula —

$$K = a^\circ/100\ \text{cm.}^{-1}$$

With this calculation, a simple measuring method can be evolved. A semi-circle divided into 5 sectors is

(*continued overleaf*)

TRANSLATIONS
FROM FOREIGN JOURNALS

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Six announcements have previously been made, as follows —

Technical Bulletin, 1954, **31** (6), 197
Technical Bulletin, 1957, **34** (1), 8
Technical Bulletin, 1958, **35** (5), 153
Technical Bulletin, 1959, **36** (4/5), 73
Paper Technology, 1960, **1** (1), 70
Paper Technology, 1960, **1** (4), 424

The following further translations are now available.

Readers are reminded that the Technical Section translations service is available to Section members at competitive rates covering the following languages —

Czech, French, German, Dutch, Italian, Polish and Russian

Rates and other information about original translations being undertaken can be obtained from the Librarian, Technical Section, B.P. & B.M.A., St. Winifred's, Welcomes Road, Kenley, Surrey.

Antisepsis—a necessary condition for improving paper quality and increasing production — R. M. Pavlinova
Bumazh. Prom., 1959, **34** (8), 10

Equipment for retaining fibres and liquor during digester blowdown — I. I. Simbyankin and V. A. Sannikov
Bumazh. Prom., 1960, **35** (1), 21

The PVR wallpaper printing machine — E. A. Zaranovski
Bumazh. Prom., 1960, **35** (2), 15

Feeding pressure of paper stock in conical beating units — J. Korda
Papir a Celulosa, 1959, **14** (11), 248

Contribution to papermachine automation — K. Schmidt
from the book 'The technique of control in papermaking' published by the German Association of Pulp and Paper Chemists and Technologists, 1960

Ammonia-base sulphite digestion — M. G. Eliashberg and M. H. Tsipkina
Bumazh. Prom., 1959, **34** (12), 2

The air content of pulp suspensions — W. Brecht and U. Kirchner
Wochbl. Papierfabr., 1959, **87** (8), 295

The measurement of the whiteness of optically bleached papers — L. F. C. Friele
De Papierwereld, 1960, **14** (3), 393

The relationship between deformation of pulp fibres and the beating process — N. Ya. Solyechnik and V. P. Alikin
Bumazh. Prom., 1959, **34** (12), 7

Beating of pulp for thin fine papers — E. Bonisch
Paper given at a Conference of the Paper Technology Section of the Institute of Paper Technology at the Oskar-von-Miller Polytechnic in Munich on 26th September 1959

Attempts to establish a technology for manufacturing asbestos paper for electrical insulation — J. Jaroszewski and H. Poradowska
Przeglad Papierniczy, 1959, **15** (15), 150

Modern methods for treating wastepaper — Klaus Kurth
Allg. Papier-Rund., 1958, (12), 617-620; (13), 674-678; (14), 722-726

Soda recovery from black liquor by the Torras-Xucla method — H. Guillon, A. Xucla and A. Bories
Papier, Carton et Cellulose, 1959, **8** (4), 83-97

Beating of hardwood pulp for use in the making of different grades of paper — F. Wultsch
Das Papier, 1959, **13** (17/18), 407-413

The control of draw on papermachine — G. Kessler
Wochbl. Papierfabr., 1959, **87** (11/12), 498-505

(Summaries continued)

drawn. One of these sectors corresponds to a curl value given by the equation —

$$K = 5/100 = 0.05 \text{ cm.}^{-1}$$

The test piece is clamped between two plates and one side of it is wetted. The test piece is then put over the measuring scale with the end of the piece in the clamp at the mid-point of the scale and the clamping plates parallel to the zero line. The measuring scale is horizontal and the axis of curvature of the test piece is vertical in order to avoid the weight of the test piece affecting its curl. The amount of deviation of the free end of the test piece is observed and when this reaches a maximum the reading is taken.

This method is rapid and simple and is convenient for use in determining the hygroscopic characteristics of pulps and, from these, the probable curl in paper made from these pulps.

RUSSIAN PAPER INDUSTRY

(*continued on page 482*)

for your reading

Attention is drawn below to a number of papers of interest to be found in recent journals available from the Technical Section library.

The transverse tensile strength of clay/starch coatings
A. C. Eames
Tappi, 1960, **43** (1), 2–10

Kinetics of the alkaline degradation of hemicellulose at pulping temperatures
R. W. Collier
Tappi, 1960, **43** (1), 15–18

Transparentising of paper
F. V. E. Vaurio
Tappi, 1960, **43** (1), 18–24

Corrugating pulp from wheat straw by cold soda process
A. J. Ernst, T. F. Clark and I. A. Wolff
Tappi, 1960, **43** (1), 34–37

Dry ashing of pulp and factors which influence it
L. H. Phifer and J. B. Maginnis
Tappi, 1960, **43** (1), 38–44

Rice straw for bleached papers
A. J. Ernst, Y. Fouad and T. F. Clark
Tappi, 1960, **43** (1), 49–53

Chemical modification of papermaking pulps
K. Ward
Tappi, 1960, **43** (1), 54–58

Physical properties of bleached high yield pulps
N. N. Coe and H. L. Crosby
Tappi, 1960, **43** (1), 65–69

A new paper formation tester applying two fundamental properties of human vision
O. Andersson and K. Sundewall
Svensk Papperstidn., 1960, **63** (6), 167–173

Dielectric properties and moisture content determination in paper
J. Vitins
Tappi, 1960, **43** (4), 318–323

Papermachine inlet performance in relation to the Fourdrinier wire
H. C. Nelson
Tappi, 1960, **43** (4), 330–342

High-amylose corn starch — properties and prospects
F. R. Senti and C. R. Russell
Tappi, 1960, **43** (4), 343–349

Effect of volatile and moisture content on electrical properties of phenolic resin paper laminates
M. Ezrin and S. H. Rider
Tappi, 1960, **43** (4), 374–379

Water immersion of resin-saturated paper
F. Rosenthal
Tappi, 1960, **43** (4), 382–384

Measurement of the smoothness of paper
T. W. Lashof and J. Mandel
Tappi, 1960, **43** (5), 385–399

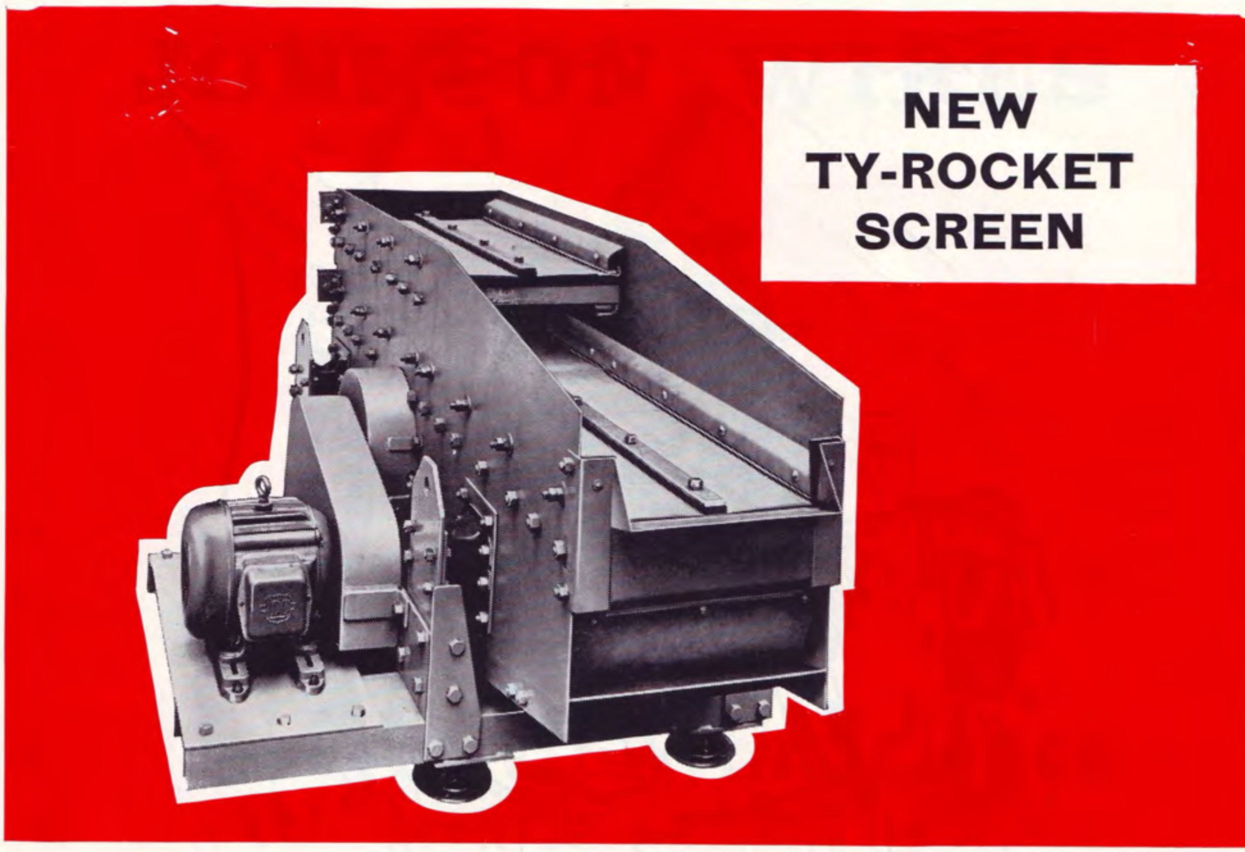
Measurement of the contribution of fluorescence to the brightness of papers treated with whitening agents
F. Grum and T. Wightman
Tappi, 1960, **43** (5), 400–405

Microscopic fusion analysis — a potentially useful technique for the pulp and paper industry
V. Gilpin
Tappi, 1960, **43** (5), 423–429

The interaction of processing variables, base materials and resins in polyethylene extrusion coating
J. P. Goslin and H. F. Sweeney
Tappi, 1960, **43** (5), 434–447

Patterns of circumferential flow in annuli
A. H. Nissan and F. C. Haas
Tappi, 1960, **43** (5), 458–465

Power transfer within wet felts
M. J. Osborne, J. Knowles and C. C. Collins
Tappi, 1960, **43** (5), 465–470



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ATTENTION

This is the fifth issue of the new journal

PAPER TECHNOLOGY

- The Journal combines and replaces the Technical Section's previous two publications, *Proceedings* and *Technical Bulletin*.

- PAPER TECHNOLOGY, 1960, vol. 1 follows on from *Proceedings,* 1959, vol. 40 and *Technical Bulletin,* 1959, vol. 39.

(see over)

• This journal is constituted from the same material that appeared formerly in *Proceedings* and *Technical Bulletin*, the two distinct sections being retained in each issue for those members who wish to file or bind them separately.

• With this in mind, additional page numbering of the *Proceedings* section has been provided on the top outer corner of the relevant pages. These page numbers are prefaced by the letter T and will commence from T1 with each volume.

• Sequential page numbering for the journal as a whole commences at page 1 with each volume and runs through the the whole of each year's issues.

• Six issues of PAPER TECHNOLOGY will be published each year—

No. 1 in February	No. 4 in August
No. 2 in April	No. 5 in October
No. 3 in June	No. 6 in December

• A number of cloth-board bound copies of the collated *Proceedings* sections from each of the six issues for 1960 can be prepared for special subscribers. The preparation and cost will depend on the demand and members interested in buying the bound volume should advise the Secretary of the Technical Section at once.

• Binders with gold blocking on the spine can be obtained from the Technical Section at special rate — enquiries are invited. Each binder will hold six issues.

• The register of members will be made up on 30th September 1960 for publication in the December issue of *Yearbook* 1960. Accuracy in the register details will be assured by members notifying the Secretary of any changes of position, address, etc. as soon as these occur.

Technical Section membership

DURING July and August 1960, the changes in membership were as shown —

Newly enrolled

London Division—
P. C. Clegg—*Full*
D. N. Hill—*Junior*
P. A. Johnson—*Full*
P. B. Johnson—*Associate*
F. R. Lehman—*Associate*
A. T. K. Marnan—*Junior*
R. Neve—*Full*
G. S. Petty—*Associate*
E. B. Porter—*Full*
P. R. Powis—*Full*
B. J. Rogers—*Junior*
A. J. Thorley—*Junior*

Northern Division—
O. G. D. Acland—*Full*
E. J. Campbell—*Associate*
J. P. Campbell—*Associate*
A. G. Cuthbert-Smith—*Associate*
J. T. Davenport—*Associate*
J. B. Haughton—*Associate*
B. M. Keeping—*Junior*
G. Lilley—*Associate*
D. W. J. Lyddon—*Full*
B. T. Riding—*Junior*
B. L. Sidebottom—*Junior*
D. B. Tooms—*Associate*
N. W. Willink—*Full*

Scottish Division—
P. Cowper—*Associate*
A. Reid—*Associate*
J. G. Russell—*Full*

Overseas Associate—
Dr. R. H. Boehm
N. Flaxman
G. D. Pai
F. A. Price
J. Thomson*

* Reinstated

Resignations and withdrawals

London Division—
G. R. Hyde—*Full*

Overseas Associate—
A. Shahid

Errata

On page 214 of this journal, No. 3 (Russian *Paper Industry*), for the title on line 12 from the bottom of column 2 *Wet web pick-up*, read *Wet web take-off*. In the abstract, read *take-off* for *pick-up*.

On page 375 of this journal, No. 4 (*The effect of filming amines on heat transfer in paper drying cylinders*), for the section heading in column 1 read *Removal and inhibition of corrosion* for *Removal and inhibition* and on page 376, Table 2, fourth column read *benzyl mercaptan on copper* for *benzyl mercaptan no copper*.

NEWS PAGE

Variation in corrosion resistance of polyester resins

TESTS have been carried out by immersing castings and laminates made from three different polyester resins (*bis*phenol A, *iso*phthalic and general purpose) in eight corrosive aqueous solutions for periods ranging from 24 hr. to 90 days and noting the changes in physical properties. The corrosive media included distilled water, 5 per cent. sodium hydroxide, 5 per cent. nitric acid, 25 per cent. sulphuric acid, 15 per cent. hydrochloric acid and 25 per cent. acetic acid.

One significant finding was the inapplicability of a fast screening technique as an index of corrosion resistance. In the screening trial, castings made from the three resins were subjected to boiling sulphuric acid, distilled water and sodium hydroxide for 24 hr. It was found that a resin might withstand the screening test satisfactorily, but would not hold up after longer immersion periods.

This information is valuable in selecting polyester resins for lining tanks and other metal surfaces.

TECHNICAL SECTION LIBRARY

TAPPI Data sheets
(*Technical Association of the Pulp and Paper Industry, New York, 1960*)

A–1 Weight of wood per cord
D–5 Ross diagram—sulphite curve
D–6 Lignin-kappa relationship for kraft pulps (poplar, spruce and Jack pine)
O–12 Weirs (discharge over weirs)
O–15 Measuring flows by the orifice method
Q–9 Bark data
Q–14 Steam pipe sizing
(Velocities for 0.25, 1, 2 and 4 per cent. pressure drops at 15, 60 and 250 lb./sq. in.)
R–15 Amperes per phase in three-phase circuits at different voltages and (transformer) kVA loads
R–16 Estimated ratings of old design oil circuit breakers
S–0 Bibliography of instrumentation (32 references)
B–3 Pulpstone markings

Book review

***Papermaking practice*—**

H. Hardman and E. J. Cole

(Manchester University Press, 1960, 322 pp., bibliography 10 pp., 45s.)

IN the preface to the book, the authors state that it is a modified form of 36 articles that originally appeared in *The Paper-Maker* and is intended to provide information not normally found in a textbook. The authors state that they have two groups of readers in mind: the student taking his final paper examination and the busy papermaker with limited time for reading.

Because of its origin as a series of articles, the book does not read as a complete work, although the chapters have been arranged in the normal sequence. It certainly lives up to its aim of providing only unusual information. For example, the chapter on beating does not contain one diagram of a beater; it hardly describes a beater, yet deals in an excellent manner with a modern theory of beating. It would perhaps have been useful to have seen this theory extended to include mixed beating of new fibre and that most widely used material, broke.

The first five chapters deal with woodpulp and include the rather newer neutral sulphite, semi-chemical pulp. All these are good, but the first one, on groundwood, is particularly good, showing the effect of variables such as stone, surface, moisture, temperature, pressure, etc., also the uses of the different types of ground pulps.

The screening of woodpulp and drainage on the papermachine have also been given thought and diagrams illustrate suitable systems based on the principles laid down by Steenberg. The importance of bleaching as a continuation of the digestion process, as far as lignin removal is concerned, is recognised in the excellent chapter on this subject.

There is a chapter on stock chest design, which is of considerable interest and should be read by anyone concerned with the design of a new system. The chapter on stock and backwater flow systems is also of general interest as probably the only one of its kind and it is pointed out that a thorough understanding of what is happening is being only slowly realised by papermakers and that very few measurements have been published.

Sizing is dealt with—both conventional beater additions, tub sizing with starch and gelatine—also the use of surface sizing by a number of newer materials. This chapter could perhaps be very usefully extended by a discussion on the moisture content of the paper entering the size bath and its effects on the penetration of the size, also the usefulness of the size press or bath in helping to produce flat paper. One might consider, too, the compatibility of other materials such as plasticisers with the various sizing materials.

There are several chapters that discuss the machine wire, patching it, changing the wire, etc. in a very readable fashion and, although these things vary considerably from mill to mill, the information contained will be very useful to any young papermaker. There is an excellent chapter that outlines the use of wet felts and their structure.

Perhaps some of the most useful and controversial chapters are those on the use of suction rolls at the couch and for pressing, the discussion on how water is removed by means of the felt and on the causes of shadowmarking. All readers are strongly recommended to study these chapters; at the same time, as this subject is so new, they would be recommended to read as well any other written matter they can find on the same subject.

There is a chapter entitled, *Some problems of drying*, which, although not intended to describe exactly what happens, is extremely useful in a greater understanding of this section of the papermachine.

In general, to sum up, this is a most excellent volume, discussing a very large number of papermaking problems. It most certainly deals with all sorts of things that have never been gathered together in one volume before and it can most certainly be highly recommended to any student or papermaker.

William F. E. Robinson

Russian Paper Industry *(continued from page 471)*

New technical development in boardmaking—
P. I. Klistov and V. V. Sharenkov 25
A description of a new and more efficient type of board dryer using heated rolls and hot air circulation.

Reducing the production costs of paper for note-book covers— P. A. Tumbin 26
Unbleached pulp was used instead of bleached.

Press felts for use in making condenser paper—
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An account of the properties required in these special felts.

The control of drying cylinders

B. W. BALLS, B.Sc., M.I.Chem.E.

Technical Sales Manager, Foxboro-Yoxall Ltd.

GIVEN AT THE FOLLOWING MEETINGS—

NORTHERN DIVISION: ENGINEERS' CLUB, MANCHESTER ON 8th JANUARY 1960, MR. P. A. DUXBURY IN THE CHAIR

SCOTTISH DIVISION: CARLTON HOTEL, EDINBURGH ON 24th FEBRUARY 1960, MR. C. G. WALLACE IN THE CHAIR

Synopsis

The need for automatic control of drying steam is demonstrated. Various indirect methods of control by temperature, pressure, pilot dryer and sheet tension are discussed. The advantages of direct moisture control are described, particularly using a capacitance method of moisture measurement. Various systems are discussed and illustrated and reference is made to transverse measurement of moisture (scanning).

The drying problem

"HAVING pressed as much water out of the sheet as possible, there is still anything from 64 per cent. to 72 per cent. of water to get rid of. This is accomplished by running the paper over steam-heated cylinders on to which it is pressed by dry felts. The cylinders are of cast iron with highly polished surfaces and may be from 3 ft. (on old machines) to 6 ft. in diameter."[1]

The purpose of this paper is to examine a specialised aspect of drying, namely, the application of automatic control to regulate the admission of steam to the drying cylinders with a view to producing a dry sheet that has the required moisture content. Why *automatic* control?—because it is well-established that manual operation of the steam valve almost invariably leads to overdrying of the paper. Besides being wasteful, this practice leads to faults in subsequent processing of the paper and increases the tendency to paper breaks.

It is well known that paper exhibits an hysteresis effect—for any given value of air relative humidity, there are two values of paper equilibrium moisture content, the higher being obtained when the paper is dried and the lower when dry paper is moistened. During subsequent processing, overdry paper will regain moisture to the lower equilibrium value and then absorb additional moisture towards the higher value. This can cause dimensional instability, leading to imperfections in processing. On the other hand, paper that is too moist will blacken in the calender or supercalender and is less tractable than overdry paper, hence the tendency for the dryerman to overdry it. A recently published paper is an excellent presentation of the subject.[2]

The following points are relevant to the economics of drying. Assume that a machine making 100 tons/day is equipped with automatic control, so that, instead of overdrying to 4 per cent., the paper can be produced at 8 per cent. to meet a sales specification. The daily savings due to the 4 tons/day of water difference are—

1. 4 tons of pulp (including cost of preparation).
2. 12 tons of steam (assuming 3 lb. steam/1 lb. water evaporated).
3. Capital savings by increased production of saleable paper.
   This means that a new machine is forestalled to the extent of 4 per cent., at least. In fact, the figure is usually higher, as controlled drying permits higher production rates. This is because the machine can operate more closely to the design limits, there are fewer paper breaks and, following a break, production is restored more quickly, since overheating is reduced. Furthermore, reduction in breaks leads to savings in broke handling and an extension to felt life.

A well-engineered dryer control installation will amply repay the capital expenditure in less than 12 months.

A dryer control system is an expensive installation to use for tracking down faulty operation. Significant changes in moisture in the dry sheet are caused by variations in consistency at the stuff gate. When checks have been made, with a substance gauge, changes in moisture content exactly reflect changes in weight; however, irregular performance in the breast box, fluctuating vacuum, faulty press operation, changes in machine speed, faulty power supply are also causes of variable drying. The steam supply pressure should be constant and controlled as closely to the machine as possible. The condensate removal system must be in proper working order so that complete dryer drainage is assured. It may be necessary to install a condensate removal pump to obtain the best results.

Control methods used

THE following list (by no means complete) is an attempt to classify a number of well-tried methods of control—

1. Indirect

Measurement of a variable that reflects changes in dryer performance—

(*a*) Temperature or pressure of the steam supply to the drying cylinders or inside a selected cylinder.
(*b*) Cylinder surface temperature.
(*c*) Pilot drying cylinder.
(*d*) Sheet tension.

2. Direct

Measurement of sheet moisture content by—

(*a*) Sheet and cylinder temperature difference.
(*b*) Surface humidity.
(*c*) Electrical resistance.
(*d*) Electrical capacitance.

In general, group *1* methods are the easier to apply to an existing machine and are essentially non-contact methods, not depending upon the properties of the sheet itself (*1*(*d*) excepted); but group *2* methods require intimate contact with the sheet, with attendant problems of location, marking, sample size, threading-through and paper break.

Group 1: Indirect methods of moisture control

1(*a*). *Steam temperature or pressure*

THIS is the simplest of all control systems to apply and is therefore the best known and the most widely used. It derives from the method of manual operation, whereby the dryerman manipulates the steam supply valve to maintain the required steam pressure in the dryers. An automatic controller measures the dryer steam pressure and automatically positions the steam valve to maintain the pressure at the desired value.[3] The dryerman makes an adjustment to the controller index value to compensate for weight and furnish changes on different orders and major variations in operating conditions. As a first approximation, all steam cylinders directly connected to a common system are at the same pressure. Therefore, a representative pressure measurement can be made in the steam supply pipe on the downstream side of the control valve before it branches to the individual cylinders [Fig. 1(*a*)]—that is, the system can be connected to the steam pipework, without interfering with the machine construction.

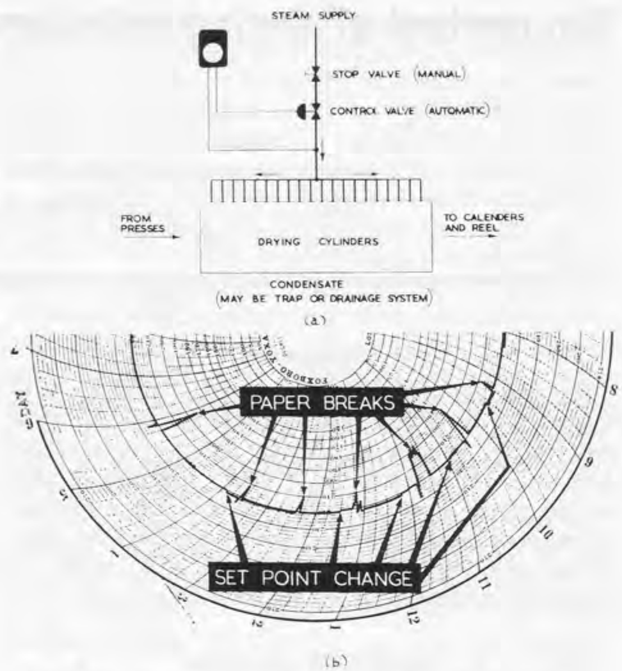


Fig. 1—(*a*) Temperature or pressure control system
(*b*) Typical chart record

Steam pressures and saturated temperatures are related by the vapour pressure curve and this indicates that, at low pressures, temperature provides the more sensitive measurement. Furthermore, for directly connected instruments (no transmission of signal), low range pressure elements may be less satisfactory than temperature elements for the corresponding values. These considerations have led to the widespread use of temperature control rather than pressure control below 15 lb./sq. in. (250°F).

Temperature elements (expansion-type bulbs, thermocouples or resistance bulbs) have been located inside a typical cylinder, using a glanded seal. Thermocouples have been embedded in the cylinder wall and connected to the instrument via a slip ring or similar device. Experiments conducted over a number of years have yielded no evidence of superiority for these more complicated devices. Provided the signal is responsive to sheet changes, to steam variations and is reproducible, its absolute value is unimportant. These conditions are fulfilled by a simple pressure or temperature controller. Fig. 1(*b*) is a chart taken from an air-operated temperature recorder controller fitted with proportional/integral[3]

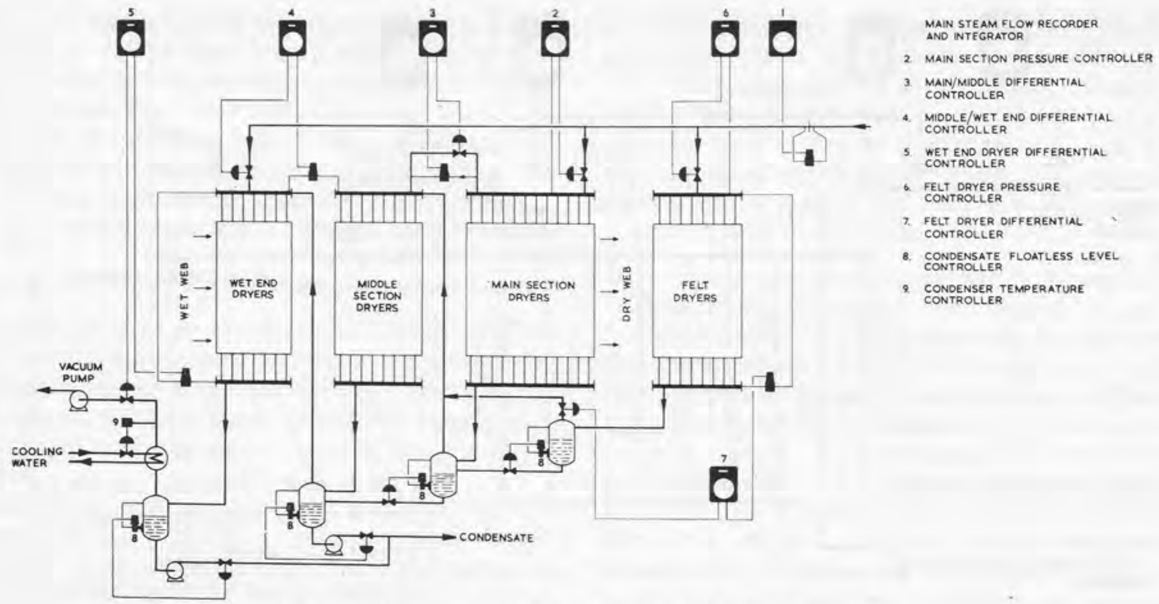


Fig. 2—Pressure control system for high speed machine

control action. The behaviour at a break is clearly seen. Note the speed at which the temperature is restored, following a break.

During a prolonged paper break, it is necessary to reduce the temperature to prevent the felts from drying out, thereby leading to overdrying when the sheet is restored. This may be done manually by the dryerman adjusting the controller index value or automatically by incorporating a photoelectric paper-break switch. When the sheet is restored, the index is returned manually or automatically, respectively.

Control should be applied at each stage of the drying section where a hand regulating valve is normally used. On machines with a size press, it is better to use two controllers—before and after the press. Many modern machines are fitted with condensate drainage and flash steam systems, which may be fitted with differential pressure control to maintain the flow of steam condensate. This is particularly applicable to high speed machines when condensate is removed by rotating siphon pipes and a high differential pressure is essential to overcome centrifugal force (Fig. 2).

1(b). Cylinder surface temperature

The surface temperature of a small section of one drying cylinder may be measured by—

1. A shoe-type element that is in contact with the surface (bi-metal strip, expansion-type bulb, thermocouple or resistance bulb).

2. A non-contact element that is shaped to the surface of the cylinder and is essentially a thermopile, measuring the heat radiated from the cylinder.

The true surface temperature of the cylinder is a most difficult measurement to make.(4) The measuring element must be mechanically robust, since it is in the dryer nest and therefore in the front line of operation. This method produces a measurement that is the resultant of the true surface temperature, friction effects and the temperature of an air gap between the element and the cylinder. The radiation element is affected by surface emissivity changes. Both elements are subject to variable errors from ambient effects such as draughts.

An additional control lag is introduced into the controller loop, because of the multiple heat transfer lag, comprising the cylinder wall and the condensate and air films on either side.(3) This leads to a slower response at paper break, with consequent lost time in restoring equilibrium conditions.

The major objections to surface elements are their liability to mechanical damage, the need for frequent cleaning and the possible interference with clearing and threading through at a paper break. No advantage is obtained compared with method *1(a)* and considerably more maintenance is incurred.

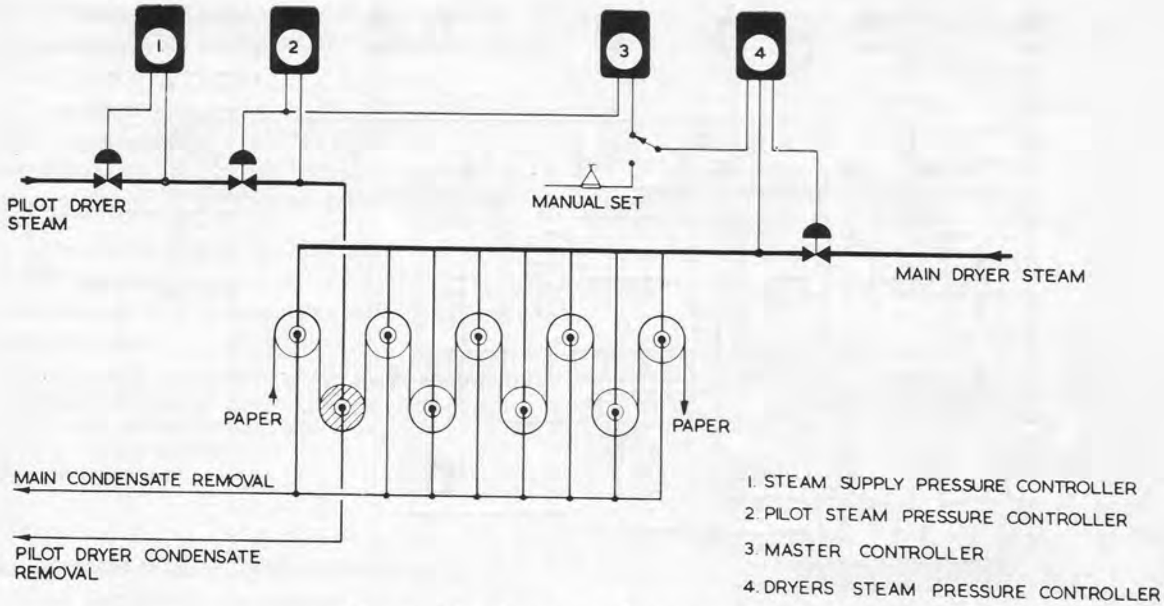


Fig. 3—Pilot dryer control system

1(c). Pilot drying cylinder

Several systems are in use that depend upon the performance of a single cylinder, which has an individually controlled steam supply and condensate removal system. The flow of steam through the pressure control valve is representative of the steam required for drying. This value is used as the measurement signal for a master controller that sets the index value of the main dryer section pressure controller in a cascade system[(3)] (Fig. 3).

In theory, the pilot dryer system is a substitute for direct moisture measurement and control, but it is susceptible in fact to a number of variables such as—

1. Superheat in the steam.
2. Ambient changes, affecting drying of felts, etc.
3. Condensate variables.
4. Changes in sheet weight and furnish, which affect ease of evaporation of water.

Furthermore, of necessity, the pilot cylinder must be located in the main dryer section to be representative and to minimise ambient effects and cannot take into account variations that occur after the sheet has passed by. Therefore, in spite of the increased instrumentation, it is doubtful if corresponding advantages can be obtained.

1(d). Sheet tension

This method is not widely employed, but is mentioned from time to time in discussion on this subject. A motion transmitter, which converts linear movement into a 3–15 lb./sq. in. air transmission signal, is installed so that the measured movement is due to the characteristic slackening or tightening of the paper web as it passes from the last dryer to the calender or at some convenient pass-line at the dry end. The air signal then operates a pneumatic receiver controller, which adjusts the steam valve to maintain a constant tension in the paper web. It is difficult to see how this measurement is truly characteristic of sheet moisture, because so many other variables affect its value. Not much has been published in a way that demonstrates comparative tests with other indirect methods. The incidence of paper breaks requires a lock-up device to prevent the steam valve from opening or closing completely because of loss of tension; care must be taken during threading-through after a break, since the measuring head is in contact with the paper.

To summarise, the methods in this group are well-established and understood in mills where they are in operation. In spite of the fact that the moisture content of the sheet is not measured directly, the dryerman has a constant, but adjustable reference point and operation is thereby improved. The results obtained are better than those possible without control, with considerable savings in steam consumption. In the absence of evidence to the contrary, method *1*(*a*) appears to be the most useful for a wide range of applications and should be used in preference to the more complicated indirect methods, unless particular circumstances warrant the additional costs involved.

Group 2: Direct methods of moisture control

EACH method of control so far described suffers to some extent, because the dryerman is dependent upon time-honoured skills to check the dryer performance. This has provided sufficient motive for development of direct moisture measurement as a basis for dryer control.

As early as 1936, an article was published drawing attention to the problems of moisture measurement and describing a successful control system based upon the measurement of equilibrium moisture at the sheet surface (surface humidity).[5] This was an early application of radio frequencies for industrial measurement and set the pattern for future development. The majority of direct measurements now in use depend for their success upon modern electronic measurement and amplification techniques.

In every case, when a direct method of moisture measurement is employed, careful attention must be given to the behaviour of the system at a paper break and on threading-through. These are major considerations in judging the suitability of a moisture control system for mill use.

2(*a*). *Sheet and cylinder temperature difference*

This method is treated first, because it appears halfway between the indirect methods described above and the methods to follow. When the sheet leaves a cylinder, vapour flashes off and there is a measurable difference in temperature between the sheet and the cylinder surface. This difference is related to the moisture content of the sheet. The method combines the difficulties of surface contact, method *1*(*b*) and the pilot dryer, method *1*(*c*), for there are two points of contact and the system must be located in the dryer nest, if effects of ambient variations and ventilation are to be minimised. Since thermocouples are normally used, only point sampling is possible and there are accuracy limitations associated with the use of thermocouples at low temperatures.

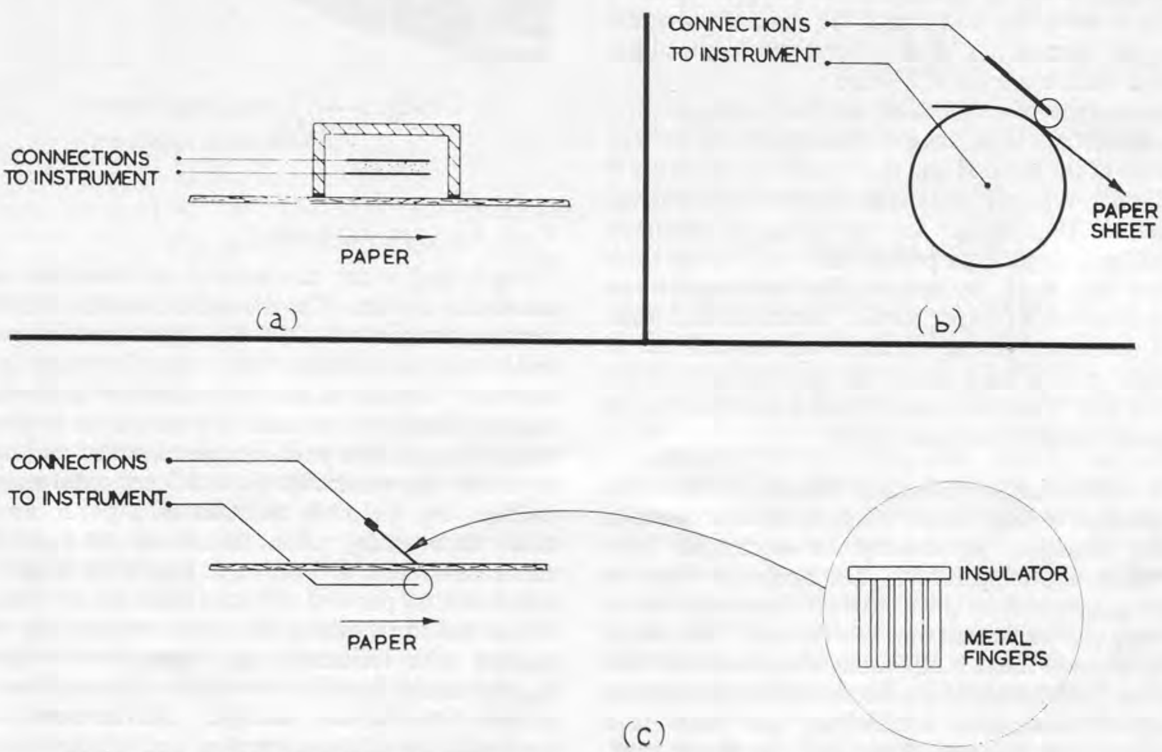


Fig. 4—(*a*) Surface humidity element; (*b*) Resistance element; (*c*) Surface resistance element

2(b). Surface humidity

The measuring element comprises a box, the lid of which is formed by the paper sheet [Fig. 4(*a*)]. The atmosphere inside the box attains equilibrium with the paper surface humidity. A condenser with a hygroscopic material for its dielectric is mounted within the box and variations in capacity are measured and amplified electronically.

Long experience with this system of measurement indicates its limitations, which are essentially similar to those described under method *2(a)*—small size of sample, the need to measure in the dryer nest to reduce effects of draughts, etc. In addition, the method has its limitations on high speed machines, on which a considerable 'wind' is generated.

2(c). Electrical resistance

Both dry paper and pure water are effective insulators, owing to their high electrical resistances; however, water in a paper sheet is contaminated with electrolytes and becomes electrically conductive to a degree determined by the nature and concentration of the electrolytes. Therefore, the electrical resistance of moist paper is a function of its moisture content, which, in turn, is a function of the concentration and type of electrolytes and operating temperature. Typical values are 10^8–10^{12} ohm.

In one type of application, a roller approximately 4 in. diameter $\times$ 10 in. long is mounted on an earthed cylinder at the dry end and the total sheet resistance is measured, together with the two surface contact resistances [Fig. 4(*b*)]. Another design of electrode system uses finger-type probes that trail on the sheet surface [Fig. 4(*c*)]. By suitable electrical connections, a combination of paper surface resistance and total sheet resistance can be obtained and several sets of contacts may be used across the sheet to increase the sample size. Constant contact pressure is necessary to eliminate contact resistance error.

To summarise, a resistance method is relatively independent of basis weight changes, but is sensitive to furnish changes, particularly to electrolyte concentration and temperature. The electrodes must be carefully mounted to give constant contact pressure, but they can be located close to the reel. Automatic lifting at paper break is advisable, with control system lock-up. The methods have limitations at high speeds, owing to electrostatic interference and there is a practical lower limit of 5 per cent. to 6 per cent. moisture content.

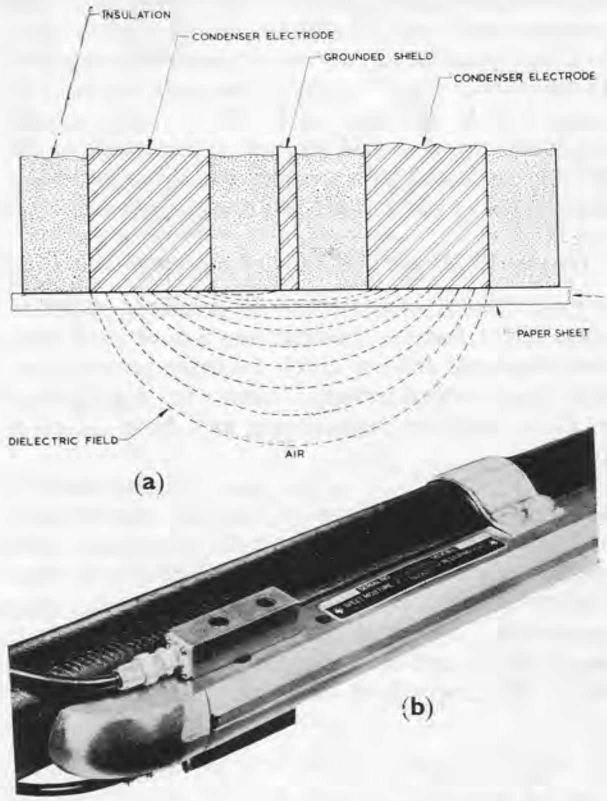


Fig. 5—(*a*) Capacitance element
(*b*) Detail of electrodes

2(d). Electrical capacitance

Paper and water can both form dielectrics for a condenser system. The dielectric constant for oven-dry paper varies only 2.5–3.5 approximately over a wide range of furnishes: the value for water is 80. Over the range 0–10 per cent. moisture content, the effective dielectric constant of moist paper is directly proportional to the oven-dry fibre content and to the square of the water content. At 5 per cent. moisture content, the dielectric constant of a paper sheet is twice the oven dry value. In addition, at 5 per cent. moisture content, a 5 per cent. change in weight will effect an 0.25 per cent. error in moisture content. At higher moisture values, this error reduces. By comparison with resistance, the capacitance method is slightly more sensitive to weight changes, but less sensitive to furnish changes. Furthermore, it is unaffected by soluble electrolyte and temperature and may be used down to 4 per cent. moisture content.

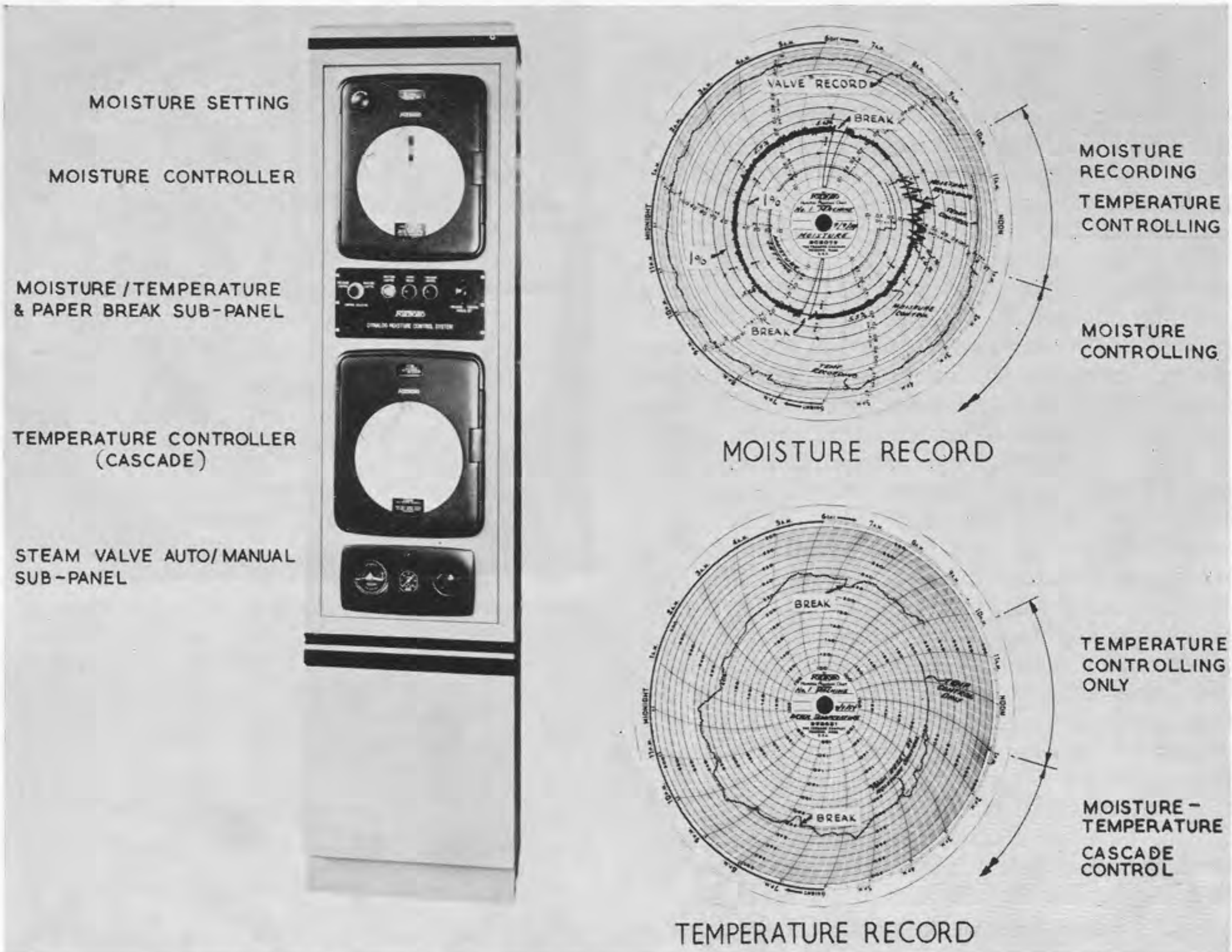


Fig. 6—(*a*) Moisture control cabinet; (*b*) Control charts, capacitance method

These fundamental considerations point to the use of capacitance and the choice is further supported by the comparative ease with which a well-designed measuring head can be installed at the reel or adapted for scanning across the sheet, since contact pressure does not affect accuracy. The B.P. & B.I.R.A. at Kenley, after considerable investigation, is supporting this method of measurement.

Modern designs of capacitance heads use the fringe field at the edges of the plates, thereby allowing the element to be placed on one side of the sheet only with obvious practical advantages [Fig. 5(*a*)]. This design reduces 'dead' capacitance almost to zero, so increasing measurement sensitivity. The construction illustrated in Fig. 5(*b*) has an electrode section $\frac{5}{16}$ in. $\times$ 60 in. long inserted in a stainless steel bar. The narrow width in the machine-direction reduces the possibility of the sheet parting from any portion of the electrode surface and permits a 60 in. length, which ensures good sampling across the machine width. A smaller head (15 in. long) is fitted to a scanning head to give moisture readings across the machine.

No mention has been made about fundamental calibration in terms of moisture content. This desirable objective is difficult to obtain. In view of the variables (other than moisture) that affect all the measurement systems described, individual calibration is advisable in every case. What is important, however, is the stability of the measurement system under given conditions of operation and repeatability when the similar conditions recur. These criteria decide for capacitance and resistance and, in practice, the capacitance method lends itself more readily to calibration *in situ*.

Moisture control

REFERRING to Fig. 1 and 2, moisture control can be obtained by measuring the moisture content of the sheet before the reel and either operating the main steam control valve directly from a moisture controller or, by connecting the output of a moisture controller to the index of the pressure (or temperature) controller [method *1*(*a*)], to form a cascade control loop.[3] The latter system has two advantages: theoretically and practically, it can be demonstrated that superior moisture control is obtained and, secondly, the pressure controller serves as a stand-by control system during emergency conditions when the moisture controller may be out of action (such as on starting-up, cleaning the measuring head or at a paper break). In general, therefore, a cascade system is employed and a typical control cabinet, using a capacitance system is shown in Fig. 6(*a*). Air-operated proportional/integral control[3] is used throughout. Additional features include automatic switching to steam control at a dry-end break or when the measuring head is lifted for cleaning, automatic switching to a lower index value of the steam controller at a wet-end break and provision for manual setting of the steam controller index by means of a reducing valve.[6] At the base of the cabinet, there is an auto-manual switch unit for the steam control valve. Fig. 6(*b*) shows typical charts taken from this moisture control system. Note the relatively good moisture measurement when the system is operating on temperature control only, also the behaviour at a paper break.

Fig. 7(*a*) shows a series of charts taken using the surface resistance method [Fig. 4(*c*)] and air-operated control. A comparison is drawn among—

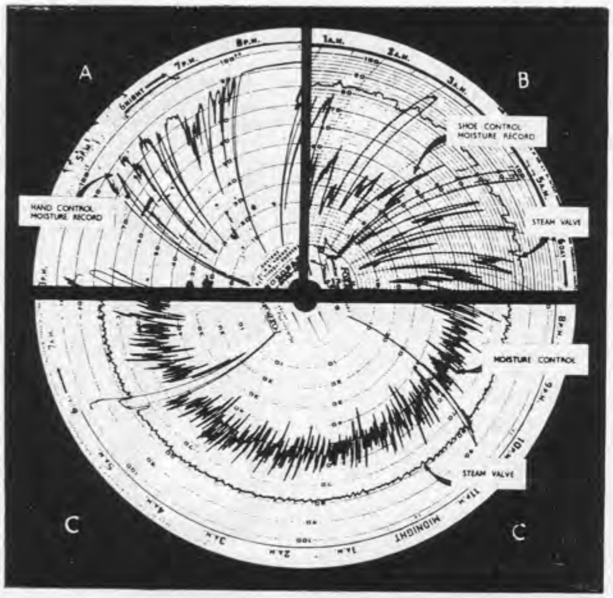
A. Hand control of steam valve—moisture measurement only.

B. Surface temperature control of steam valve, method 1(*b*)—moisture measurement only.

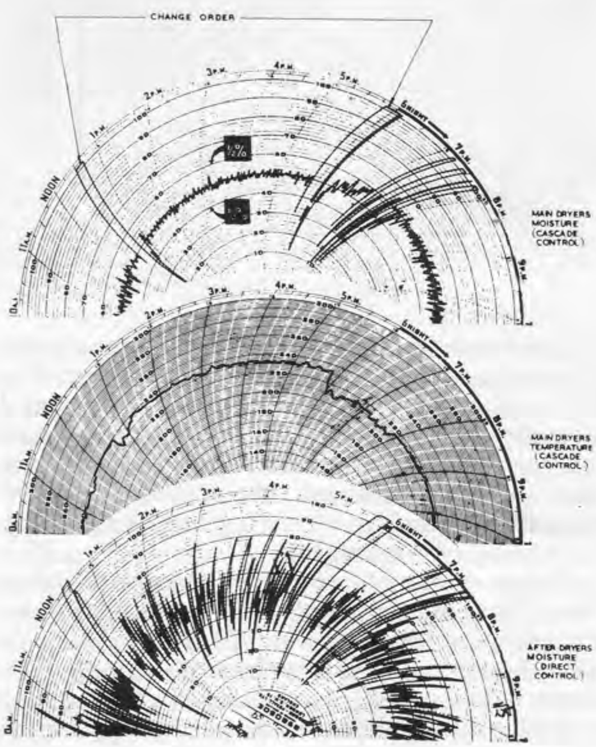
C. Moisture control of steam valve.

The relative quality of surface temperature control and the inadequacy of hand control are clearly demonstrated.

When a size press is employed, it is advisable to control moisture before and after the press and two control systems are required. In certain cases, adequate control of moisture can be obtained by using cascade control for the main dryers and direct moisture control for the after-dryers. Fig. 7(*b*) shows a typical set of charts, again using the surface resistance method [Fig. 4(*c*)] of moisture measurement.



(a)



(b)

Fig. 7—Control charts, surface resistance method

It should be noted that all the charts illustrated show average moisture control better than $\pm \frac{1}{2}$ per cent.

It is difficult in the space available to give a full analysis of the charts shown, but the apparently erratic peaks closely follow the changes in the machine performance, particularly the weight variations, chest changes, variable pressing and vacuum and erratic performance of cyclone cleaners. Fig. 8 shows typical reflections in moisture content from basis weight changes.

Scanning

OUR study would not be complete without reference to scanning. The installation cost is greatly increased due to the additional equipment required to traverse the sheet at uniform speed and to correlate the results on a chart. There is the problem of how to use the information obtained. In many cases, wet streaks are relatively constant in their location, but they may disappear and reappear in a random fashion. Nevertheless, in pursuance of a perfectly dried sheet, such information (however embarrassing) is necessary and the demand for scanning equipment is increasing. Control problems incorporating scanning are already being studied and the larger field is coming into focus.

Conclusion

MANY mills still rely upon hand operation of the steam valve. Whether the choice of equipment is in the direction of simple temperature control or full cascade moisture control, with built-in scanning, every machine now in operation can be improved. It is hoped that this paper will increase the interest in this vast field of study and serve to encourage many who may be standing hesitant upon the threshold of better dryer performance.

Acknowledgements

Thanks are due to many patient people in mills who have helped to sort the wheat from the chaff. Particular acknowledgement is made to considerable assistance received and permission to publish data obtained from the Wiggins, Teape Group Research Organisation, Beaconsfield; Bowaters United Kingdom Pulp & Paper Mills Ltd., Sittingbourne Division; Tullis, Russell & Co. Ltd., Markinch; Alex. Pirie & Sons Ltd., Stoneywood; Alex. Cowan & Sons Ltd., Penicuik; also to my colleagues at Foxboro-Yoxall Ltd., without whose help this work would not be possible.

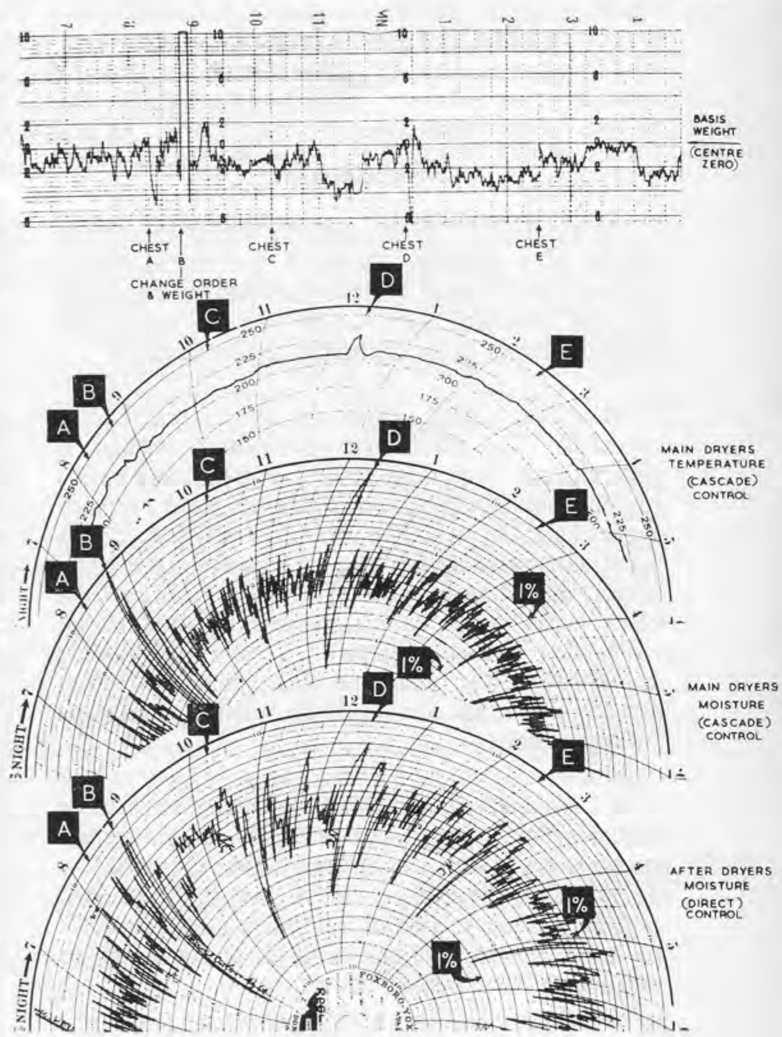


Fig. 8—Effect of basis weight changes

REFERENCES

1. Clapperton, R. H., *Modern Paper Making* (Blackwell, Oxford, Third Edition, 1952), 303
2. Grant J., 'The dimensional instability and conditioning of paper': *World's Paper Trade Rev.*, 1959, **152** (22), 1669
3. Balls, B. W., 'The application of instruments, with particular reference to automatic control': *Proc. Tech. Sect. B.P. & B.M.A.* 1956, **37** (2), 195
4. Hopkins, L. F., 'A new drying cylinder surface temperature thermometer': *Proc. Tech. Sect. B.P. & B.M.A.*, 1958, **39** (1), 11
5. Ehrishman, H. O., 'Moisture control on papermachines a necessity': *Paper Mill News*, 1936, **59** (26), 99
6. *U.S.P.* 2 724 903 (29th Nov. 1955); *B.P.* 774 758 (15th May 1957)

discussion

Manchester

THE CHAIRMAN: When applying drying control by means of a moisture meter, it was stated that a moisture variation of $\frac{1}{2}$ per cent. is measurable. How are the moisture tests carried out to enable the moisture meter to be calibrated to this accuracy?

MR. B. W. BALLS: There are several well-known methods. The traditional gravimetric method is difficult, but, by careful control, reproducible results are possible. Spot tests with resistance meter or sword hygrometer are used. The main difficulty is to obtain representative samples. The capacitance meter has a direct calibration in the range $\pm$ 2 per cent. of the centre scale value, which reduces the number of calibration checks necessary. I have had limited experience in the technique of machine calibration checks. I see that Mr. G. Hyde is here: perhaps he will contribute.

THE CHAIRMAN: It was stated that both the resistance methods and capacitance methods of measuring moisture are to a greater or lesser degree influenced by paper quality (substance, electrolytes, etc.), but it is possible in spite of this to calibrate a moisture meter to control drying. How often is it necessary to recalibrate the moisture meter?

MR. BALLS: In general, a calibration check is necessary grade by grade. Once the calibration has been established for a particular grade of paper, then a return to that grade requires only that the instrument is reset to the required settings.

MR. G. R. HYDE: Mr. Balls has mentioned the improvement in moisture control that can result from the minimisation of variables entering the moisture system. I would like to endorse this view. We have recently had experience on a machine with a size press of the use of two moisture control systems, one before and one after the size press. A noticeable improvement is obtained in post-size press control following the introduction of pre-size press control. The latter system helps to minimise supply side disturbances entering the post-size press system.

A slide was shown indicating the effects on moisture control of chest changes. The resulting variations in moisture are large, far larger than anything I have experienced on moisture systems. May I ask Mr. Balls whether this machine was equipped with consistency control, since it is evidently a step change in this property that causes trouble?

On the subject of capacitance type moisture meters, I had always understood that the measurement is affected by furnish differences. Mr. Balls has implied that this is not so. Perhaps he could amplify this. The capacitance meter is sensitive to substance and an error of $\frac{1}{4}$ per cent. moisture content arising from substance changes of $\pm$ 5 per cent. is quoted. I would have thought that the magnitude of this effect would begin to be troublesome as far as accuracy of moisture control is concerned. Certainly, one would hope for nothing larger than this.

The Chairman has mentioned the difficulty of calibrating moisture meters and of checking that calibration is maintained over a period. The oven-drying method as an absolute measure suffers from inaccuracies; however, with a well-trained and organised team, accuracies of $\pm$ 0.2 per cent. moisture content on about 7 per cent. moisture content can be obtained using six samples. Probably the best method of checking the calibration over a period is by regular sampling checks using either the oven-drying method or one of the laboratory moisture meters.

MR. BALLS: You referred to Fig. 8: the machine had no consistency control at the time and the charts were chosen to emphasise the interrelationship between weight and moisture. Good consistency control considerably reduces deviations in weight and therefore helps to stabilise the dryer system.

The capacity system is only slightly affected by basis weight, but not by furnish. This derives from the high dielectric constant of water in relation to all other components in the paper. The figure of $\pm \frac{1}{4}$ per cent. variation for $\pm$ 5 per cent. weight variation relates to 5 per cent. moisture content. At higher values—and we are often concerned with paper at 6–8 per cent.—the variation is less. Good consistency control will reduce weight variations to less than $\pm$ 5 per cent., so that the corresponding moisture error is never greater than $\pm \frac{1}{8}$ per cent.

MR. D. G. PETRIE: I think that Mr. Balls has oversimplified the question of moisture control and given the impression that it is only necessary to fit a controller for all one's worries to be over. This, I am sure, is completely erroneous and a dangerous way of thinking, especially for a smaller mill that has not had much previous experience with control instruments. We installed our first moisture measuring instruments seven years ago and, despite a very large amount of work that has been done since, would still not say that we know all the answers.

At first, the best one can hope for on an older machine is to be able to follow trends and to see how some of the other variables in the process are interrelated. At this stage, one then has to concentrate on these individual points—consistency, head box level, couch and flat box vacuum, press loadings, beater settings—and work on them until they can be considered to be under control. Then one is in a position to install moisture control and will undoubtedly derive great benefits from it.

MR. BALLS: I must apologise if I conveyed the impression that the fitting of a moisture controller meant the end of all troubles. I would never intentionally encourage such an idea. I have tried to show that at least a consistency controller is essential and the points made by Mr. Petrie are all vital steps towards improved machine performance. When all these have been made, there is still the need for moisture control and it was the purpose of the paper to emphasise this point. I submit that some of the developments in recent years have made good moisture control a reality. I agree that we still do not know all the answers.

MR. C. G. LAWRENCE: A chart recording cylinder heat showed a very sudden and dramatic temperature drop and an equally dramatic recovery spanning the period when the paper was out of the dryer. Please explain fully the type of installation and method used to adjust the temperatures with such rapidity.

MR. BALLS: This question refers to Fig. 1, I believe. The dryerman reduces the setting index by about 5° at a paper break. This immediately closes the control valve sufficiently to keep the cylinders just hot enough during the break period. The setting index is restored to its original value when the sheet is returned. By this means, overheating is avoided. The same effect can be achieved using a photoelectric switch and an automatic setting unit.

MR. H. B. WHITEHOUSE: Any system of control of paper moisture content that operates through the steam supply to the papermachine is inherently rather sluggish, owing to the thermal inertia of the drying cylinders. Does Mr. Balls know of any application of controlling the supply of hot air to the papermachine that should result in substantially quicker response, therefore better control?

MR. BALLS: The drying system is not so sluggish as is commonly believed. The cascade system overcomes thermal inertia. Control by hot air is another subject, as is the use of hoods and I did not wish to broaden this paper. Control by hot air should be most effective and amenable to automatic operation.

MR. B. P. HEMINGWAY: How far would you say the accuracy of the capacitance method of moisture measurement is affected when the moisture content is not uniformly distributed throughout the sheet thickness, as in the case of multi-ply board using a water finish?

Secondly, when a scanning head is being used to supply a signal to the master controller, is the average moisture across the sheet automatically computed for purposes of control in the machine-direction?

MR. BALLS: The capacity head measures the average moisture content: special considerations are necessary when the method is applied to thick boards. Free water must not be present on the surface and therefore sprays should not be used. In most cases, sprays are used to correct overdrying, but, with moisture control to the required value, sprays can be eliminated in these cases.

The scanning head provides a signal proportional to moisture profile. The average signal can be computed or the system can be set to operate from the required section of the sheet, usually the wettest streak. This is a matter for individual case study.

Edinburgh

MR. B. WALTON: Referring to the charts recording moisture content at the end of the machine, there is a much wilder swing from low to high moisture content recorded when the backtender was manually controlling the drying section, compared with the small deflections on the chart reflecting instrumental control of the drying section. Do these swings reflect proportionally actual moisture content changes or does this property increase logarithmically as the deflection from the median line of no deflection increases?

MR. B. W. BALLS: The latter. Fig. 7(*a*) is a resistance record and is exponential from centre zero (50 on chart). The illustration shows how difficult it is for the dryerman to manipulate the steam valve and to maintain a constant moisture record on the chart. The controller is deviation-sensitive to values much less than the eye can detect. Furthermore, a human operator inherently waits to see what is going to happen and applies his correction too late.

MR. W. J. V. ANDERSON: What 'follow-up' devices are incorporated to prevent such a control system from hunting?

MR. BALLS: There is no 'follow-up' device. A modern pneumatic controller using proportional, integral and derivative actions is fully adjustable, so that the speed of response can be adjusted to match the natural response time of the drying system. If hunting occurs, the response of the controller is adjusted by routine methods until the correct response curve is obtained.

MR. T. CLAPPERTON: Paper is dried down to the low figure of 3 per cent. moisture because of the wide variation in moisture that can occur across the web of paper on the papermachine. By drying down to a low figure, the effect of these variations is considerably minimised and the paper reeled up is, as a result, more regular.

On the question of steam saving, would Mr. Balls confirm that in many mills nowadays the steam produced for the power demand is above that required for process work and therefore any saving of steam in the drying cylinders of the papermachine becomes much less attractive?

MR. BALLS: These are both good points. Overdrying is not the correct answer to the first question, as I indicated in the first part of the paper. Bad moisture profile requires correction on the machine. The first step is to obtain control of the required value of the average moisture content.

I agree that there is a surplus of steam in some mills, but many mills in my experience are interested in saving steam. Steam economy is just one advantage of moisture control.

Written contributions

MR. W. F. E. ROBINSON: The statement concerning the hysteresis effect is not entirely true. For example, a certain paper when dried from the higher value was found to have an equilibrium moisture content of 9.5 per cent. at 65 per cent. R.H. If made, oven-dried and reconditioned, the equilibrium moisture value was 7.0 per cent. and the paper was more stable. To reach the other side of the hysteresis curve, the moisture content must be increased to 25 per cent.

A simple method of expressing savings by moisture control is as follows. For the same raw materials, more water is sold when the paper is at the correct moisture content and not overdried. This extra quantity of water requires no production cost, no overhead cost and is sold at paper price.

In practice, I have found the surface temperature method to be satisfactory and better than an internal measurement. There is a measurable difference between inside and surface temperature, which is eliminated when there is a break, thus causing the steam valve to close. When paper returns, the extra heat present in the cylinders must be absorbed before controllable conditions are restored. I agree that there is the liability to mechanical damage and the need for cleaning. Suitable installations can be designed.

Having tried most of the methods for control described in the paper, I agree that direct moisture measurement, using resistance or capacity, provides the best basis for control of drying. In comparing the two, the required size of electrode is a debatable issue. The surface resistance method can be used with multiple electrodes or a single electrode, as required.

With closed circulation, the electrolyte concentration builds up to provide virtually a constant value, so that the resistance measurement is substantially unaffected. On the other hand, substance changes are more short term and would affect the accuracy of a capacity system.

I think this paper is a valuable contribution and is a good summary of the position to date.

MR. B. W. BALLS: In view of Mr. Robinson's experience in this specialised field, his comments are most welcome. In an effort to be brief, I over-simplified the statement on hysteresis and regain. The main point is to recognise the difference between the two values of moisture content for the same R.H. value.

My own experience of the use of surface temperature measurement systems differs: I believe Mr. Robinson compared surface temperature with inside cylinder temperature. We find that the best representative measurement is made in the steam pipe, as described in the paper, using a specially designed condensing chamber to measure the saturated steam temperature. The speed of response in the control loop is high and this is beneficial, particularly when there is a break. Furthermore, the system settles down rapidly when the sheet is restored. I have never observed equally good results from a surface measurement system. By comparing the chart records in Fig. 6(*b*) and 7(*a*), it can be seen that the moisture record when controlling from steam temperature is more nearly constant than when controlling from cylinder surface temperature.

The comments made on the resistance method of moisture measurement are interesting. I have explained in the text and in reply to Mr. G. Hyde (Manchester discussion) that the basis weight effect upon capacity measurement of moisture is negligible for all practical purposes.

MR. M. I. MAC LAURIN: The author states, "Over the range 0–10 per cent. moisture, the effective dielectric constant of moist paper is directly proportional to the oven-dry fibre content and to the square of the water content." This is contrary to the usually quoted simple equation—

$$K_x = K_o + 0.8x,$$

where K_x is the dielectric constant of paper having x per cent. moisture content, K_o when oven-dry.

Taking a representative value of 3.0 as K_o and the accepted value of 80 for the dielectric constant of water, however, the value of K_x for $x = 5$ per cent. is 7.0, agreeing with the author's calculation. Perhaps I am misinterpreting the expression *effective dielectric constant*?

MR. BALLS: By effective dielectric constant, we mean the dielectric constant measured by the instrument when a sheet of moist paper is located under the measuring head.

The equation of the curve obtained by plotting effective dielectric constant against percentage moisture content is—

$$K_x = K_o + 0.125x^2.$$

By substituting $K_o = 3.0$ and $x = 3$ to 10, the following results are obtained

x	3	4	5	6	7	8	9	10
$K_o + 0.8x$	5.4	6.2	7.0	7.8	8.6	9.4	10.2	11.0
$K_o + 0.125x^2$	4.1	5.0	6.1	7.5	9.1	11.0	13.1	15.5

From this, it can be seen that, in the practical range of 4–8 per cent. moisture content, there is reasonably close agreement between the two equations.

The equation we use agrees very closely with some figures published in *A.T.I.P. Bulletin*, 1953, No. 7, p. 206 and is believed to be more correct than the simpler equation quoted by Mr. MacLaurin.

Instruments and methods for the evaluation of head box performance

G. GAVELIN
Central Laboratory of the Swedish Papermills

GIVEN AT A MEETING OF NORTHERN DIVISION ENGINEERS' CLUB, MANCHESTER ON 4th MARCH 1960, MR. P. A. DUXBURY IN THE CHAIR

Summary

When beta-gauge profiles are fed through a computer, information is obtained that allows calculation of the standard deviation of the basis weight, as well as the cross-direction, machine-direction and random components of this entity. This is used to classify paper samples reproducibly with regard to evenness of basis weight and indicates where the variations may have originated. Caliper profiles are also helpful in this tracing. Pressure oscillations in piping and head box have been recorded, with special emphasis on the tracing of slice area oscillations back to their places of origin. Trouble caused by vibrating machinery was studied with a vibration analyser.

High speed photography has proved useful in revealing the state of the jet and the manner of impact of the jet on the wire.

Since the air content of stock influences flow conditions, head box air was determined with a sensitive air analyser.

Introduction

WHEN old papermachines are replaced by new ones with considerably higher operating speed, the papermakers are faced with many new and vexing problems, especially in connection with head boxes. To management, the problem presents itself when the machines are ordered and it is found that the head boxes offered today differ materially from those built a year or two ago, without any sign as yet of the arrival of a commonly accepted type of head box.

The investigation of head boxes calls for expensive instrumentation and qualified personnel for the operation of it. Few European paper producers are large enough to keep such a group of head box investigators occupied constantly, even if the expenses could be justified. In a situation, when efficient use of engineers is of paramount importance, it is believed that the head box field offers a very good example of an area where national resources are advantageously pooled.

Beta-gauge profiler

BETA-GAUGE profiles of paper are well known and much used by papermakers as a guide in running their machines. If the profiles are to be used for head box investigations, however, it is necessary to apply some method whereby the profiles can be converted into figures for filing. A method developed by D. D. Forsythe of Powell River has been found quite satisfactory.[1]

According to this method, eight cross-direction strips are taken from adjacent layers of a reel and fed through a beta-gauge, one at a time. The strips are also fed through all together and it is assumed that the resulting composite profile eliminates seven eighths of the random variations. If the standard deviation of each beta-gauge profile is known, it then becomes possible by simple calculation to determine the cross-direction and random components of the basis weight variation.

The standard deviations are obtained with a Litton computer equipped with a curve follower. Table 1 shows results obtained by this method.

TABLE 1—STATISTICAL ANALYSIS OF BASIS WEIGHT VARIATIONS

Date	*Machine*	*Variations of cross-direction strips*			*Variations in machine-direction strips,* %
		Total, %	*Cross-direction,* %	*Random,* %	
3/ 4 /59	1 A	2.1	1.5	1.5	—
11/ 4 /59	1 B	4.1	3.2	2.5	—
6/ 5 /59	2 C	3.2	2.9	1.5	1.3
10/ 6 /59	1 D	3.6	2.9	2.1	1.3
10/ 6 /59	9 D	3.2	2.7	1.8	1.6
12/ 6 /59	1 E	3.2	2.2	2.3	2.2
17/ 6 /59	1 D	2.9	2.4	1.6	1.4
14/ 9 /59	4 D	4.7	4.1	2.4	2.1
20/11/59	4 D	2.6	2.1	1.6	1.5
20/11/59	4 D	2.9	2.4	1.7	1.5
2/12/59	1 D	2.6	2.1	1.6	0.8

It is advantageous also to test three machine-direction strips, 50 ft. long, cut out at front, middle and back in order to check on the existence of regular basis weight variations with time. The average standard deviation of these strips is presented in Table 1 as another indication of the level of basis weight control obtained.

Now, from theoretical considerations, one would expect the cross-direction component to indicate above all the success of the slice adjustment. The machine-direction component alone would be affected by consistency or wire speed variations while the random component would indicate the turbulence level in head box and slice jet. In practice, however, one cannot at all be convinced that the lines of demarcation between the components are very strict. At least, there are factors that may conceivably affect all three components—for example, head box consistency, freeness and slice setting.

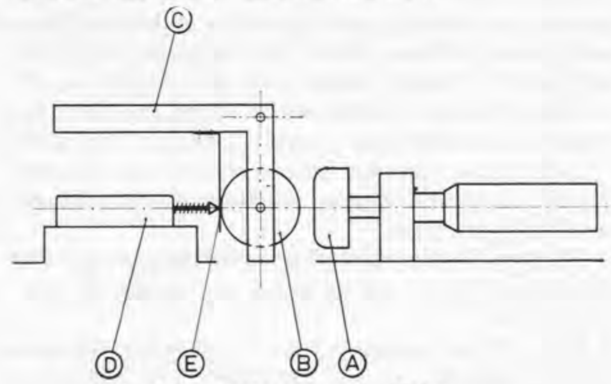
When basis weight variations are used as an indication of the stability and evenness of the slice jet, one also has to take into account all the factors that will affect the basis weight after the slice. Some of these are wire speed with relation to jet speed, wire speed variations, a ridged or plugged wire, a slack wire, backwashing from the table rolls and spraying or spouting on the wire. All these factors, however, constitute flaws that ought to be corrected before head box investigations are undertaken.

If the figures in Table 1 are studied, it is seen that results obtained on the various machines are rather consistent. When the same machine was sampled twice with a couple of hours' interval, the cross-direction component had changed far more than the random component that would be expected. When the whole head box was replaced, as was done in one case, this caused considerable reduction of both cross-direction and random components.

Figures like these will become more meaningful, of course, the more data one has to compare them with. By building up a file of such data, it may be possible one day to pass judgment on the basis weight control achieved by a given papermachine at a given speed.

Caliper profiler

If basis weight profiles are relied on for judging the performance of a head box, it may be helpful also to study the caliper profiles of the paper produced. For this purpose, a caliper profiler was built at the Central Laboratory of the Swedish Paper Mills, the principles of which are made clear in Fig. 1. The paper is drawn through a gap between a rotating roller with 1 in. face and the stationary shoe of a micrometer screw. The roller, which is pivoted, acts on a strain gauge transducer. Similar instruments have long been on the market, but this instrument offers the considerable advantage of being combined with a beta-gauge. The caliper profiler sits on top of a basis weight profiler using the same feeding device and an identical recorder with recorder and electronic parts inside the original cabinet. The instrument will draw two curves of the same strip of paper with a spread of less than 0.001 mm. between the two curves. The results correlate very well with those obtained by standard caliper testing. With this combined instrument, basis weight and caliper curves are obtained in one operation on chart papers of identical length, so that the two properties can easily be compared at every location across the width of the wire.



A—Micrometer C—Yoke
B—Steel ball D—Strain gauge
E—Metal sheet

Fig. 1—Principle of caliper profiler

Fig. 2 illustrates the use of this instrument. It shows two sets of eight profiles each, made from the same eight strips of paper cut from eight consecutive layers of a newsprint reel. The upper set was obtained with the basis weight profiler, the lower set was obtained with our caliper profiler. Now, a study of these profiles reveals that the correlation between basis weight and caliper is very poor. The basis weight profiles were quite level, but marred by a number of deep ridges, probably caused by a corroded or damaged top lip. The caliper profiles showed up a very pronounced sine curve that strongly suggests improper crowning of some press or calender rolls. If the operator had tried to straighten out the caliper profile in this case by manipulating the adjusting screws on the top lip, the result would have been a most irregular basis weight profile, for which the head box could quite erroneously have been blamed.

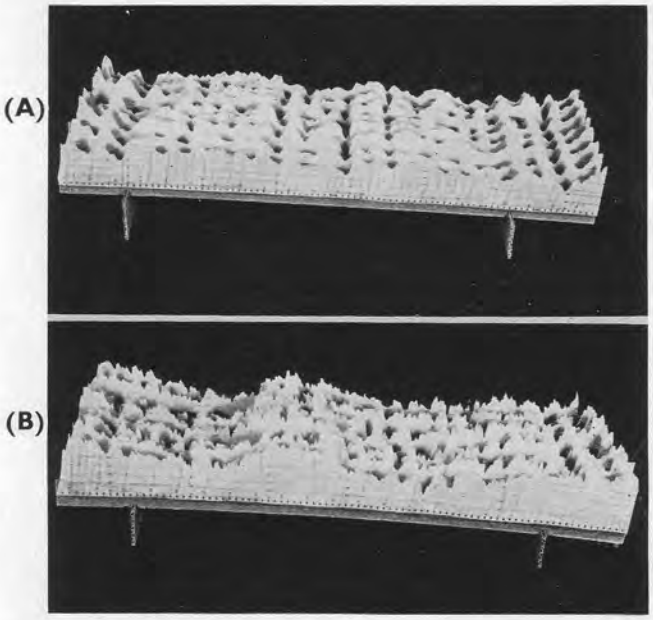


Fig. 2—(A) Basis weight and (B) caliper profiles of a newsprint sample

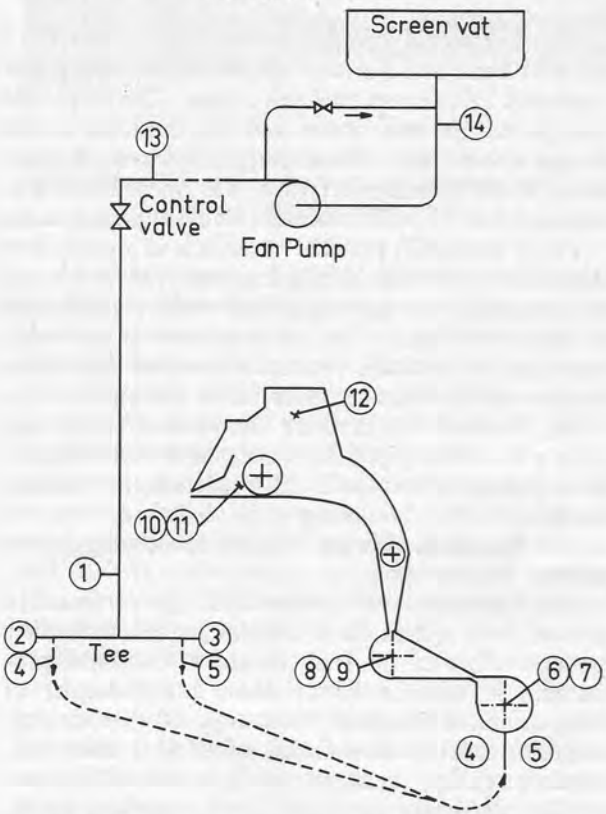


Fig. 3—Head box system with measuring taps

It is at once clear that this example points to a very serious limitation in the use of basis weight profiles for head box evaluation. Head box performance, however, is of interest only so far as it has a bearing on the basis weight distribution. Therefore, in spite of all the pitfalls, it is justifiable to look for the ultimate answer in the paper produced.

In practice, the solution to the problem is to make the investigation so thorough that it becomes possible to sort out the effect of the head box from all other factors influencing the quality of the paper. For this purpose, it is really not enough to have the basis weight and caliper profiles.

It would be a great help to have an instrument that will plot the moisture profile as well. Suitable moisture recorders are on the market. With a similar moisture profile available, it would be much easier to interpret the other two profiles.

One more very simple instrument is needed in order to judge basis weight profiles: this is a wedge, which is inserted into the slice at and in between each adjusting screw in order to measure the width of the slice-opening. If this test shows a distorted slice opening, the basis weight profiles should be given little significance. Preferably, the slice should be levelled up before the start of a head box evaluation. A lack of correlation between slice opening and basis weight is indicative of uneven flow in the head box, skating or a ridged wire.

Pressure oscillations

PRESSURE oscillations in the hydraulic system are of interest, only if they affect the paper produced. Such an effect, however, is often very difficult to prove only from analysis of basis weight variations. It is therefore necessary to analyse the pressure oscillations directly and then try to determine their harmfulness to the paper, if any.

Strain gauge transducers, mounted directly on $\frac{1}{4}$ in. taps screwed on to the pipes of head box walls may be used to take up impulses, which are suitably amplified, filtered and recorded on a two-pen recorder of the ink jet type. Although frequencies up to 100 c/s can be distinguished on such a recorder, interest is generally centred on the lower frequencies.

Fig. 3 shows a head box system with the positions marked where taps were provided for measurements. Two measuring sets were used simultaneously, one of which was kept all the time on one of the taps at the slice, while the other was moved from position to position. The idea behind this procedure is to trace

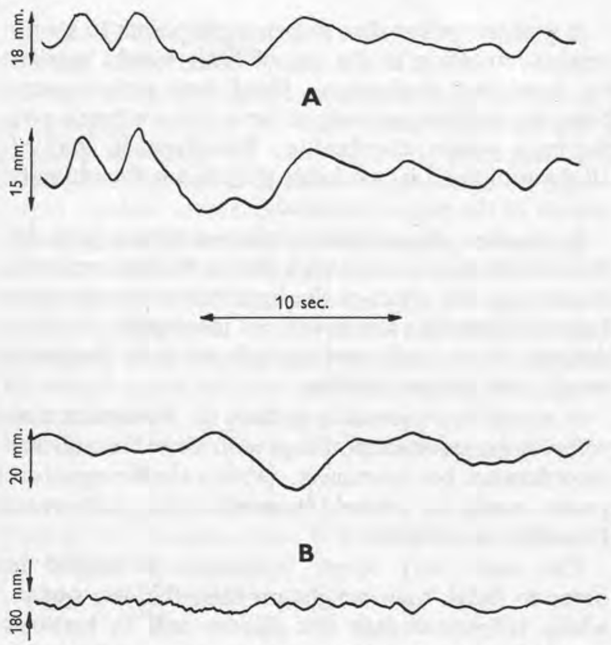


Fig. 4—Pressure oscillations at (A) both sides of a head box and (B) between the last perforated role and the slice

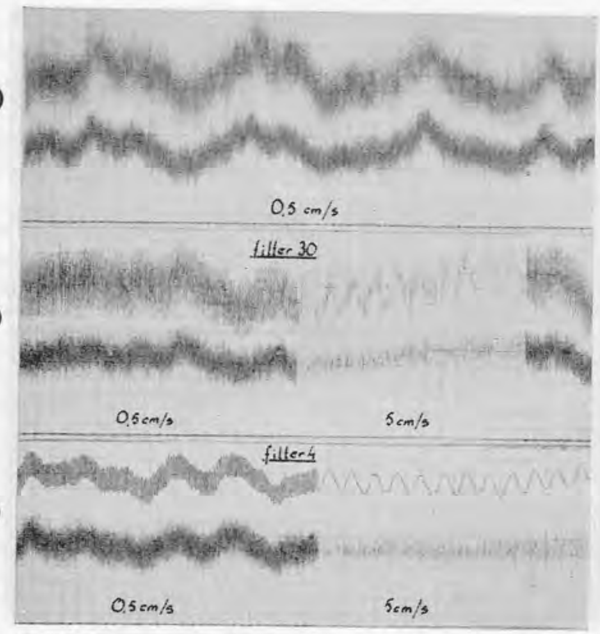


Fig. 5—Pressure oscillations in (A) slice area and in air space, (B) slice area and after fan pump

pressure oscillations from the slice, where they are definitely detrimental, back through the hydraulic system to their origin.

A few examples will perhaps best demonstrate the usefulness of this method. Fig. 4 shows irregular pressure fluctuations at the two sides of a head box in the area between the last perforated roll and the slice. The range is about 40 mm. water and the time 3–8 sec. Since the fluctuations at the two sides are obviously simultaneous, they cannot be caused by crosswaves or head box turbulence, but represent genuine pressure variations. The width of the band that represents the fast oscillations is 15 mm. water. In the middle and bottom graphs, one of the signals has been filtered to depress frequencies above 30 and 4 c/s, respectively. A small regular vibration of 9 c/s was all that remained. The high frequency oscillations were not judged to be detrimental.

Fig. 5 shows the same slice position compared in the upper part (*A*) with the air space at the top of the head box and in the lower part (*B*) with the pipeline after the fan pump. High frequency oscillations are not recorded. The correlation between the pressure fluctuations in the slice area and in the air space is striking and, since no correlation with the slice area could be discerned at any other position, it was concluded that the disturbance recorded at the slice originated in the air control system in this case.

Fig. 6 shows (*A*) pressure fluctuations at the slice of another head box that were caused by the opening of the reject valve on an enclosed screen. The amplitude was about 100 mm. water and the duration of the surges about 5 sec. These surges, however, did not occur every time a reject valve was opened and it is believed that proper adjustments would eliminate them.

Fig. 6 shows (*B*) pressure variations in a cross-flow distributor. The dominating frequency was 10 c/s, but the amplitude was modulated into waves with a length of about 40 sec. The phenomenon is probably explained by periodic resonance between the waves created by the rotating vanes inside the screens.

Fig. 7 shows (*A*) pressure fluctuations before and after a tee in the pipe after a fan pump. The disturbance caused by this tee is still moderate, the velocity of flow at the tee being only 4 ft./sec.; but, at higher velocities, this tee is likely to develop into a serious trouble spot.

When pressure oscillations of this type are found in a head box system, it is helpful to calculate their possible effect on the basis weight of the paper produced. It will be found that, for example, at 200 ft./min., a pressure fluctuation of $\pm$ 1 in. corresponds to a speed variation of $\pm$ 45 ft./min. and, consequently, a basis weight variation of $\pm$ 22.5 per cent. At 2 000 ft./min. machine speed, however, the same pressure variation means only

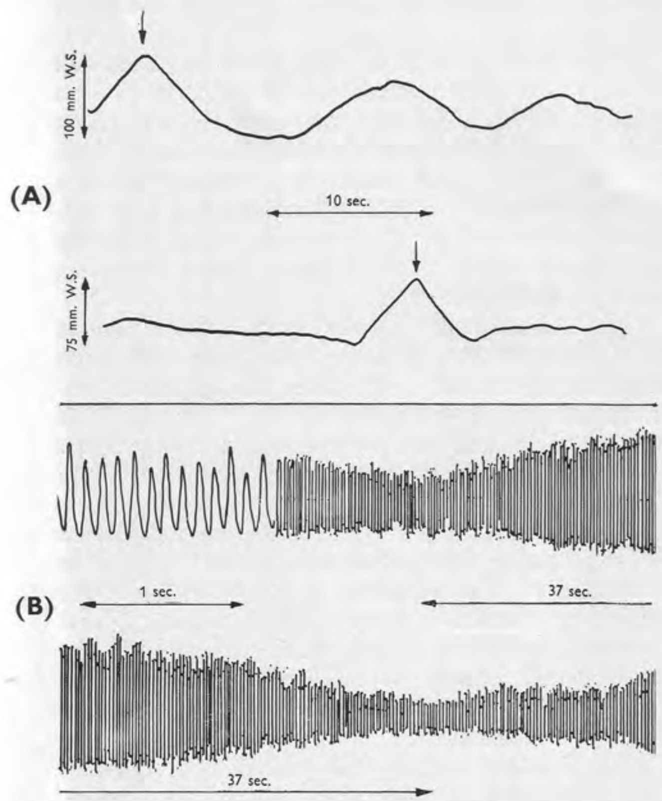


Fig. 6—(**A**) Pressure surges caused by the opening of a reject valve on an enclosed screen; (**B**) Pressure oscillations in a cross-flow distributor

$\pm$ 4 ft./min. speed variation, which should be insignificant. One should perhaps not conclude from this that speeding up the machine is the best cure for pressure fluctuations. Flows larger than the design flow generally mean increasing turbulence and this factor often weighs far more heavily than the stabilising effect of the higher head box heads.

Higher machine speeds also mean less time in the head box for disturbances to die down. This is especially noticeable in the area after the last perforated roll, where one wants to generate an intense, homogeneous, small scale turbulence that should, however, be largely dissipated at the time the flow reaches the slice.

Correlation of pressure oscillations in the hydraulic system, with basis weight variations in the paper, is more of a problem than one might think. If the pressure oscillations are regular, they can be traced by a Fourier analysis of beta-gauge curves. If, on the other hand, the pressure fluctuates in a fully irregular

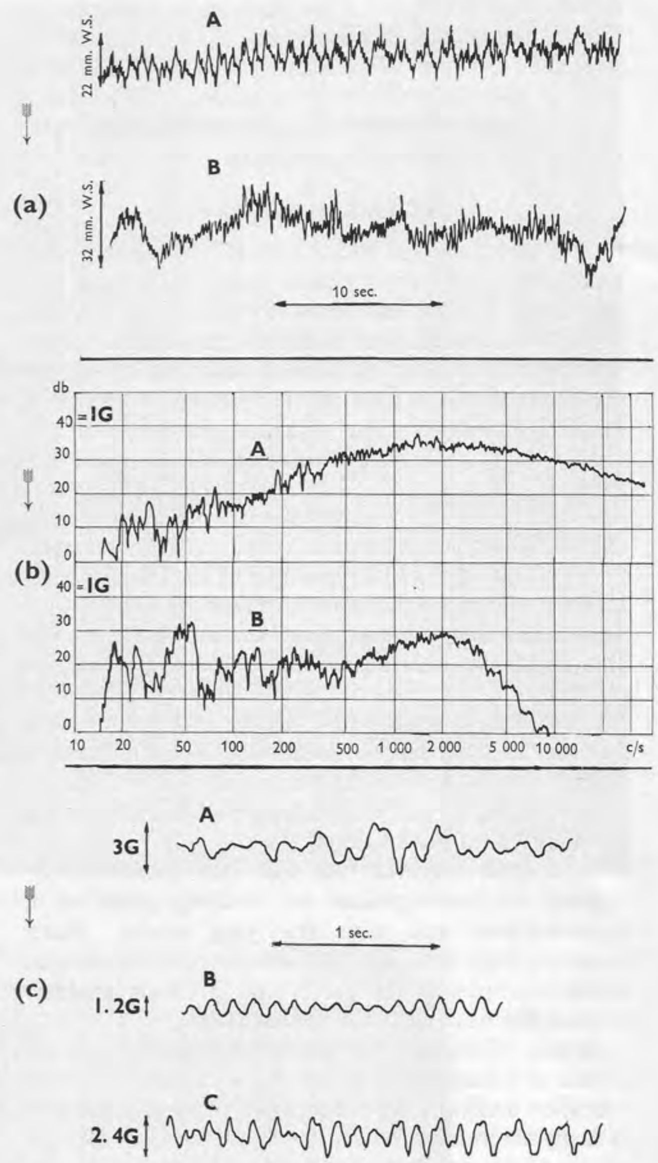


Fig. 7—(*a*) Pressure oscillations before and after a tee in the supply piping after a fan pump; (*b*) Pipeline vibrations before and after a tear drop valve; (*c*) Vibrations of the front wall of a head box at front, middle and back

manner, as was actually the case in these investigations, it is all but impossible to prove a correlation with the basis weight.

The effect of pressure oscillations on the stability of the jet is a problem in much need of investigation. It is conceivable that high frequency pressure oscillations will result in the breaking up of the jet—at least locally—before it reaches the slice. Indications of such a phenomenon can be observed in some of our photographs of the slice. Such a process will result in both random and cross-direction variations, which cannot be traced back to pressure fluctuations in the head box, except by a method of elimination.

Vibration analyser

IT is useful in some cases to study vibrations around head boxes and to correlate these with head box performance. The instrument to use for this purpose is the vibration analyser commonly used in shipyards. The pick-up of this instrument produces an electric signal proportional to its acceleration in the frequency band 2–30 000 c/s. The signal is preamplified and fed to the frequency spectrometer, where it is automatically filtered through 34 filters covering the range 16–32 000 c/s. The preamplifier can be set to record the vibrations as acceleration, velocity or displacement.

Fig. 7 shows in (*B*) an example of such a frequency distribution curve. It shows the vibration of a pipeline before and after a valve. Since the lowest filter is 16, the frequency distribution curves will give no indication of vibrations of lower frequency. The pick-up, however, is sensitive to vibrations down to 2 c/s. In order to study the vibration band 2–16 c/s, which is often the most interesting one, an ink-jet recorder is used. In Fig. 7, (*C*) is an example of ink-jet records showing vibrations of about 9 c/s.

It is quite obvious that this instrument can be applied to investigations on rotating parts of a papermachine and with gratifying results. Here, however, only head box problems are considered and a few examples of the use of the vibration analyser around the head box will be discussed.

Screen vibrations constitute the most common source of vibration trouble at the head box. With the vibration analyser, the propagation of these vibrations is easily determined and, if they reach the slice because of poor isolation between screens and head box, this is clearly indicated by the readings. Should the vibrations be amplified by the screens occasionally vibrating in phase or if resonance phenomena appear, this will also be apparent from the vibration charts. Mapping of floor vibrations around screens and head box will indicate if the floor beams are too weak or in the wrong positions relative to the machinery. Remedial measures such as floor reinforcements, vibration absorbers, out-of-phase drive of screens, increasing the number of vanes in pressure screens from two to three or four are other objects for vibration analysis. Sometimes one may have to start at the slice and try to trace a slice vibration back to its source.

Fig. 7 shows in (*C*) the vibration of the front wall of a pressure head box. A regular frequency of 9 c/s can be seen. This phenomenon was observed during a large survey of five papermachines and time did not permit a closer study of it. It is believed to have caused no serious operating troubles, but it is presented as an example of what might be found during a vibration survey. The frequency would indicate a rotary screen effect.

The measurement of hydraulic pressure variations by means of strain gauge transducers has been described previously. In many cases, similar information can be obtained faster and more easily with the vibration analyser: for example, this instrument will reveal exactly at what setting the turbulence on the downstream side of a control valve is at a minimum. The frequency curves before and after a valve, a tee or some other obstruction will also be informative. The weakness of the approach is the unknown correlation between pipe vibrations and pressure oscillations in the fluid medium. On the other hand, it may be safe to assume that pipe vibrations are more or less deleterious and should be kept to a minimum.

Fig. 7 shows in (*B*) the vibration at different frequencies before and after a tear drop valve. Apparently, the valve eliminated most of the high frequency vibrations, but created severe vibrations in the lower frequency range. The vertical scale is decibels.

High speed photography

THE use of high speed photography around the wet end is by now so common that it will need little presentation.

It is possible to use a not too expensive camera with a shutter time of 1/500 sec. The camera, however, should be synchronised with devices to produce high intensity flashes with a duration of 30 microsec. During the time of exposure, the wire of a 2 000 ft./min. machine will move no more than 0.001 ft. This equipment is very simple to use and one does not have to be an expert photographer to take good pictures. The only difficulty is to find how to place and direct the flashlights. It is then far more difficult to know what to look for—what phenomena the camera can reveal.

Fig. 8 shows two pictures of slice jets taken from above (*A*). The picture to the right was taken on an old head box with a small perforated roll placed very close to the slice. The intense turbulence seen in

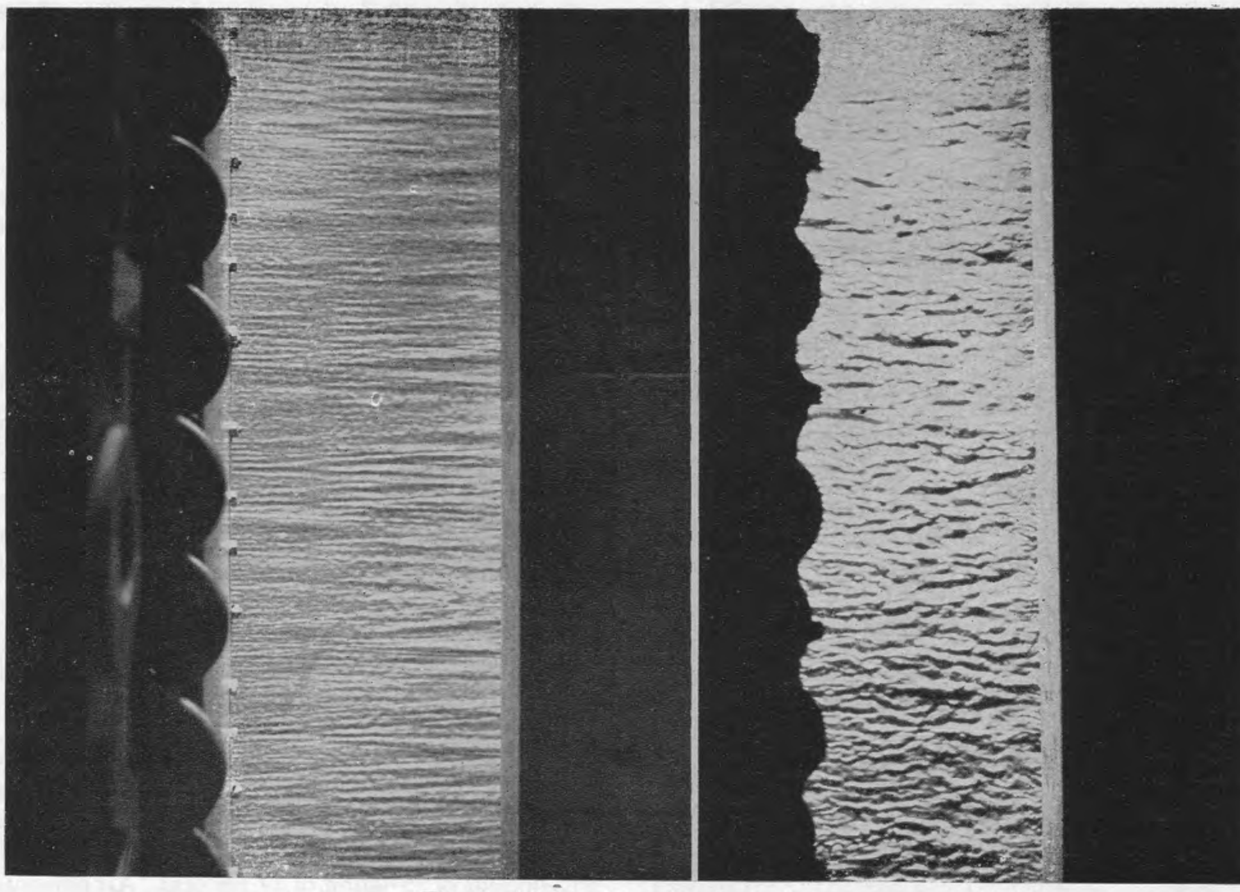


Fig. 8—(A) Slice jets taken from above

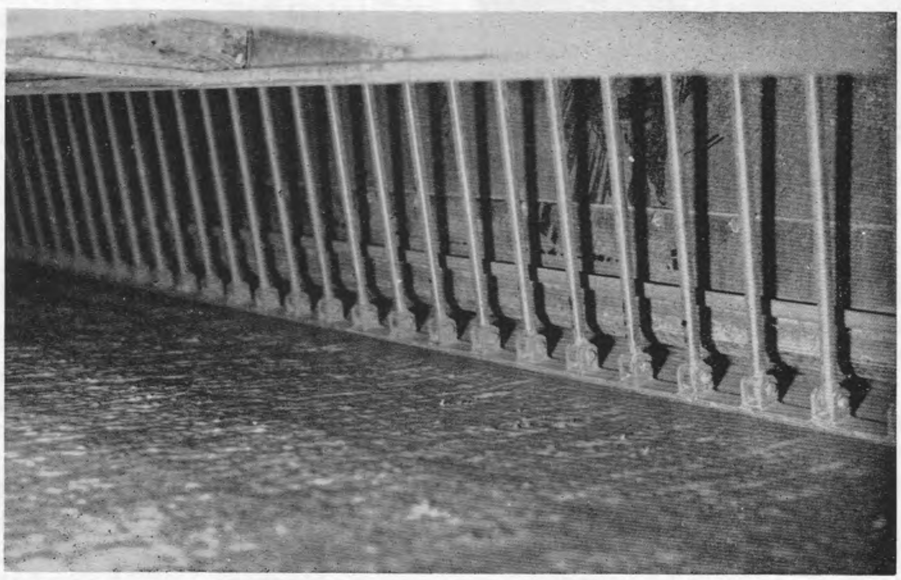


Fig. 8—(B) Slice jets seen from the side

the picture coincided with an extremely wild and streaky formation. The picture to the left was taken after the head box had been replaced by a new one. Furnish and machine speed were identical. In the latter case, the turbulence level after the last perforated roll clearly was not detrimental to the stability of the jet. The amplitude of the pressure oscillations at a point between the roll and the slice was ± 8 mm. water, which gives a rough idea of the level permissible in the 1 000–1 200 ft./min. speed range.

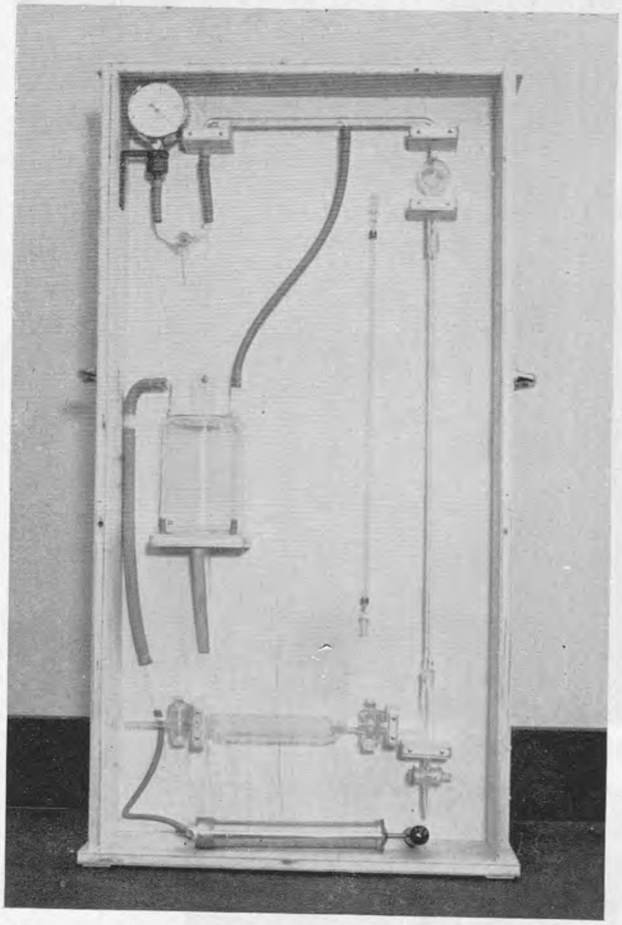


Fig. 9—Air analyser

The photograph (*B*) in Fig. 8 shows an unstable jet seen from the side. It can be observed that the surface of the jet is broken at intervals even before the jet hits the wire.

Air analyser

THE air content of the head box stock may account for many difficulties and it is therefore desirable to have satisfactory means of checking it. Fig. 9 shows an analyser based on the principles developed by J. D. Boadway.[2] The pipette is connected to the sampling line and filled with stock, with every precaution taken to maintain the original air content in it. The pipette is connected to a graduated burette, which is evacuated by means of a small handpump, then filled partly with clear water. When the cock between burette and pipette is opened, the pipette will be set under vacuum and the air bubbles in it will expand accordingly. As a result, some stock will be pushed into the burette, where the increased volume can be read on the scale. This instrument is simple to use, fast and accurate. Thus, ten repeated determinations on the same sample gave a coefficient of variation of 17 per cent. Air contents as low as 0.02 per cent. by volume can be determined with fair accuracy.

REFERENCES

1. Forsythe, D. D., *Pulp and Paper Mag. Can.*, 1958, **59** (8), 119
2. Boadway, J. D., *Pulp and Paper Mag. Can.*, 1956, **57** (3), 185

discussion

MR. W. J. BINNS: Could Mr. Gavelin explain to us how the measurements of pressure and vibration in the flow box are taken?

Am I correct in thinking that these measurements are taken from the outer surface of the box and, if so, is it reasonable to assume that their full effect is operative throughout the whole of the flow area inside the box?

MR. G. GAVELIN: This point was our main reason for obtaining a second set of pressure recording apparatus so that we could record pressure variations at two symmetrical places in the system simultaneously. When identical impulses are obtained at two points, it must be concluded that the frequency and general pattern of fluctuation is the same between these points. Some variation in amplitude, however, is possible and even likely.

MR. BINNS: The paper seems to deal principally with factors covering equality of pressure and flow throughout the slice and flow box: is any cognisance being taken in these investigations of such factors as flocculation, which seems to be just as often the cause of trouble in the finished sheet as variations in weight and caliper?

MR. GAVELIN: We are quite aware that a lot of work will have to be done on flocculation in head boxes. We have recently bought the prototype of a formation tester developed by Dr. Ollé Andersson at the Swedish Forest Products Research Institute and, with this instrument at hand, we intend to attack the problem.

MR. BINNS: Mr. Gavelin mentioned that a matter of eight or ten investigations of actual flow boxes had been undertaken. It would be interesting to know what aspects in particular were emphasised by the various mills as those requiring investigation.

MR. GAVELIN: Our investigations have been undertaken on comparatively fast papermachines, on which basis weight control was the main concern.

MR. P. H. DIXON: Whilst you say that you are seeking a perfect flow on to the wire, my cousin did so at about 1 200 ft./min., just like a mill pond, but it gave a very poorly bonded sheet. To improve it, he had to alter the jet angle and create the bounce you have drawn. It has therefore been our experience that flexibility of adjustment of the slice lip is essential to get the best performance for a given stock and speed.

I congratulate you on the work that you are doing through the foresight of the Swedish papermills. It must be comforting to them to know that when they are in a mess there is someone they can send for. I am sure we look forward to the day when we can do the same, instead of individually doing this sort of work at a cost considerably higher than the cost of such a collective effort.

MR. GAVELIN: The practice of deflocculating the head box stock by the use of a steep slice jet impact angle on to the wire will be found occasionally in Sweden, too. I believe it should be considered a poor substitute for head box deflocculation.

MR. G. CULLEN: Has Mr. Gavelin any observations to make on the angle of the jet to the wire and the ideal position for the jet to make contact with the wire relative to the breast roll centre line?

MR. GAVELIN: I should like to answer this question with a reference to a paper by J. Mardon and A. B. Truman—*The wake effect, ridge formation and spout development on the wire of a Fourdrinier machine*.* What observations I have made are entirely in accord with those presented in this article. I might add that I favour a horizontally adjustable bottom lip.

MR. T. R. YOUNG: As a result of his experiments, has Mr. Gavelin been able to decide on any basic principles to be followed in the design of machine flow boxes?

* *Paper and Timber (Finland)*, 1959, **41** (9), 391

MR. GAVELIN: Our investigations have taught us what pressure drops and flow velocities are permissible at various points of the hydraulic system. We are at present rebuilding the head box of our own 37 in. pilot machine, taking advantage of our collected experiences. We have also had a hand in the redesigning of a number of Swedish head boxes.

MR. A. B. TRUMAN: When making measurements of head box pressure fluctuations, exactly where were the pressure transducers located? If none were placed in the body of the stock, did you make assumptions about the pressure distribution across the head box, based on the pressures at the walls?

MR. GAVELIN: The transducers were let into the side walls of the box and, if the pressures at opposite walls were identical, we assumed that they were typical of the pressures within the box.

MR. TRUMAN: With reference to the photograph taken directly above the slice jet, I notice that the familiar criss-crossing pattern of ridges is there. This is a fairly common phenomenon in newsprint pressure head boxes and is generally believed to result from the presence of vortices in the flow leading up to the slice jet, caused by an incorrectly placed perforated roll. Recent investigations in North America (including those of J. Mardon and myself**) have shown, however, that, even when all the known causes of these ridges have been removed, faint ridges will still be visible, sometimes issuing from the slice in the direction of flow of the jet stream, but often at a small angle to it. Can Mr. Gavelin—or anyone else present —add to our knowledge of this phenomenon?

MR. GAVELIN: I hardly think that anyone outside the Quebec school, with which both Mr. Truman and I have been associated, has much to add to its recent contributions on the subject of instabilities in the slice jet. I believe that Mr. Truman has some slides from his Quebec investigations.

(*At this point Mr. Truman showed several slides of ridges in the slice jet and of the effect on the ridges of moving the perforated roll or of altering the breast roll discharge.*)

** *Paper and Timber (Finland)*, 1959, **41** (9), 391; (10), 457

Inverform — An account of the experimental work during the development of a new method of paper and paperboard manufacture

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St. Anne's Board Mill Co. Ltd.

GIVEN AT A MEETING OF WESTERN DIVISION: THE COUNTY HOTEL, TAUNTON ON 24th JUNE 1960, Mr. L. A. LAWRENCE IN THE CHAIR

Summary

An account is given of experimental work carried out at St. Anne's Board Mill Co. Ltd., Bristol, during the development of a new method of paper and paperboard manufacture. The origination of the project is discussed and a description given of the pilot plant used during the investigations, together with details of the early work and the evolution of the 'Inverform' unit and its ancillary equipment.

Introduction

THIS paper gives a survey of experimental work carried out at St. Anne's Board Mill during the development of the 'Inverform' method of paper and paperboard manufacture. Descriptions of the 'Inverform' method of sheet formation and its commercial application to a production machine at St. Anne's Board Mill Co. Ltd. have been published. A list of the relevant literature is given in appendix 3.

In 1950, it was decided to commence a research development project, the object of which was to design a new method of forming multi-ply high quality folding box board at speeds in excess of those obtainable from modern cylinder mould machines. There is a real upper speed limit when operating cylinder mould machines, above which certain properties of the product, such as formation and basis weight level deteriorate.

Our experience at St. Anne's has indicated that for high quality folding box board this limit is in the order of 400 ft./min. Various attempts have been made to overcome these limitations using, for example, modified vat inlets, special vat circles and moulds, including the use of vacuum type moulds; these attempts have not been wholly successful and, in some cases, have introduced further complications such as poor ply adhesion.

With this experience behind us, it was decided that in order to further our project we would have to investigate and evolve another method of producing multi-ply folding box board.

Initially we were attracted by work being carried out in the United States with the use of subsidiary head boxes on Fourdrinier machines. As a consequence, it was decided to construct a Fourdrinier pilot plant in order to investigate the application of subsidiary head boxes to the production of multi-ply folding box board.

Description of pilot plant

FIG. 1 shows a general arrangement drawing of the pilot plant constructed for the above purpose. The original unit consisted of a Fourdrinier table fitted with a 32 in. wide wire and having a table length of approximately 45 ft. The table was fitted with a conventional breast roll and a 24 in. diameter suction couch, the machine being driven at this point and having a maximum speed of 500 ft./min.

The table was fitted with a large number of 4 in. diameter table rolls and a number of vacuum boxes, all of which could be easily interchanged; facility was made to introduce shake to the wire. Straddled across the machine wire were 4 flow boxes, each movable and each supplied via a mixing pump from its own stock chest.

Beneath the wire run was a concrete pit that could be operated as a single unit or divided to give a separate pit for each ply. Backwater was taken from the pits and added to the stock coming from the chest at a point immediately before the mixing pump. It was possible to control (*a*) the quantity of stock fed to the flow box, (*b*) the quantity of water added to the

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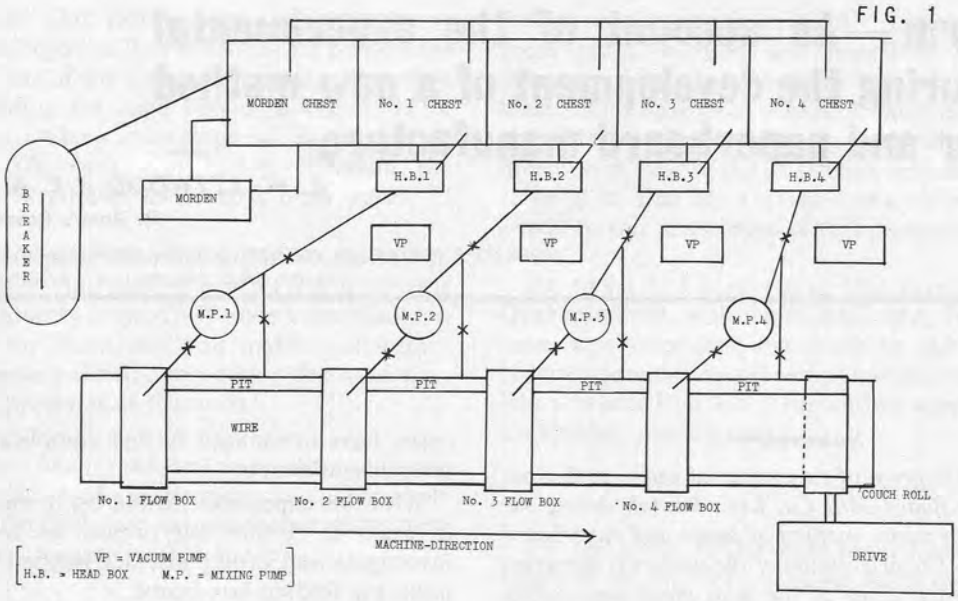


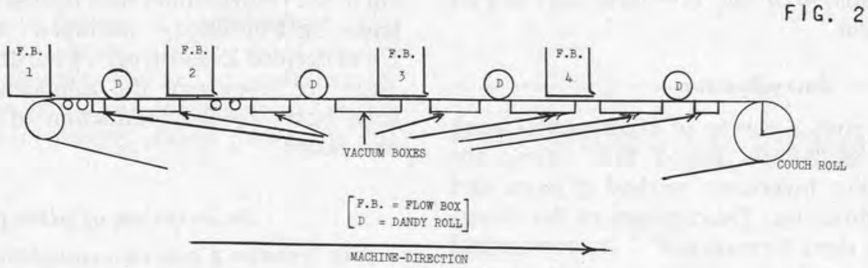


Fig. 1 (*above*) — Plan of pilot plant

Fig. 2 (*below*) — Four-ply machine (first arrangement of experimental machine)

stock, hence the consistency of the stock fed to the flow boxes. This system introduced some minor operating difficulties, particularly with work covering a wide range of conditions and, as a consequence, was somewhat modified at a later date.

The stock preparation plant consisted of a Bentley & Jackson beater used as a breaker, the stock from which was pumped to a chest from which it could be passed through a Morden Stockmaker into the required machine chest.

For simplicity, no strainers were fitted to the machine; at a later date, a pipeline was installed in order that stock could be supplied from the mill to enable prolonged runs to be carried out.

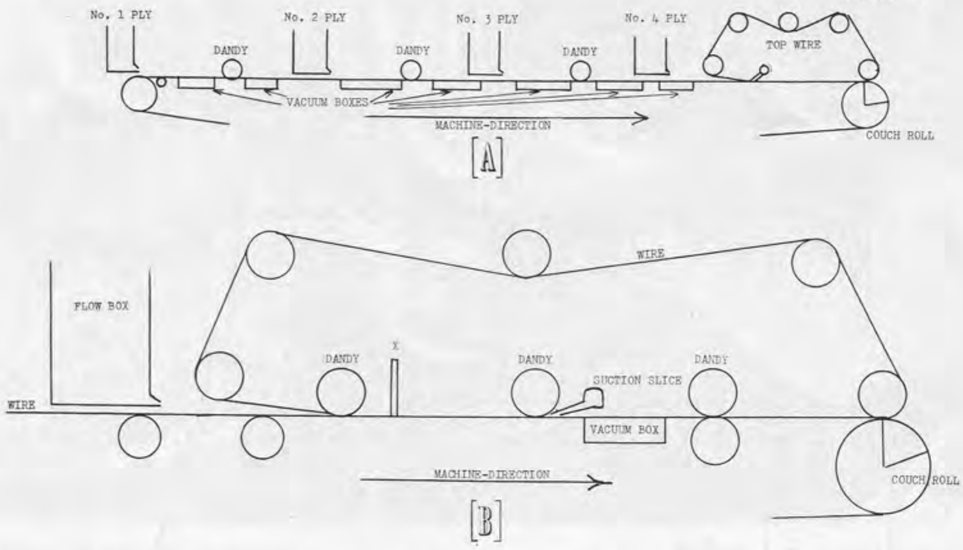
Stock supply pumps, flow pumps, motors, etc. in use throughout the plant were in most cases mill spares.

Description of early work

AFTER initial trials in early 1951, the experimental machine was arranged as shown in Fig. 2 and this arrangement became the basis for our experimental work. The method of operation for these experiments was as follows.

Stock was applied to the machine wire via the first flow box and, after a given amount of drainage had taken place by means of table rolls and vacuum boxes, the second layer was applied via flow box No. 2; this layer was then drained through the first ply using only vacuum boxes, as there was no appreciable downward drainage without application of vacuum. Again, after the requisite amount of water had been removed, the third layer was applied and the aforementioned water removal process repeated, the same applying for

FIG. 3



(A) — Four-ply machine using one top wire (B) — Earliest top wire arrangement

the fourth ply. The sheet was then removed from the machine at the couch roll, samples being obtained at this point. Appendix 1 gives details of sampling methods used.

Using this mode of operation, early work consisted of investigating the following items—

1. Methods of delivering the fibrous suspension to the wire (flow box design, etc.).
2. Determination of the best point at which to apply the second and subsequent plies.
3. Determination of the degree of web drainage required before another ply could be satisfactorily applied.
4. Methods of water removal, including design of vacuum boxes and arrangement of vacuum boxes.
5. Effect of wire shake.
6. Effect of dandies.
7. Types of stock.

With item *4*, it should be noted that much valuable information was obtained using a dynamic drainage tester that had been constructed for this purpose. A description of this apparatus and an analysis of results obtained will be the subject of a further paper. During the investigation of item *4*, various experimental vacuum boxes were installed in the machine, including some fitted with strain gauges in order that information might be obtained of the dimensional changes that take place in a box while in operation. A laboratory investigation took place examining the best types of materials from which to construct vacuum box tops and the factors influencing machine wire wear.

It was not long before this initial work on the pilot plant indicated to us that having always to drain downwards (which in the case of the second and subsequent plies meant not only through the main wire, but also through the previous plies), our main problem was one of filtration. As a matter of interest, it was found that, if under given conditions one vacuum box was required to remove water from a given weight of stock at the first ply, 3 boxes were required for the same weight at the second ply, 9 for the third ply and 27 for the fourth ply. This filtration problem caused this method of producing a multi-ply sheet to be impracticable, owing to (*a*) the high power requirements, (*b*) the large number of vacuum boxes required, which meant a large quantity of associated equipment and high maintenance costs, (*c*) the very short wire life.

Consequently, we were faced with the immediate problem of how to drain without taking the mass of the water through the previous plies. As has already been mentioned, this problem of downward drainage was at its worst in the fourth ply and, because of this, it was decided to concentrate our immediate work upon this section. In passing from this stage of the work, it should be mentioned that we did in fact produce a well-formed 4-ply sheet having a basis weight of 200 lb. Q.C. (each ply of equal weight) at a speed of approximately 400 ft./min. This sheet had a typical high quality folding box board furnish—that is, a liner of bleached chemical, an underliner of groundwood, a middles of wastepaper and a backs of groundwood.

FIG. 4

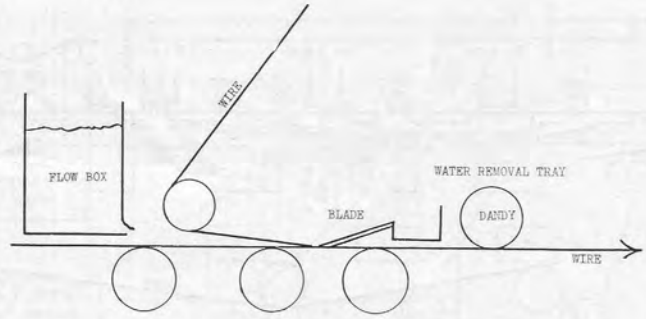


FIG. 6

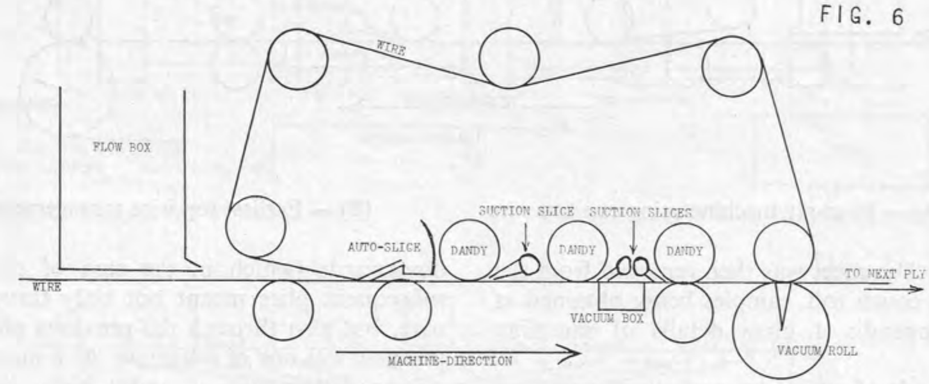


FIG. 7

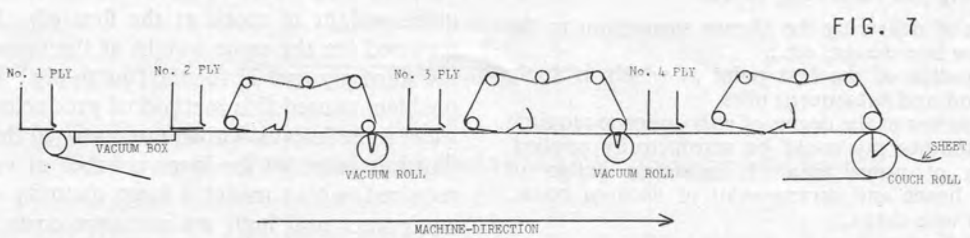


Fig. 4 (*above*) — Auto-slice **Fig. 6** (*centre*) — Top wire used during very early experiments
Fig. 7 (*below*) — Four-ply machine using three Inverform units

Development of the Inverform section

At St. Anne's, we have had much experience operating machine wires at the baby press section of multi-ply boardmachines, the water extracted by the press rolls passing easily through the wire cloth. With this background, it was decided to install a top wire at the fourth ply position of the experimental machine.

The arrangement decided upon was basically as that shown in Fig. 3(*a*) and 3(*b*), it being hoped with this arrangement that when the top wire was placed upon the fourth ply stock, which had been laid upon the previous three plies, much of the water associated with it would flow upwards through the top wire, where it could be collected and removed, the operation taking place without disturbance of the fibrous web. The very first experiment with this arrangement indicated that indeed this was the case and it was soon found that by varying the pressure and position of the board *X* shown in Fig. 3(*b*) not only could we remove large quantities of water, but we could also control the quantity of water being removed and at the same time the formation of the web.

Experimental work with this board led to the development of the unit shown in Fig. 4 and 5. This

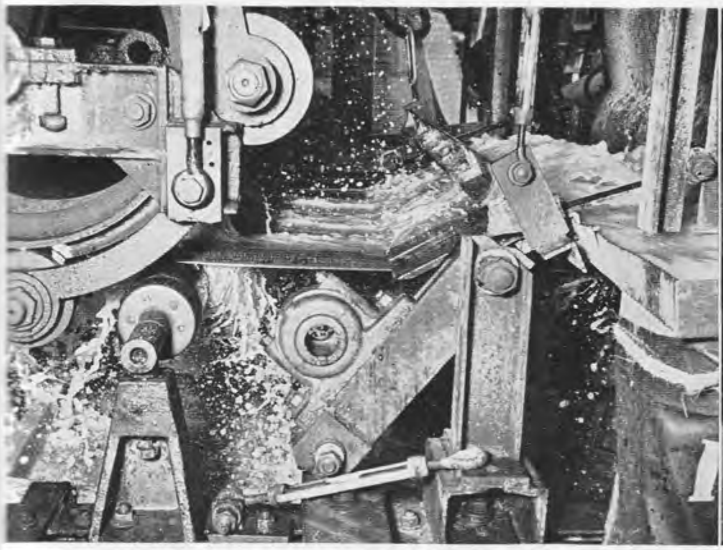


Fig. 5 — Auto-slice in operation

Fig. 13 — Sampling at 'dry' end

is known to us as an auto-slice and, in operation, water brought to the surface of the top wire follows the blade of the auto-slice and is removed from the machine via the tray. With this simple arrangement, trial runs were carried out at speeds in the order of 750 ft./min., whereas, prior to the use of a top wire section, our limit had been 400 ft./min. As well as this increase in speed, we had greatly cut down the quantity of vacuum equipment in the fourth section. It was found that at speeds in excess of 800 ft./min. the energy associated with the water being upwardly removed was sufficient to cause this water to run up the auto-slice blade without assistance; however, at speeds below 800 ft./min., assistance was needed. At a later date, we developed for this purpose—

(*a*) A brush roll immediately before the auto-slice blade.
(*b*) A suctionised slice.

Fig. 6 shows the complete top wire assembly installed in the fourth section of the machine and used during a detailed examination of this new method of sheet formation, which we called the 'Inverform' process. During this investigation, the following factors were among those studied—

1. Type of stock.
2. Stock consistency.
3. Stock velocity from flow box.
4. Method of applying stock.
5. Position of components in top wire section.
6. Machine speed.
7. Water removal at various points.
8. Determination of correct condition of a ply for reception of the next ply.

With item *1*, it was found that we were able to produce a well-formed sheet from a wide range of materials ranging from wet-beaten stock to virtually raw stock and covering all types of fibre.

It was found possible to produce a well-formed sheet at far higher consistencies than is normal practice with cylinder mould or Fourdrinier machines; for example, short-fibred materials such as groundwood can be applied to the Inverform section at a flow box consistency of 1.5—2 per cent., long-fibred materials can have a flow box consistency of 1 per cent. This work also showed that, as machine speed increased, there was a tendency for formation to improve and it was found at the same time that the method of applying the stock to the wire (or, as the case may be, to the previous ply) was nowhere near as critical as is the case with a conventional machine—for example, irregularities across the machine width were evened out in the formation area and it was not too important to match closely stock velocity with wire velocity. It was obvious that we had developed a completely new method of sheet formation, so new in its concept that we had to abandon the old rules of conventional papermaking.

After many months of development work, the pilot plant was gradually evolved into the arrangement shown in Fig. 7, where the last three plies are produced in an Inverform section, the wire table length having been extended to 75 ft. Using this arrangement, a four-ply sheet having a total basis weight of 200 lb. Q.C. was produced at 1 200 ft./min.

FIG. 8

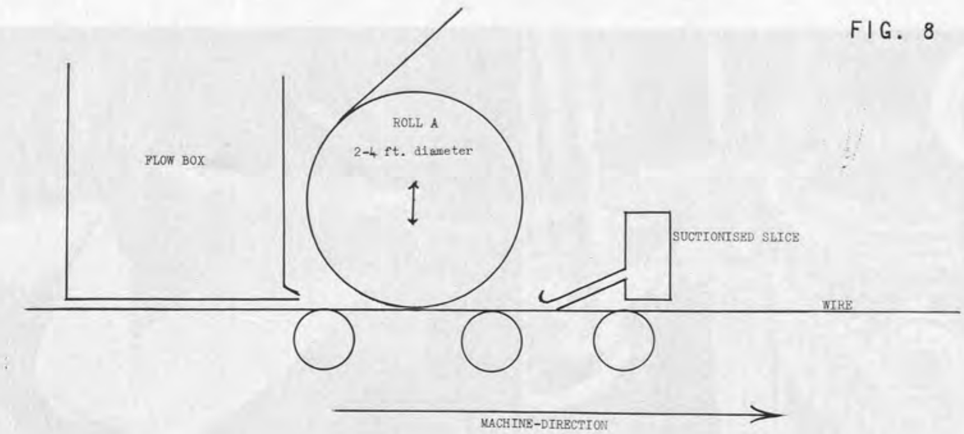


FIG. 9

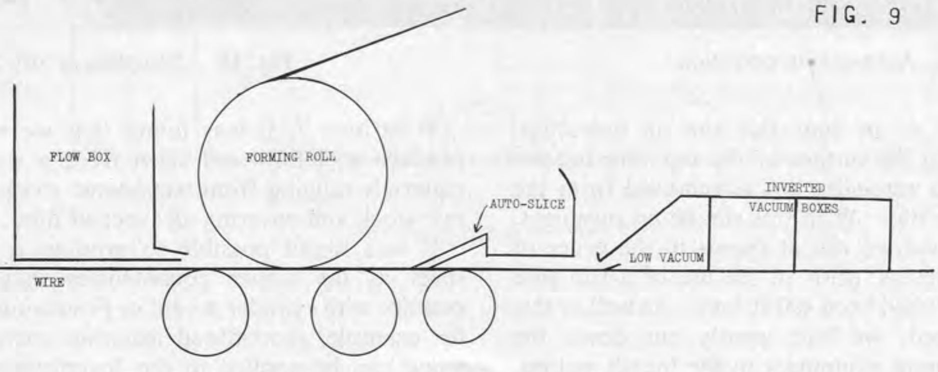


Fig. 8 (*above*) — Arrangement of forming roll and suctionised slice
Fig. 9 (*below*) — Top wire assembly showing inverted vacuum boxes

Development of the forming roll

OUR production personnel were critical of one section of the Inverform unit so far described, the section in question being where the top wire converges on to the auto-slice section and meets the auto-slice at a sharp angle, it being felt that this treatment of the wire would lead to serious running difficulties. As a consequence, a further study was made of formation in this area and, from this, emerged the arrangement shown in Fig. 8.

Here, the stock emerges from a flow box either on to the bottom wire (as is the case with the first ply) or on to the previously formed sheet as is the case with subsequent plies. The stock then moves forward towards roll *A* (which we call the forming roll) and, upon reaching this roll, a small pond is produced immediately in front of it, this being particularly so at low speeds. At higher speeds, this pond may exist somewhere between the bottom dead centre of the forming roll and the leading edge of the auto-slice. The pond acts as a levelling device, with the result that we obtain an extremely level sheet across the machine width. It is also felt that the pond helps in fibre dispersion, thus playing a part in sheet formation.

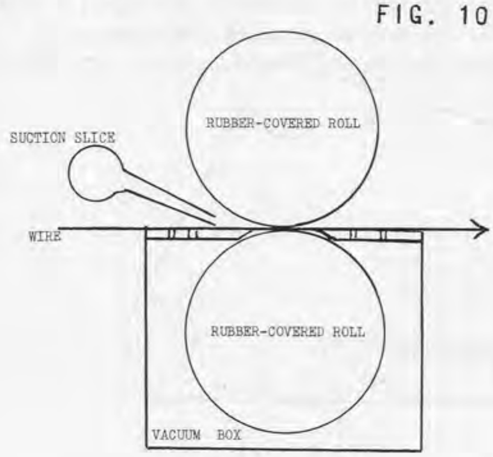
For water removal, the forming roll acts as a very large inverted table roll, so bringing water through the top wire where it can be scraped off and removed by the auto-slice. We found by experiment that the roll should be of hollow construction, in order to reduce the vacuum developed by this roll: with a solid roll at high speeds, the vacuum developed was sufficiently high to lift the top wire from the sheet, thus disturbing formation. As can be seen, this arrangement of forming roll overcomes the objection of a top wire running in to meet the auto-slice blade at a sharp angle.

At this period of the development, we were also evolving the design of vacuum boxes for use in an inverted position, to follow the auto-slice as shown in Fig. 9. The object of the boxes was to remove as much water upwardly through the top wire as possible, this being very important in the second and subsequent plies.

Another development of this period was the rotary vacuum box, which consists of a roll surrounded by a vacuum box as shown in Fig. 10. In practice, this box operates with a roll pressing on top of the roll inside the box, so that there is a controlled nip for water removal, the water extracted being immediately removed by virtue of the fact that the bottom roll is in a vacuum box.

As the top wire leaves the sheet to make its return run, it is essential to ensure that the formed sheet does not follow this wire. This had been ensured in the past by the use of small diameter suction rolls as shown in Fig. 7, but, with the advent of the rotary vacuum box, these suction rolls were replaced by rotary vacuum boxes as seen in Fig. 11. Thus, the rotary vacuum box in this position not only removes water, but ensures that the formed sheet does not follow the top wire.

FIG. 10



Rotary vacuum box

Machine wires

ONE of the problems foremost in our minds during the development work was the type of machine wires to use and, in collaboration with machine wire manufacturers, an intensive study was carried out. It was during this period that the machine wire manufacturers developed the following two methods of installing machine wires—

1. Joining the ends of an open wire together by means of a pin seam.
2. Joining the ends of an open wire together by a special brazing process.

Thus, using methods *1* and *2*, open-ended wires could be installed on our Inverform machine and this in itself reduced serious engineering complications that would otherwise have had to be overcome.

Method *2* has been further developed and is used on our production Inverform machine for the installation of all its wires.

At a later date, trials were commenced using various types of plastic wire. These tests have shown very promising results and the work is still continuing.

While discussing machine wires, it should be mentioned that during this period many trials were carried out in the laboratory covering—

(*a*) Examination of machine wires for drainage and wear characteristics.
(*b*) Development of methods of examining machine wires while still on the machine in order that an estimate could be made of the amount of wear and type of wear taking place.

Press assembly work

INITIALLY, the experimental unit terminated with a suction couch roll, the sheet being blown from the wire at this point. Increased speeds made this method of operation unsatisfactory and, as at the same time data was required on the operation of press assemblies, including the use of suction transfer at high speeds, together with information on the effect of pressing, etc. upon the characteristics of the finished product, it was decided to install a press assembly. The first unit consisted of a simple suction press, later modified to incorporate a suction pick-up. At one stage of the work, we investigated a cloverleaf press assembly. Finally, our press assembly was modified to the following form.

System A
Suction couch followed by open draw leading into a suction press fitted with top and bottom felts; this followed by two plain presses.

System B
Suction transfer followed by a suction press, which in turn was followed by two plain presses.

In both of the above systems, the two plain presses could be replaced by a carrier felt or wire. The press assemblies were equipped with variable speed control and the press weighting was controlled by pneumatic operation.

Conclusion

EVENTUALLY, the Inverform machine was evolved into the arrangement shown in Fig. 12.

In this arrangement, each of the 4 plies was produced in the Inverform unit and the arrangement became the basis for the commercial Inverform machine at St. Anne's.

This paper has given a factual account of the development of the Inverform process for the production of paper and paperboard. Many of the topics covered in this paper have only been touched upon and no mention has been made of—

(*a*) Single ply application (including construction and operation of a very high speed experimental machine).

(*b*) Development of some of the ancillary equipment.

(*c*) Production of various types of products, including some that we believe cannot be produced by any other way (for example, multi-ply papers).

Development is still in progress and we are continually finding more applications of the Inverform process for the production of new grades of paper and paperboard.

Acknowledgement

In conclusion, we should like to thank the Directors of St. Anne's Board Mill Co. Ltd. for having given permission to publish this paper.

Appendix 1—Sampling methods used during experimental work

THE method of sampling from the experimental machines and treatment of the samples afterwards were quickly standardised. Samples were removed either after the couch or one or more of the presses, the technique being to use a flat plate fitted with a handle, the plate being held in the hand and carefully swept through the web. It was found that by careful manipulations it is possible to 'capture' a sample of the sheet without serious deformation taking place. Fig. 13 shows this process in operation.

Sometimes samples have been removed by reeling on to a hand-held roller.

The samples (however taken) are removed to a laboratory where, while still wet, they are cut to a given size and are carefully pressed between sheets of blotting paper using a calibrated household wringer as the pressing medium. The pressed samples, still between the blotting paper, are fed into a felted, steam-heated drying cylinder and after drying are removed, cut to a standard size and filed.

FIG. 11

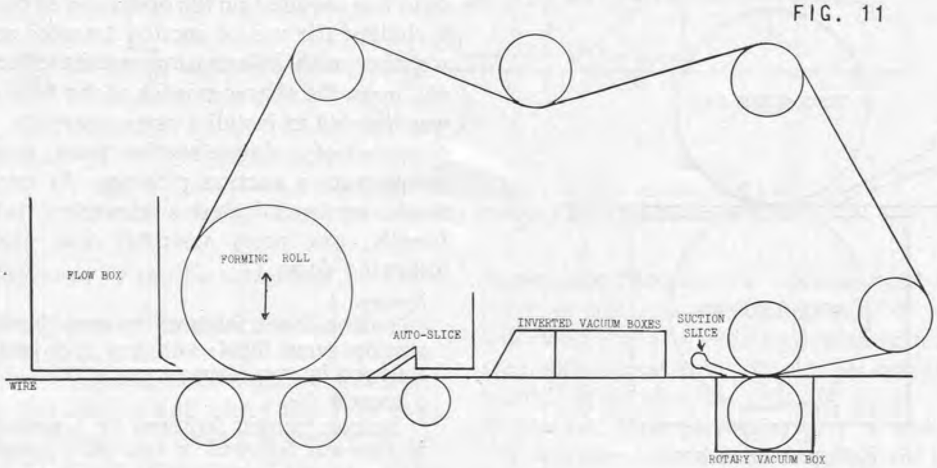


FIG. 12

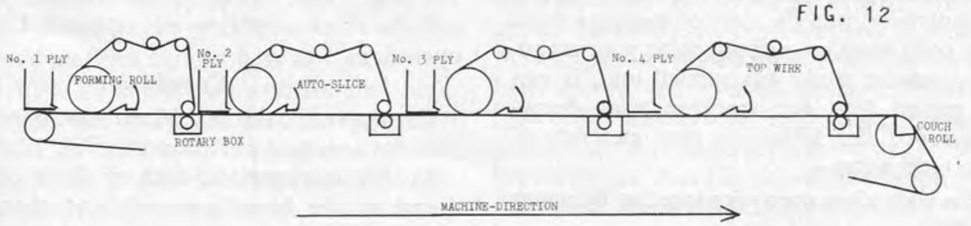


Fig. 11 (*above*) — Typical top wire assembly **Fig. 12** (*below*) — Four-ply Inverform machine

Appendix 2—Brief description of St. Anne's No. 4 machine (Inverform)

BY 1955, work had proceeded sufficiently for the design of a production wet end to be completed; this was duly carried out and construction of the wet end took place, the unit being installed during early 1958. The Inverform section replaced a somewhat inefficient vat section of our No. 4 production machine, the unit going into production during June 1958.

The wet end consists of four Inverform units, each served by a simple flow box designed for operation with consistencies from 1 per cent. to 2 per cent. The main wire is 200 ft. long and each top wire is approximately 40 ft. long. The trim deckle is 118 in. The forming rolls are of open-faced stainless steel construction. The auto-slices consist of resin-bonded laminate sheets followed by stainless steel trays, the blades being capable of adjustment.

Because of the low operating speed, it is necessary to assist the water up the auto-slice blades and, to do this, nylon brush rolls were initially installed. These brush rolls have given some trouble in operation and are now being replaced by suctionised slices. Each top wire is fitted with a number of inverted vacuum boxes and a pair of nip rolls, the bottom one of each being in a rotary vacuum box. The wet end terminates with a suction couch roll, after which the sheet is passed by means of an open draw into a primary press assembly consisting of three suction press rolls and then through three plain presses before entering into the dryer section. In practice, low vacuum is used on the vacuum boxes, for example, 1.5—3 in. mercury on the inverted boxes, 3.5 in. mercury on the rotaries.

It was decided to install the Inverform assembly just described, without (in the initial stages) modification to the dryer section. Consequently, the speed of the machine is limited by its drying capacity. A further stage of development will be modification of the dryer assembly, thus allowing operation at far higher speeds.

Appendix 3

THE following list covers the most important articles published to date, dealing with the Inverform method of paperboard and paper manufacture and includes descriptions of St. Anne's commercial Inverform machine with photographs and diagrams.

1. *Paper Mill News*, 1959, **82** (25), 12
2. *Paper Trade J.*, 1959, **143** (10), 35
3. *Paper Trade J.*, 1959, **143** (25), 20
4. *Pulp and Paper*, 1959, **33** (4), 80
5. *World's Paper Trade Rev.*, 1959, **152** (8), 109

discussion

MR. B. KING-SMITH: We have heard a lot tonight about the revolutionary methods of sheet formation introduced by this process. It would seem clear that there are revolutionary methods of removing water from the sheet, but I am wondering just how revolutionary the formation itself really is. Has Mr. Attwood any idea what really goes on under the forming rolls?

In addition, can Mr. Attwood tell us more about the plastic top wires? What material are they made of and what gauge is used? How do you join them or repair them and how do you find they stand up to wear in comparison with conventional wire gauzes?

MR. B. W. ATTWOOD: At St. Anne's mill, we have many views about what goes on at the forming roll and auto-slice. Without going into details, I should like to prove to you by quoting a simple experiment that formation does take place at this point.

A Fourdrinier table is run at a given speed and a long-fibred kraft stock at 1.2 per cent. consistency is supplied by means of a normal flow box. Samples are then taken at the couch roll. The sheet is found to be very poorly formed and lumpy. Now, using the same stock, wire table and flow box, but with the use of an Inverform section on top of the main wire, another sheet is formed under otherwise identical conditions. Samples are again taken at the couch. Quite an improvement in formation is now found and many of the cloths dispersed. Thus, we have shown that formation is taking place within the Inverform unit.

The plastic wires we have tried to date have been of nylon, other details concerning their preparation are held by the manufacturers. Generally speaking, the wires are coarser than those used on conventional papermachines. Up to the moment, we have not been able to join open-ended plastic wires except by sewing, which has not turned out to be too successful. Consequently, all the successful wires tested to date have been endless.

Work carried out on the experimental machine has indicated that we can expect something in the order of a 600 per cent. increase in life over a normal metal wire when plastic wires are used in an Inverform section. On the commercial machine, we have just removed from an Inverform unit a plastic wire that gave 14 weeks' life. Examination of this wire after removal indicated that we could probably have obtained a few more weeks' use from it.

In conclusion, let me point out that the development of plastic wires is moving along at a steady pace and I feel sure that we will see many other developments within a short period of time.

MR. C. J. MOORE: From your talk, Mr. Attwood, I have the impression that it is considerably easier to remove water upwards (through the top wire) than down through the normal wire. If this is so, could you explain it?

MR. ATTWOOD: It seems that it has not been made clear in the paper that, when producing a single-ply sheet, that is, one in which drainage can take place both upwards and downwards, then the quantity of water removed downwards before the auto-slice is approximately equal to the quantity removed by the auto-slice. Of course, this applies to a typical Inverform section and modifications could be made whereby proportionally more water is removed either upwards or downwards.

MR. K. C. WEEDY: Even allowing for the fact that you are discharging stock on to the wire at higher than normal consistency, can you explain why practically no drainage occurs through the wire between the slice lip and the forming roll?

Have you examined the effect on water extraction from the sheet of superimposing a roll containing a positive pressure chamber above the vacuum box in the roll mounted in your rotary suction boxes? I feel that this would give greatly accelerated movement of the moisture droplets in the sheet.

MR. ATTWOOD: My only explanation of the fact that there seems to be little drainage occurring through the wire between the slice lip of the forming roll is, as you say, because of the high consistency at which we operate. I am not in agreement with you, however, that this is indeed the case and that in making a single-ply sheet we do remove downwards approximately as much water before the auto-slice as we do at the auto-slice. Of course, on subsequent plies, there is little initial downward drainage and the bulk of the water is removed upwards at the auto-slice.

We have not examined the effect on water extraction from the sheet of superimposing a roll containing a positive pressure chamber above the vacuum box in the roll mounted in the rotary suction box. I feel your suggestion is a very interesting one that might well be explored. We have used a hollow roll in this position, however, the roll being fitted with a blow box to blow the sheet off the top wire, thus preventing it following the top wire, without having to use high vacuum in the bottom vacuum box. Later studies of this section of the machine led us to abandon this method and we achieved the same results by careful design of the wire run.

MR. J. W. BODEY: Because the sheet is formed and pressed between two machine wires, what problems arise with wire marking?

The impression is that most of the tests carried out during the development of the Inverform process were on relatively short-fibred stock. Were trials made using longer fibred pulps (say, a softwood kraft pulp) and, if so, how was the formation of the sheet controlled as formation took place in the area of the forming roll?

MR. ATTWOOD: We have found with the Inverform machine that the wire marks produced are easily removed by subsequent pressing. This is probably because of—

(*a*) Throughout the Inverform section, low vacuum is used.

(*b*) Forming takes place very quickly and we do not have a large number of table rolls, with their associated washing of the fibrous web, which is the case with a normal Fourdrinier machine.

We have found that our wire mark is in effect not a basis weight variation, but an indentation that is easily removed by pressing. It is an interesting point to note that forming a single-ply sheet both upwards and downwards, as is the case with a single-ply Inverform unit, it can be arranged that drainage is the same both upwards and downwards, consequently producing a sheet that is not two-sided.

During our investigations, we have used long-fibred furnishes as well as the short-fibred furnishes noted. When running long-fibred stock, it is necessary to run at a lower consistency than is the case for short-fibred furnishes, although consistencies are still higher than those used on conventional Fourdrinier machines.

We have had many trials runs producing multi-ply paper sheets made from long-fibred kraft pulp and these have had very good formation and possessed very interesting strength characteristics. The events taking place in the forming area of an Inverform section help to disperse the fibre bundles and this, of course, improves formation.

MR. A. P. HIGHTON: On the high speed single-ply experimental machine, what values did you obtain for stock retention on the wire and for whitewater consistency?

Kindly elaborate on the suction slice and indicate the position in which the slice is located in relation to the nip between the wire and the roll.

In the paper, you describe how the pilot plant runs comfortably at 800 ft./min. and has run as fast as 1 200 ft./min.; yet the full size commercial machine runs at only 400 ft./min. Could you please tell us the limitations on the commercial machine?

MR. ATTWOOD: When running the high speed machine on a groundwood furnish and at a speed of 2 800 ft./min. with a flow box consistency of 1.8 per cent., we find that the solids content of the backwater at the auto-slice is of the order of 0.35 per cent. With a long-fibred kraft furnish, having a flow box consistency of 1.1 per cent., the backwater consistency is found to be of the order of 0.09 per cent.

If, in your second question, you mean the suction slices in front of the rotary roll nip, then these slices are positioned so that without touching the wire they just contact any pond formed at the nip, extract the water and so keep this pond to a minimum size.

The answer to your third question is simply that, when we installed the first commercial Inverform unit on our No. 4 machine, we did in fact take out a cylinder mould wet end and replace it by the Inverform wet end. At the same time, we installed a new press assembly, but did not alter the dryer train; consequently, the machine speed on the commercial machine is limited to its drying capacity. As a matter of interest, we have run the wet end up to the dryers at 540 ft./min., producing a very well formed sheet. The next stage of development will of course be to rebuild the dryer section so that we can utilise to the full the capacity of the Inverform wet end.

MR. L. BROOKS: Do you heat the stock?

MR. ATTWOOD: When we had to drain water always completely downwards from the web, it was found necessary to heat the stock in order to improve the rate of drainage. With the advent of the Inverform unit, this has not been found necessary and has ceased.

MR. G. K. ABERCROMBIE: Would Mr. Attwood elaborate on the effect of the dandy rolls when acting through the top wire?

MR. ATTWOOD: To explain best the action of dandy rolls operating inside a top wire, one should consider these rolls to be in effect open table rolls in an inverted position. Consequently, at the trailing side (owing to vacuum development), water is brought through the wire and is then extracted by means of slices.

It was found when operating dandies inside a top wire that, if too much pressure were applied by means of the dandy, then crushing could take place.

MR. P. SADLER: Would Mr. Attwood give more details of the construction of the forming roll? If this is hollow and perforated, does water gather inside it and, if so, how is this removed?

MR. ATTWOOD: The forming rolls in use on the machine are of cellular stainless steel construction, very rigid and ground before being covered on the face with wire of 14 in. mesh stainless steel. We have inserted a camera inside one of these rolls and, using high speed electronic flash photography, photographed the inside of the roll. The photographs showed that water does not gather inside the roll.

MR. R. TOMLINSON: Do you shake the wires on the Inverform machine?

MR. ATTWOOD: In the early stages of the development of the Inverform process, that is, before a top wire unit had been installed, we did shake the last part of the main wire. With the development of the Inverform sections, this practice ceased. It would be very difficult to carry out: I cannot see any advantage.

MR. D. R. BARBOUR: What type of guides are used on the wires and has it been found necessary to oscillate the wires whilst the machine is in operation?

MR. ATTWOOD: We use air-operated guides of the Beloit type. On our commercial machine, we arranged for the machine wires to be oscillated continuously in order to eliminate grooving at the suction boxes.

MR. D. R. COLES: Since chemical and heat fusion have been found unsuitable for joining the open ends of a plastic wire, what method is used in patching it?

Does the length of the forming pond affect the formation of the sheet, as it is difficult to visualise fibre movement between the wires?

MR. ATTWOOD: One should explain when answering your first question that many developments are at this moment taking place on methods of patching plastic wires. We have patched a small section of a plastic wire damaged on our commercial machine, using a chemical process and this technique gave reasonably satisfactory results. I am confident that, because of the rapid advances being made, it will not be very long before other methods of patching are in existence.

I find your second question very difficult to answer, because we know that there are many interrelated factors—for example, running an Inverform section to produce a given basis weight sheet under known conditions, we have a certain length of forming pond. If this same basis weight sheet is made at a lower speed, the pond size will increase, whereas the pond size will decrease at a higher speed. As the size of the pond becomes larger, so the turbulence taking place in the pond dies away; consequently, there is less chance of dispersing the fibrous suspension.

At higher speeds, the forming pond is small and very turbulent; consequently, we do obtain improvements in formation with speed. I agree it is very difficult to visualise any fibre movement between the wires taking place after the auto-slice position, especially when one considers the solid content of the sheet at this point.

Fibre-to-fibre bonds

Part 2—A preliminary study of their properties in paper sheets

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Synopsis

A preliminary survey of bonding in paper sheets has been carried out using the technique described in Part 1 for the direct observation of fibre-to-fibre bonds. The geometry of bond formation, bonding in various furnishes and the behaviour of bonds in paper under strain have been investigated and are discussed.

Introduction

IN Part 1[1] of this series, a technique was described that permits the direct observation of fibre-to-fibre bonds in suitably prepared handsheets. This technique has proved of value in an integrated programme of work, the object of which is to relate the physical properties of a sheet to the fundamental properties of its components and their geometrical arrangement. This paper is immediately concerned with the geometry of bond formation, the effect of furnish on this geometry and the behaviour of bonds in a sheet under tensile stress.

Geometry of bond formation

FIBRE-TO-FIBRE bonding in handsheets has been examined with particular reference to a spruce sulphite pulp furnish. It will be apparent from later comments that the concepts derived from this examination are applicable to other furnishes.

Fig. 1 shows, by the metal-shadowed replica method,[2] the surface of the top side of a handsheet of bleached spruce sulphite pulp beaten in a Valley beater for 10 min. to a freeness of 560 C.S.F. Fig. 2 is exactly the same field photographed in polarised vertical illumination to reveal the fibre-to-fibre bonds, which are the dark areas labelled *a–f*. These illustrate the different bond formations that have been observed and that the authors now classify into three types—

Type I— Bonds that show complete optical contact over virtually the whole of the mutual area of the two crossing fibres.* These are illustrated by bonds *b* and *f*, which exhibit a characteristic diamond shape.

Type II— Bonds that are clearly prevented from bonding over the whole of the mutual area by the intervention of a third fibre in the immediate locality of the bond. This is illustrated particularly well by bond *d*, which is prevented from forming its complete diamond by the intervention of the fibres responsible for bonds *c* and *b*. The arrangement of the fibres in this area is clarified by Fig. 3, which is a representation of the cross-section on the line *XX*.

Type III— Bonds that do not show optical contact over the whole of the mutual area between two clearly observable fibres, but for which incomplete bonding cannot be explained by the mechanism of type II.

There may be various reasons for incomplete bond formation within type III, but it might be impossible to prove conclusively for each individual bond what the overriding factors are. We have obtained overwhelming evidence, however, that the surface topography of fibres is important. Emerton,[3] from his work on softwood fibres, has pointed out that the collapse of a many-sided cell may give rise to a structure that is ribbon-like, except for the presence of longitudinal ridges corresponding to the original corners of the cell and this proposal is now well supported by further micrographic evidence.[4,5]. This behaviour is clearly brought out in Fig. 4, which shows diagrammatically the effect of collapse on cells of different shapes. It will be appreciated that, if a fibre of the type illustrated on the left of this figure crosses a fibre of the type shown on the right, the ridge formation permits contact at eight distinct places as shown in Fig. 5. Unless the fibres have sufficient local plasticity to allow the forces of surface tension and wet pressing to bring them into complete contact during drying, bonding will occur only at these eight sites. This is strikingly revealed in the micrograph of Fig. 6(*a*). It should be pointed out that this micrograph shows an extreme case of this effect, the opposite extreme being a complete diamond bond of type I.

* Any elongated papermaking cell is described in this article by the word 'fibre', except in the few cases that it is necessary to use the specific botanical description

Fig. 1—Surface of spruce sulphite handsheet (metal-shadowed replica) [× 650]

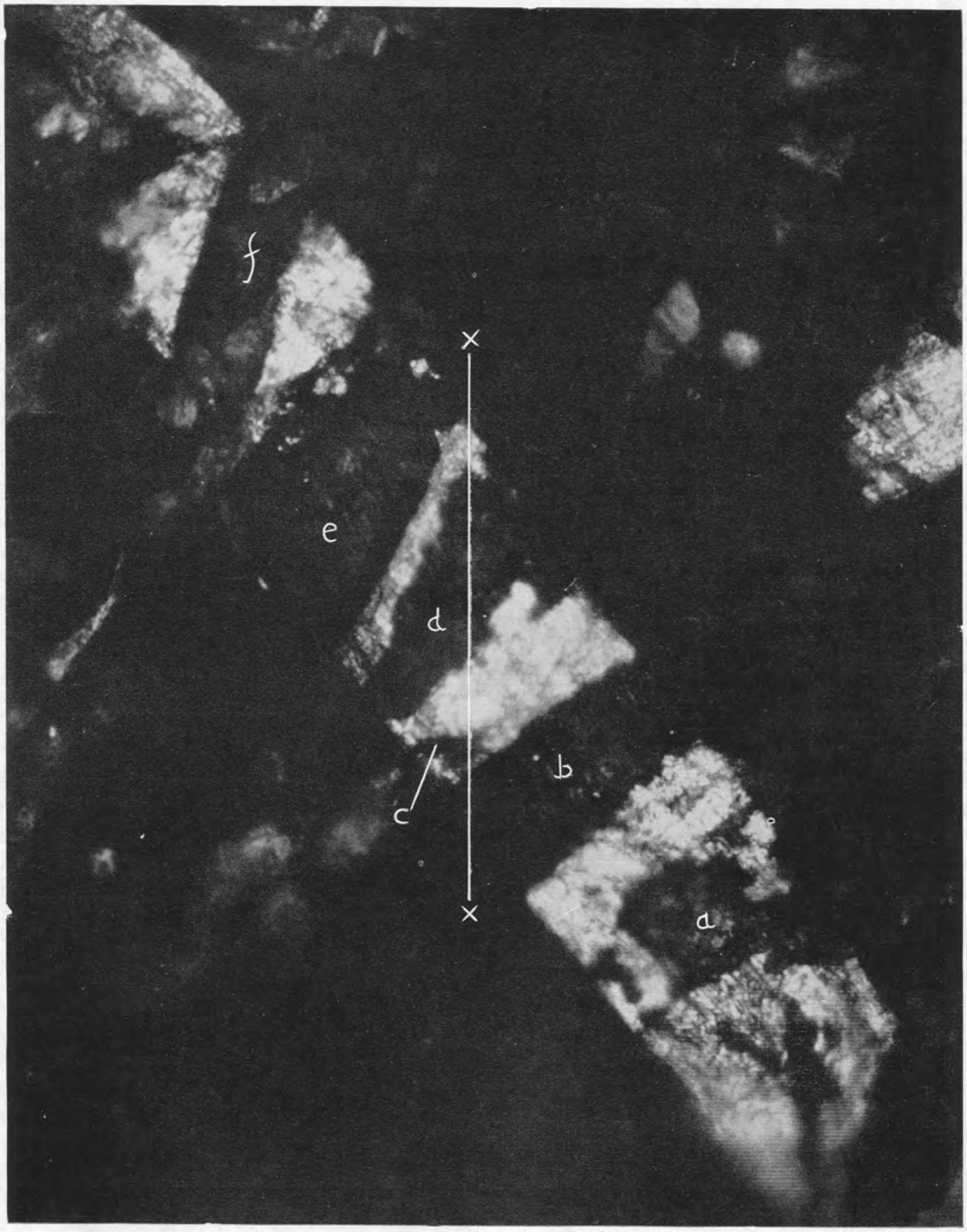


Fig. 2—Same field as Fig. 1, taken in P.V.I. to show bonds [× 650]

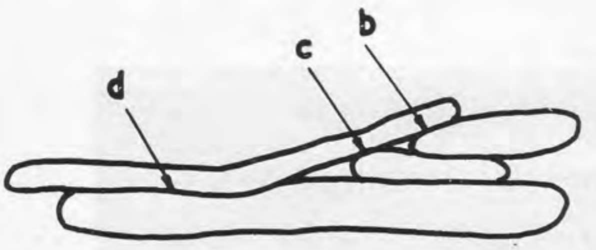


Fig. 3—Representation of cross-section of fibres on line *XX* in Fig. 2

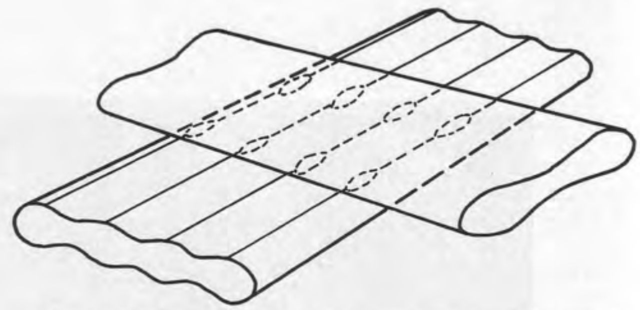


Fig. 5—Regions of bonding between collapsed fibres with ridge formations

The factors that control the degree of bonding at a fibre crossing are the local plasticity and surface topography of the fibres and the magnitude of the compacting force at that crossing. A whole range of bonds between these two extremes can be produced and these are illustrated progressively in Fig. 6(*b*), (*c*) and (*d*). The bond of Fig. 6(*d*) is almost a complete diamond bond of type I, except for the re-entrants, which almost certainly correspond to the valleys between ridges on the original fibre surfaces. Bonds have been observed within the definition of type III that cannot be accounted for by the surface topography effect discussed above and it is thought that in many cases these bonds are inhibited from complete formation by restraining forces of other fibres not immediately in the field of view and by the non-local inflexibility of the fibres themselves.

The investigation of the percentage of observed bonds falling into each of these three categories and the variation in these percentages with factors such as beating and wet pressing will form part of a later publication. An initial survey has indicated, however, that about a fifth fall within type I, a fifth in type II and two fifths in type III. Difficulties in determining the configuration of the underlying fibre in each case prevented the precise classification of the remaining one fifth. An example of this is bond *a* of Fig. 2.

The effect of furnish

THE method has been used to examine the bonding in handsheets prepared from some typical furnishes. Some of the micrographs that have been obtained are illustrated in Fig. 2 and 6–11; they serve to show the limitations and advantages of this technique applied to the various types of common papermaking fibres.

Spruce sulphite

This furnish is illustrated in Fig. 2 and 6 and has been adequately discussed above.

Pine kraft

Bonds similar to those seen in spruce sulphite are apparent and are particularly well defined when the upper fibre is early wood. Examples are shown in Fig. 7 (Valley beaten to a freeness of 620 C.S.F.). The micrographs on the right of this and succeeding figures

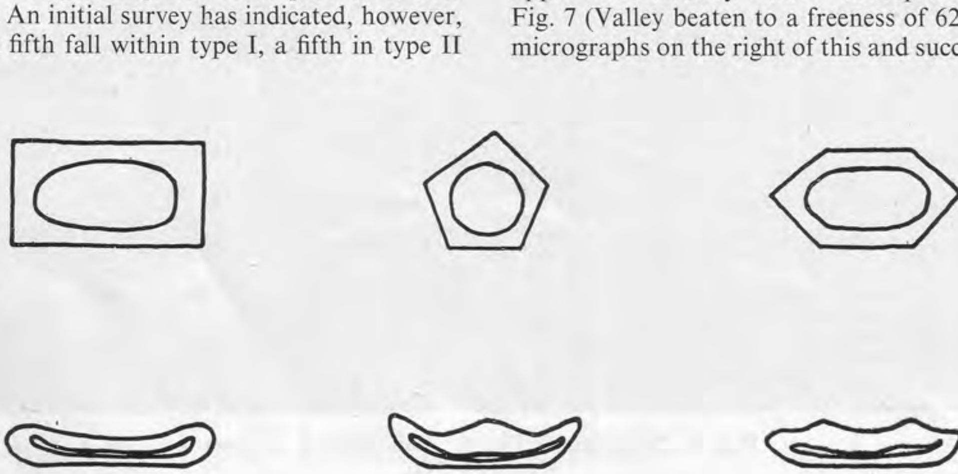


Fig. 4—Effect of collapse during drying on topography of fibres, after Emerton[3]

show the bonds, taken in polarised vertical illumination, in the field that is shown on the left in unpolarised vertical illumination. The lower bond of Fig. 7(*b*) is of type III, inhibition of complete bonding being caused by the surface topography effect. In the upper half of this figure is seen a bond between an early wood fibre and a typical, thick-walled, latewood fibre and, although it may be said that this bond is of type III, it is not possible to state the reason for incomplete bonding in this case. The very incomplete bond (type III) between an early wood and a compression wood fibre in Fig. 7(*d*) is noteworthy in view of the well-known adverse effect of compression wood on paper strength.[6]

Esparto

The very commonly occurring, thick-walled, cylindrical fibres tend to impair the clarity of the bonds; nevertheless, it has been observed that, despite the shape of the fibres, relatively large areas of optical contact are formed between them. It will be evident that, since the intervention of a third cylindrical fibre in the locality of a fibre crossing would almost certainly completely inhibit bonding between the other two fibres, type II bonds occur infrequently. Moreover, because of the small diameter of these cylindrical fibres compared with, for example, the average spruce fibre, there are more individual fibre-to-fibre contacts per unit volume; but, owing to the relative inflexibility of esparto fibres, the ratio of unbonded to bonded area is larger. These effects are apparent in Fig. 8. Fig. 8(*d*) shows the bonding between fibres and a thinner walled fibre tracheid. The pulp was beaten for 15 min. in a Valley beater to a freeness of 270 C.S.F. The few vessel elements that were observed in this brief survey showed that, because of their complex wall structure, they were not suited to this method of examination. No observations were possible on the shorter cells, as the pulp had been screened.

Mixed hardwood

The bonds in this furnish were very badly defined, owing (it is thought) to irregularities in the fibre wall. It was readily apparent, however, as Fig. 9(*b*) and (*d*) illustrate, that type III bonding predominated. The furnish photographed here was beaten heavily in the Valley beater to 66° S.R., but a less beaten furnish showed similar characteristics. Vessel elements behaved in a way similar to that mentioned for those of esparto.

Cotton rag

The thinner-walled fibres showed good definition of bonds and large areas of optical contact [Fig. 10(*b*)], whereas the thicker-walled fibres tended to show less bonding and, as already pointed out in the case of esparto fibres, poorer definition in the image. This micrograph was of mill beaten cotton rag of freeness 175 C.S.F.

Bagasse

This furnish is included to complete the range of the type of fibre examined and a typical field is shown in Fig. 11. The furnish was Valley beaten to a freeness of 280 C.S.F.

Behaviour of bonds in sheets under stress

A MOST significant observation on which work is proceeding at the moment is in connection with the behaviour of bonds under strain. Fig. 12(*a*) shows bonds in a handsheet of spruce sulphite beaten to a freeness of 560 C.S.F. The same field is shown in Fig. 12(*b*) after this specimen, in the form of a tensile strip 10 cm. by 1.5 cm., had been strained to failure, the failure taking place at a point quite remote (4.5 cm.) from this field. Three bonds, all of type II, are completely broken, while two bonds of type I show partial failure; slight failure is also shown in a bond of type III. The breakage of fibre-to-fibre bonds during straining, but before rupture, of a paper sheet was first considered in detail by Rance,[7] who was "led to believe that the irreversible flow, which gives a permanent set to the paper, is itself the first stage of the disintegration of the fibrous sheet and involves the breaking of fibre-fibre bonds at an increasing rate."

The excellent work of Nordman and his colleagues[8] has been accepted by many as evidence in support of this theory. While Nordman's work demonstrates the change in scattering coefficient of a paper sheet undergoing strain, it does not necessarily follow that this change arises from the breakage of bonds between fibres as various people have pointed out.[9,10] The work described in this report is the first direct observation of bond breakage in a paper sheet after straining and this is very strong evidence in favour of the view that the change in scattering coefficient during straining can be attributed mainly to fibre-to-fibre bond breakage. (Although in the work to date it has not been investigated whether intrafibre bond breakage occurs, the writers have never noticed the appearance of new unbonded areas within a fibre.) In the course of the studies described, the authors have also watched bonds breaking in a handsheet during the straining process and this phenomenon has been recorded by a ciné camera attached to the microscope.

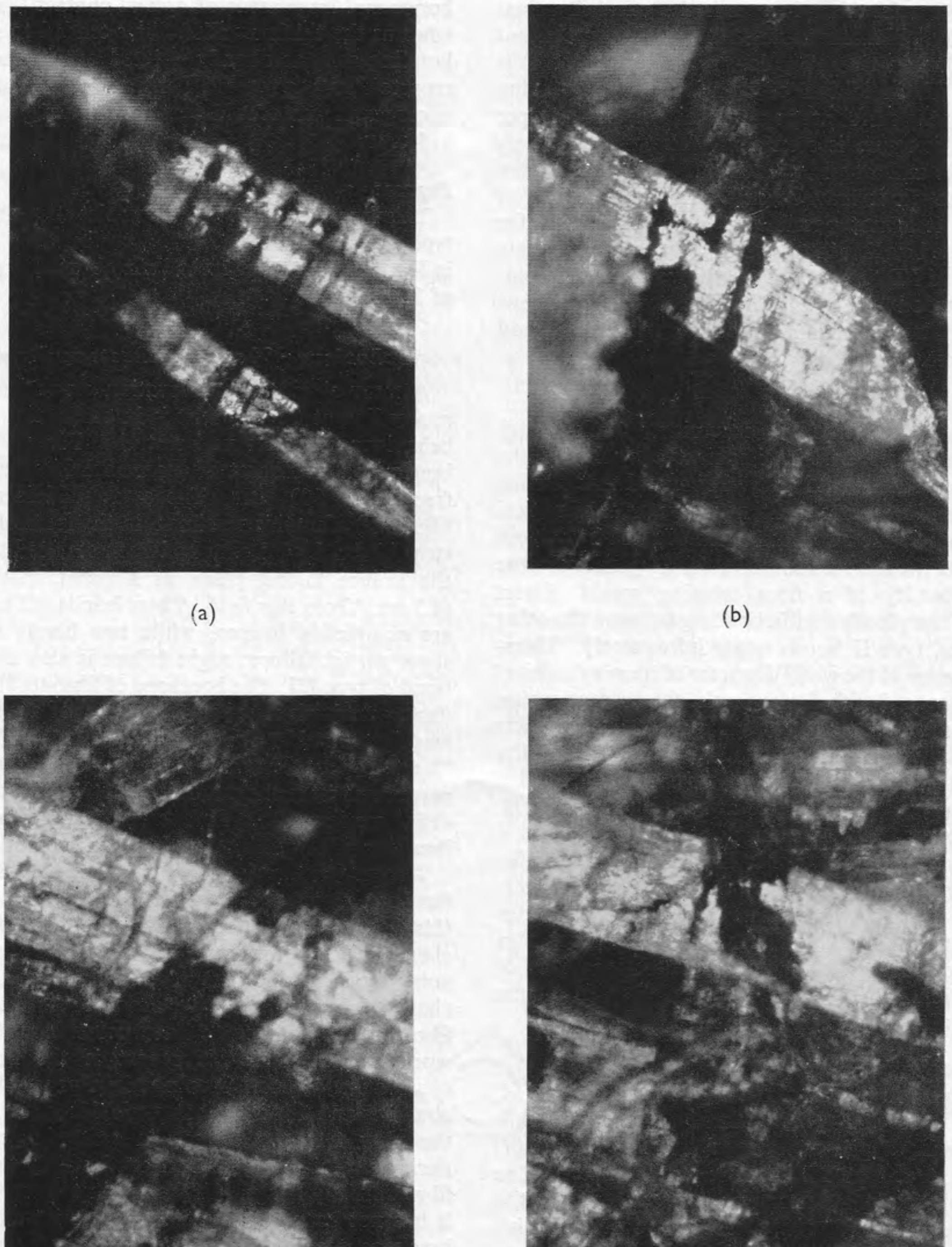


Fig. 6—Spruce sulphite (showing type III bonds) [× 430]

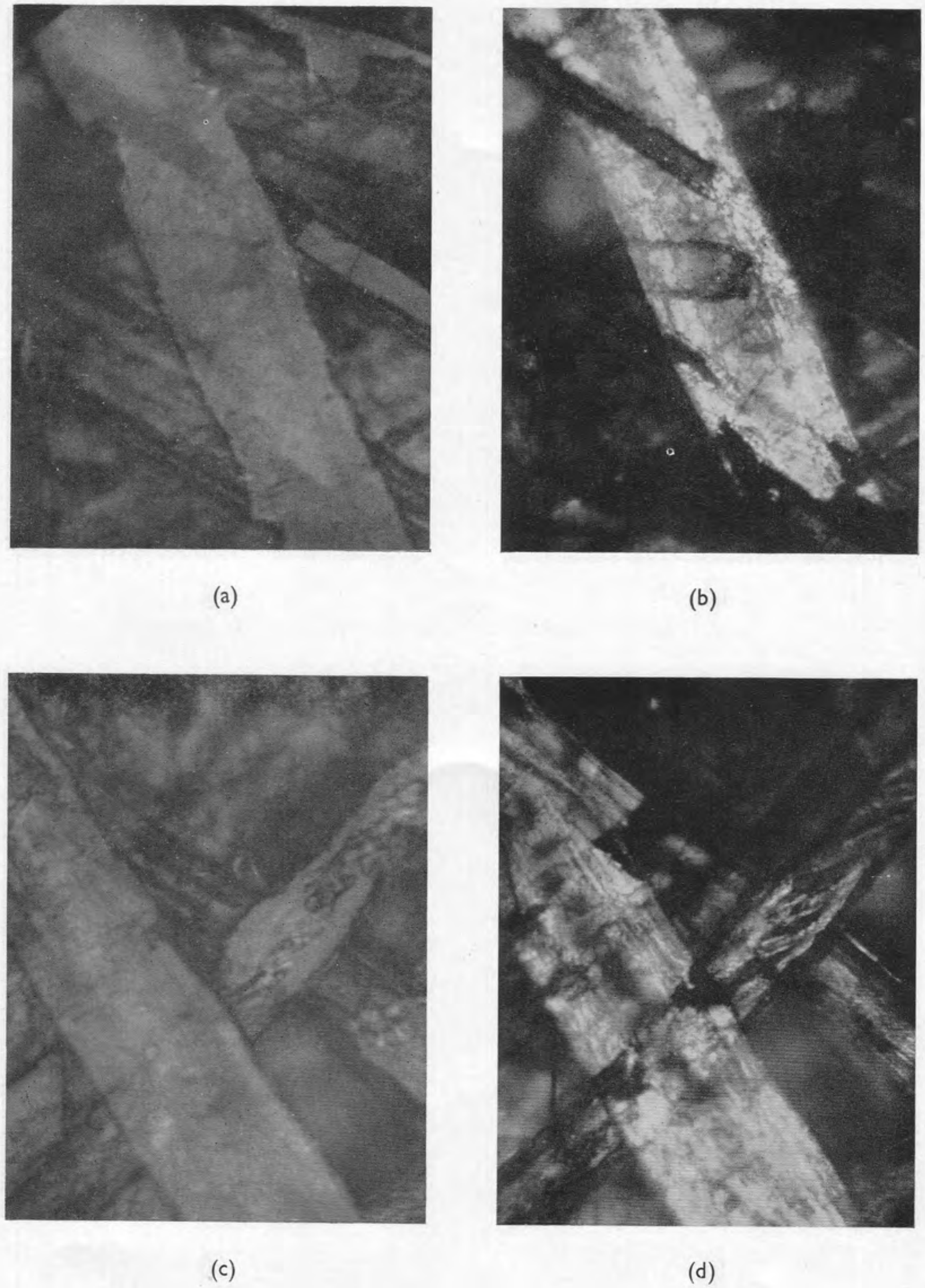
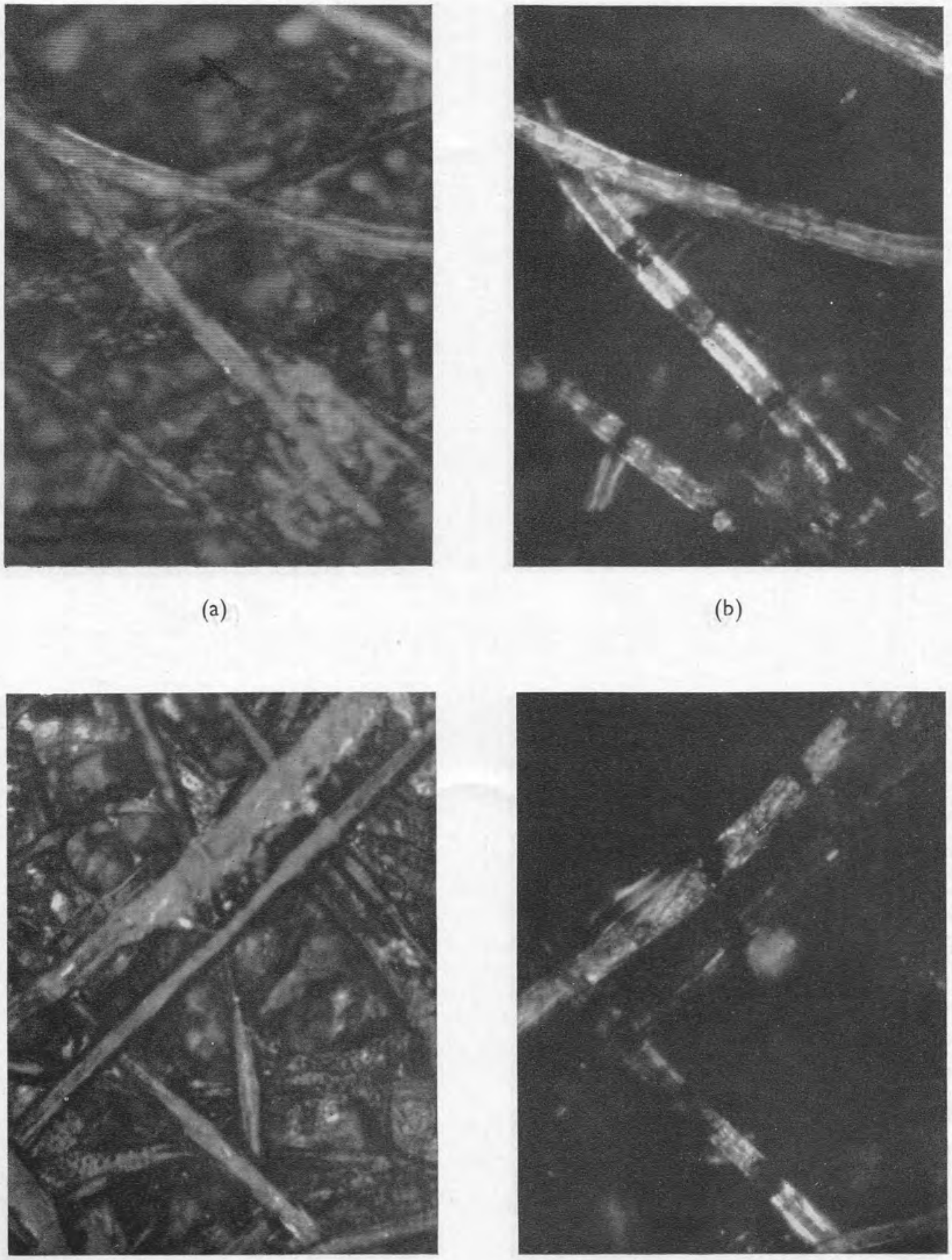


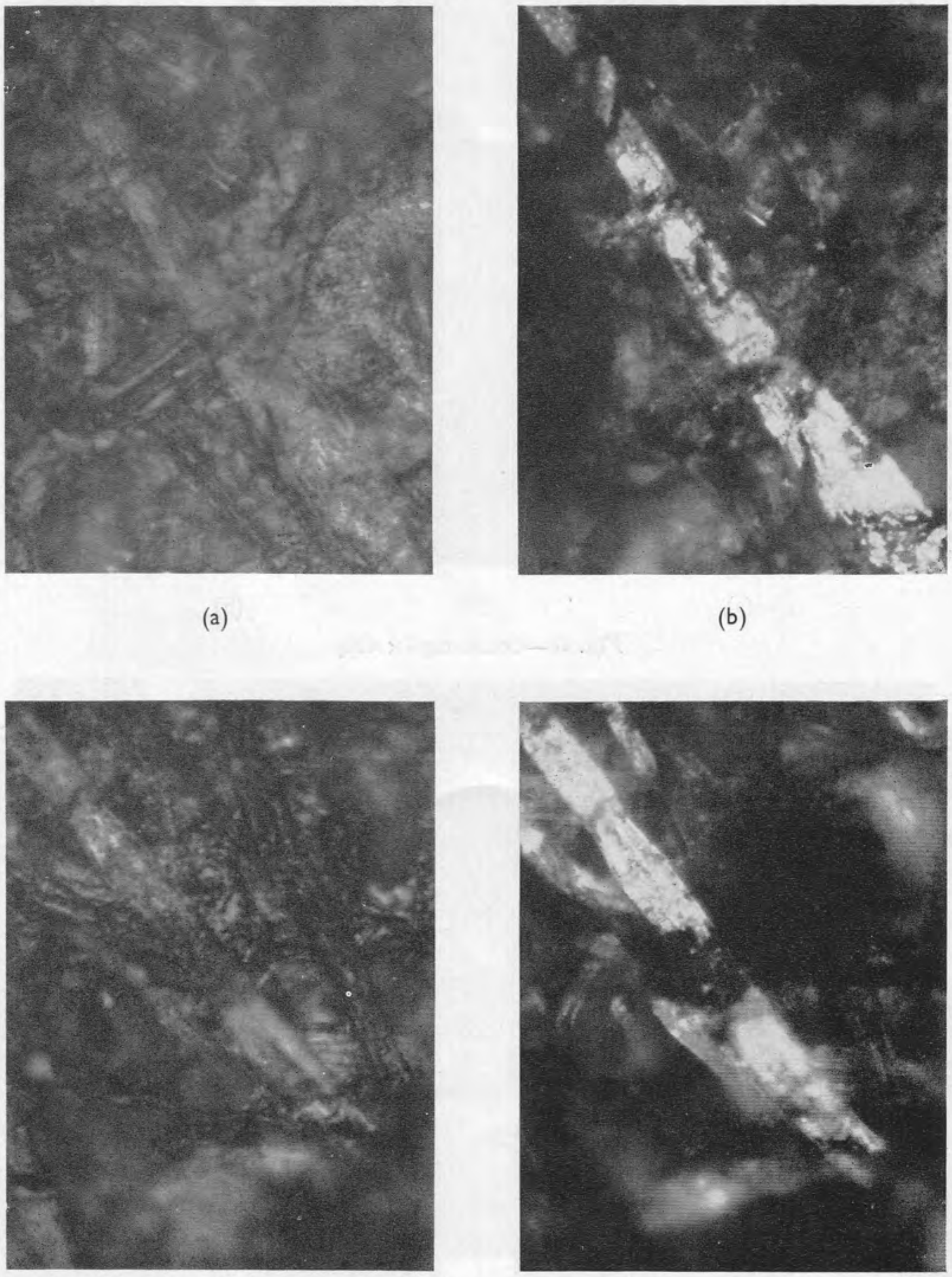
Fig. 7—Pine kraft [× 430]



(a) (b)

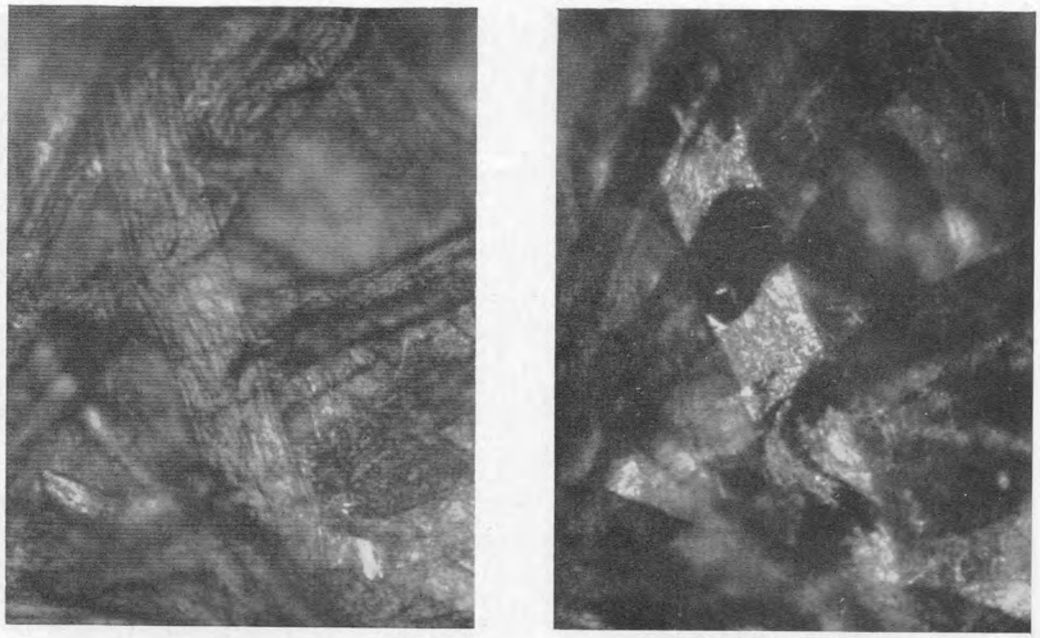
(c) (d)

Fig. 8—Esparto [× 430]



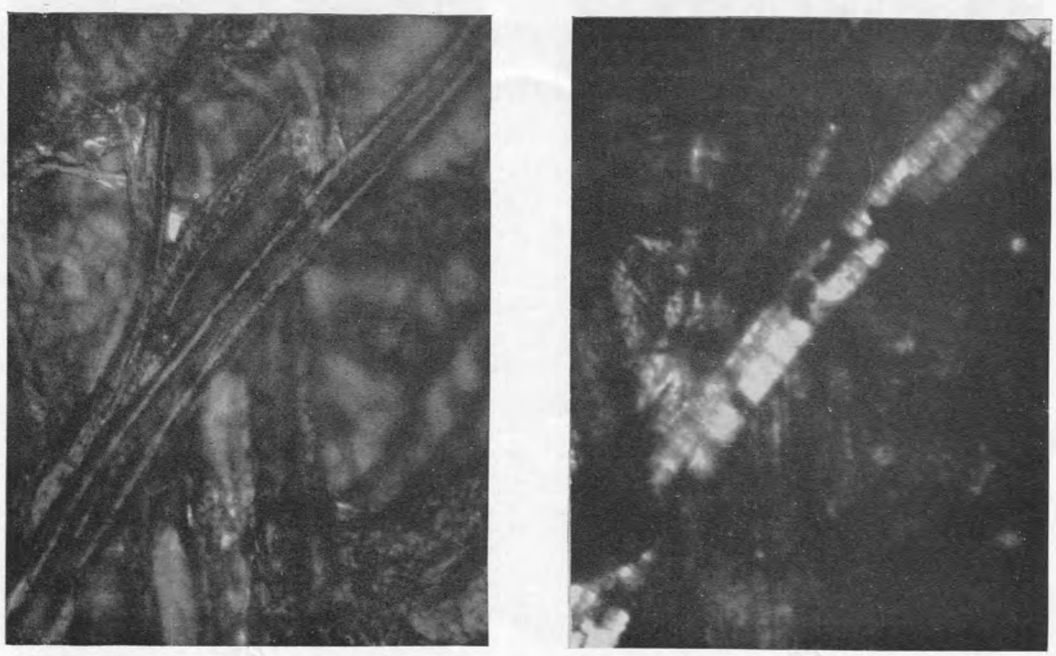
(a) (b) (c) (d)

Fig. 9—Mixed hardwood [× 430]



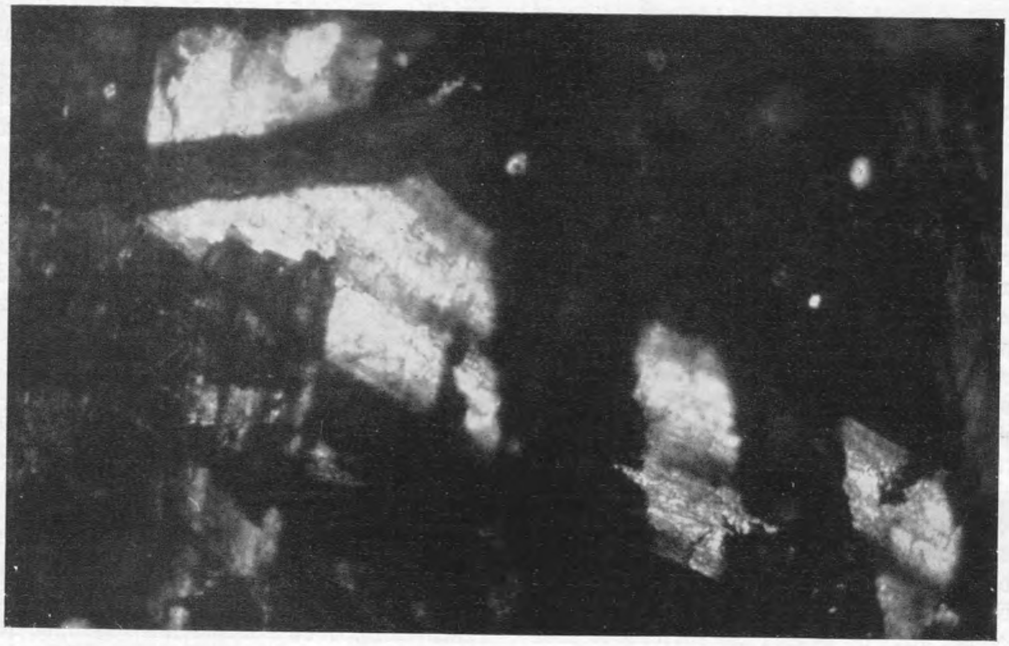
(a) (b)

Fig. 10—Cotton rag [× 430]

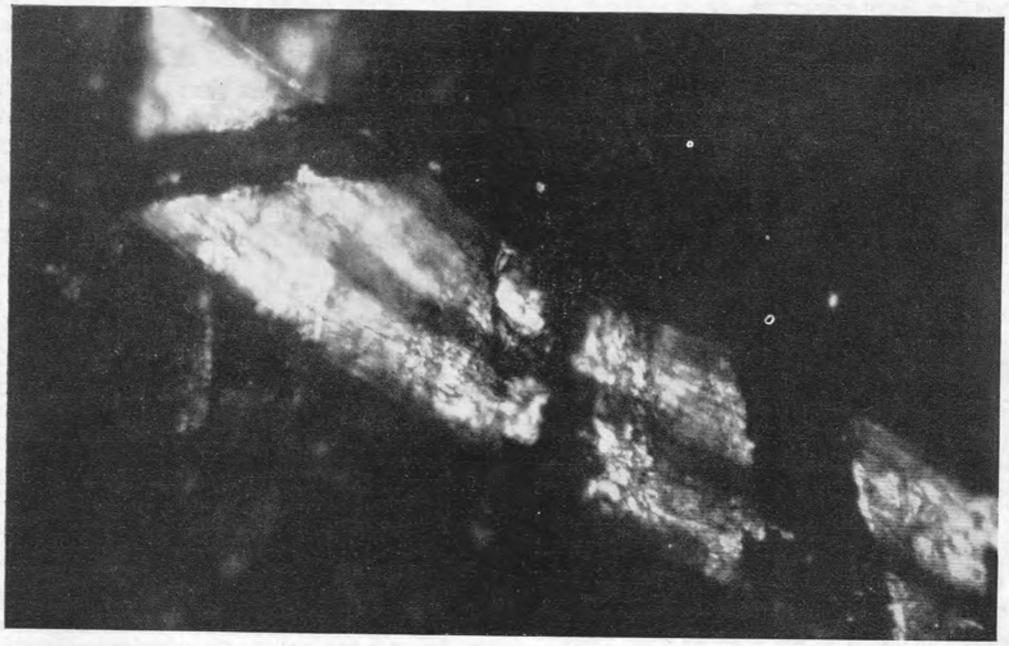


(c) (d)

Fig. 11—Bagasse [× 430]



(a)



(b)

Fig. 12—(*a*) Spruce sulphite handsheet, which on straining shows breakage of bonds as in (*b*) [× 430]

The film record shows both very gradual reduction of bonded areas and such rapid fracture that it must have occurred between frames of the film. Bonds have also been observed to diminish in size while under load at constant strain, showing that bond breakage can depend on time; equally, partially broken bonds have been observed to remain at constant area while the sheet was under stress at constant strain.

A further conclusion to be drawn from Fig. 12(*a*) and (*b*) discussed above (also from incompleted work that will be reported later) is that partial breakage of the contact area between fibres is a common occurrence. The opinion recently expressed by Van den Akker[(11)] "that, when two macroscopic bodies such as fibres are bonded together, failure, once started, will proceed rapidly to complete an irreversible destruction of the bond" is thus shown to be incorrect. It has been mentioned on several occasions that reversible breakage of hydrogen bonds may occur during straining, but our observations are that, whenever sufficient hydrogen bonds are broken to give a detectable change in contact area, no subsequent increase in area has ever arisen; furthermore, no increase in optical contact has been observed at any time. This all adds weight to the assumption that bonding exists wherever optical contact has been observed.

Discussion

PRESENT views on fibre-to-fibre bonding in paper have been formed by deduction from a variety of macroscopic data including the behaviour of paper under stress and the estimation of total bonded area in paper sheets from measurements of specific scattering coefficients. The only reported work on the measurement of actual fibre-to-fibre contacts is that of Asunmaa and Steenberg,[(12)] who examined in the electron microscope sections of thin handsheets (not wet pressed). Without resorting to the tedious procedure of serial sectioning, they could not gain information on the shapes of the bonded areas, but they were able to establish the existence of a whole range of areas of bonding from almost a point contact to 100 sq. microns. One of the most remarkable facts arising from this study is the quite frequent occurrence even in unbeaten sheets of contact over virtually the whole of the areas of crossing. Thus, although we have found that the average fibre-to-fibre contact area is of the order of a few hundred square microns, bonded areas of the order of several thousand square microns are surprisingly common. This implies a high degree of plasticity in the fibres, allowing them to respond to the forces of wet pressing and surface tension. The incidence of such large, discrete bonded areas in a sheet will influence its physical properties and any theory relating structure to, say, mechanical and optical properties must incorporate their existence as a basic feature. One can visualise, for example, that such large areas of bonding have strengths far exceeding anything that could arise from the entanglement or bonding of fibrillated cell wall material.

An impression that was gained from the survey was that the type III bonds of the nature shown in Fig. 6(*a*) were most common in unbeaten sheets, which leads us to suggest that the formation of optical contact over the complete mutual area between two fibres depends on the *local* plasticity of the fibres. It does not seem that, in the existing theory of beating based on the increase of fibre flexibility or plasticity, the relative importance of local, as opposed to non-local, plasticity has been considered. *Non-local plasticity* may increase the total number of contacts between fibres in the sheet, whereas *local plasticity* may increase the areas of the bonds at these contacts; a study of the relative importance of these factors in the development of strength properties by beating will form part of the future work.

Conclusion

THIS preliminary survey of the use of the technique described in Part 1 of this series has illustrated the new approach that can now be made to the general problem of the relationship between the structure and physical properties of paper. This work is being extended to enable statistical information to be gained on bond properties and their dependence on the papermaking variables outlined in the conclusion of Part 1.

REFERENCES

1. Page, D. H., *Paper Tech.*, 1960, **1** (4), 407 (T165)
2. Page, D. H. and Emerton, H. W., *Svensk Papperstidn.*, 1959, **62** (9), 318
3. Emerton, H. W., *Proc. Tech. Sect. B.P. & B.M.A.*, 1955, **36** (3), 595
4. Emerton, H. W., Page, D. H. and Hale, W. H., *Unpublished work*
5. Jayme, G. and Hunger, G., *Holzforsch.*, 1959, **13** (1), 1
6. Dadswell, H. E., Wardrop, A. B. and Watson, A. J., *Fundamentals of Papermaking Fibres* (Ed. F. Bolam, Tech. Sect. B.P. & B.M.A., Kenley, 1958), 187
7. Rance, H. F., *Proc. Tech. Sect. B.P. & B.M.A.*, 1948, **29** (2), 449
8. Nordman, L., *Fundamentals of Papermaking Fibres* (Ed. F. Bolam, Tech. Sect. B.P. & B.M.A., Kenley, 1958), 333
9. Van den Akker, J. A., Contribution to discussion, *ibid.*, 365
10. Upton, P. B. G., Contribution to discussion on paper by van Royen, A. A. H., *Proc. Tech. Sect. B.P. & B.M.A.*, 1959, **60** (3), 367
11. Van den Akker, J. A., *Tappi*, 1959, **42** (12), 940
12. Asunmaa, S. and Steenberg, R., *Svensk Papperstidn.*, 1958, **61** (18B), 686

The compression strength of corrugated fibreboard cases and sleeves

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Synopsis

An equation is derived that enables the compression strength of corrugated cases or sleeves to be predicted from a knowledge of case or sleeve dimensions and of two distinct 'strengths' of either the individual paperboard components or of the combined board. Experimental verifications of each stage of the work are described.

Introduction

THE prime function of a corrugated case is to protect its contents against all hazards. It may be stacked and must subsequently be able to resist steady compressive forces. It may also be shaken, dropped in a variety of different ways or subjected to adverse atmospheric conditions.

The performance of a case cannot therefore be evaluated by a single test and a study of compression strength forms only one part of the whole question of performance. Why, then, has it been chosen in preference to other factors?

Firstly, it is generally agreed that the compression test is the best all-round test for assessing the performance of a case.

Secondly, it must be remembered that many other tests such as the drop test, vibration test, etc. must be performed with a filled case to be of any value and that the weight, shape, form and distribution of the contents are additional variables that complicate the issue.

Lastly, it is a quantity that is frequently of importance in its own right. The ability of a case to prevent its contents from being crushed when the case itself is situated at the base of a stack is sometimes its most important characteristic.

A manufacturer of corrugated cases, concerned with continuously improving the compression strength of his products, should have adequate information on the following main points—

1. The strength characteristics of the individual paperboard components relevant to compression strength.
2. The relevant strength characteristics of the combined board.
3. The effect on compression strength of the geometry of the case and of the board.

This paper presents a theoretical study of compression strength, in which the geometry of the case is accounted for and which predicts that two distinct strength properties of the combined board must be considered. These two board 'strengths' are then dealt with separately and in each instance the influence of the appropriate strength characteristics of the paperboard components and of the board geometry is determined.

The mathematical treatments have been verified by experiment and the agreement is shown to be satisfactory.

Previous work

A CRITERION by which the value of any theoretical study of this problem may be assessed is provided by the following experimental observations.

The effect of varying height

Most observers agree that the strength of sleeves (cases without top or bottom flaps) decreases with increasing height (at constant length and width) in the low height region (say, 5–10 in.). Above a certain height, however, there appears to be little further change. Case strength, on the other hand, appears to be largely independent of height over all the values normally investigated. W. Vollmer[1] has tested sleeves of heights down to about 1 in. and finds that, in this region, the strength once again becomes independent of height. Fig. 1 is reproduced from this paper (the dimensions and forces having been converted to British units) and clearly shows the three distinct regions. It will be seen that the fall in strength between the two horizontal sections depends markedly on the length and width, being greatest for the largest perimeters and disappearing altogether for the smallest.

The effect of varying perimeter

Here again, there is general agreement that the compression strength increases with increasing perimeter (at constant height); whilst Neuhäusser,[2] for instance, is of the opinion that the graph should be curved with the concave side to the perimeter axis (Fig. 2), Maltenfort[3] finds no evidence for this and assumes a straightline relationship. This straight line, however, does not pass through the origin and the curve therefore seems more likely, although the assumption of a linear relationship may well be acceptable over a limited range.

Apart from the fact that cases generally have a lower compression strength than sleeves, there does not seem to be any significant difference between the two structures in the form of the strength versus perimeter relationship.

When length and width are considered individually, there is one other effect that is generally recognised. If the perimeter and height are maintained constant and the length and width are varied, it is found that the shape with the greatest compression strength is a square and this is true for both cases and sleeves.

The effect of strength of material

The findings of different investigators on this question vary widely. Kellicutt and Landt[(4)] conclude that the relevant strength characteristic of the individual components is the ring stiffness (in cross-direction) and they add the three separate figures in proportion to the lengths of components in the board. This gives the relevant strength figure of the board. Maltenfort, on the other hand, although using a similar component test (cross-direction once again), finds no evidence for any direct contribution to strength by the fluting medium. Dagel[(5)] finds a good multiple correlation between the Concora medium test and the fluting medium ring stiffness (cross-direction) on the one hand and box compression strength on the other, but these experiments excluded variations in liner quality and included only one case size.

Several investigators have examined the problem of compression strength from a theoretical viewpoint, among whom may be mentioned Kellicutt and Landt,[(4)] Neuhäusser[(2)] and Maltenfort.[(3)] The individual methods of approach, however, have been so varied that an adequate discussion of each would be beyond the scope of this paper. Sufficient to say that, whilst each author has made distinct and valuable advances in the subject, no single treatment has yet achieved general acceptance.

Development of the compression strength equation

BEFORE attempting any mathematical treatment, the physical behaviour of the specimen during the compression test must be clearly understood. Initially, a sleeve will be considered and the behaviour of a case dealt with subsequently.

During the initial stage of load application, the panels of the sleeve remain vertical and the linear pressure (load per unit length) along the top and bottom horizontal edges is everywhere the same. When the linear pressure rises to a certain critical value, the panels begin to bow. There is an obvious analogy here to the situation of a simple strut undergoing longitudinal compression. The critical linear pressure in this instance, however, is sufficient to maintain any degree of curvature in the strut and such a structural member cannot withstand a linear pressure greater than this critical value. This is not so with a sleeve, since the 'struts' in the middle of the panel are all connected eventually to the vertical edges and receive support from them. Consequently, the sleeve does not collapse when the critical linear pressure is passed: instead, the degree of bowing of the panels steadily increases. During this stage, the linear pressure is a maximum at the vertical edges, with a minimum at the midpoints of the horizontal edges and the formulation of a possible equation of pressure distribution is the first step in the present treatment.

Commonsense considerations show that this relationship must satisfy the following requirements—

1. It must be symmetrical about the middle of the panel.
2. It must be continuous, which implies that the gradient at the mid-point must be zero.
3. It must be almost flat when the length is small compared with height and curve more as the length to height ratio increases.
4. When the length is very large compared with the height, the force per unit length must exceed the critical buckling load by only a very small amount (except near the corners).

The following distribution equation satisfies all these requirements—

$$P = (P_A - S)\left\{\frac{ad}{ad + l} + g\left(\frac{4x^2}{l^2}\right)^{(bl/d+1)}\right\} + S \ldots (1)$$

where P = total linear pressure at any point along the edge,
P_A = average value of P,
S = critical linear pressure for a simple strut of the same board,
l = total length of the panel,
x = distance of the point considered from the mid-point of the edge,
d = height of the panel,
a, g and b are constants.

Since x occurs only as a second order term in this equation, requirement (*1*) is satisfied. The index term $(bl/d + 1)$ ensures the satisfaction of requirements (*2*) and (*3*), since the term must be greater than unity (b being positive) and its value increases with l/d. Finally, if the linear pressure at the mid-point of the panel is examined by putting $x = o$, it will be seen that the only dimensional term remaining is $ad/(ad + l)$, the value of which decreases steadily as l/d increases, thus satisfying condition (*4*).

The constant g is not independent, since—

$$\int_{o}^{l/2} P dx = \frac{P_A l}{2}$$

which, when evaluated, gives—

$$g = \frac{l\left(\frac{2bl}{d} + 3\right)}{ad + l}$$

Therefore,

$$P = \frac{(P_A - S)}{(ad + l)}\left\{ ad + l\left(\frac{2bl}{d} + 3\right)\left(\frac{4x^2}{l^2}\right)^{(bl/d+1)} \right\} + S$$

The value of the linear pressure at the corners (P_c) is now obtained by putting $x = l/2$.

$$\text{Thus, } P_C = \frac{(P_A - S)}{ad + l}\left\{ ad + l\left(\frac{2bl}{d} + 3\right) \right\} + S$$

It is now assumed that, when this corner pressure reaches a certain critical value, collapse occurs in the vertical edge and this initiates breakdown of the panels and complete failure of the sleeve. McKee and Gander,[6] using high-speed photography, have obtained some evidence that this does occur. If this value is C, then—

$$C = \frac{[(P_A)_{max} - S]}{ad + l}\left\{ ad + l\left(\frac{2bl}{d} + 3\right) \right\} + S$$

$$\text{Therefore, } (P_A)_{max} = \frac{(C - S)(ad + l)}{ad + l(2bl/d + 3)} + S$$

Now, the maximum load W_l that can be supported by a panel of length l is—

$$W_l = l(P_A)_{max}$$

$$= \frac{l\left\{ aCd^2 + ld(C + 2S) + 2bSl^2 \right\}}{ad^2 + 3ld + 2bl^2}$$

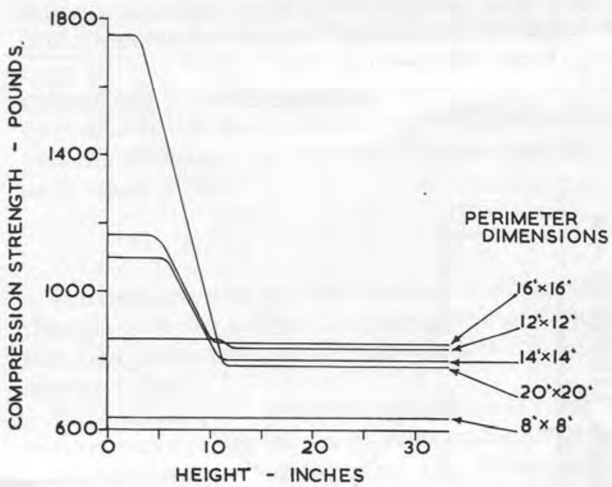
For a sleeve of length l and width w, therefore, the total supportable load W is given by—

$$W = \frac{2l\left\{ aCd^2 + ld(C + 2S) + 2bSl^2 \right\}}{ad^2 + 3ld + 2bl^2} + \frac{2w\left\{ aCd^2 + wd(C + 2S) + 2bSw^2 \right\}}{ad^2 + 3wd + 2bw^2}$$

When this equation was fitted to the experimental results (see later section), it was found that the middle terms in numerator and denominator could be neglected with little effect and the final fitted form reduced to—

$$W = \frac{2l\,(5Cd^2 + 2Sl^2)}{5d^2 + 2l^2} + \frac{2w\,(5Cd^2 + 2Sw^2)}{5d^2 + 2w^2} \quad . \; . \; . \; (2)$$

It should be noted here that above the upper critical height (discussed below), d is no longer the true height of the sleeve or case.



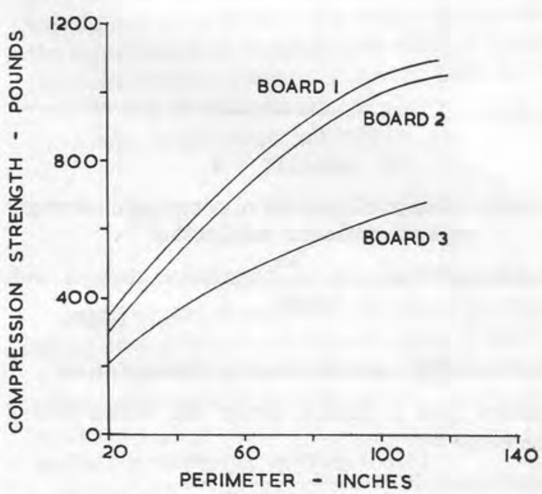
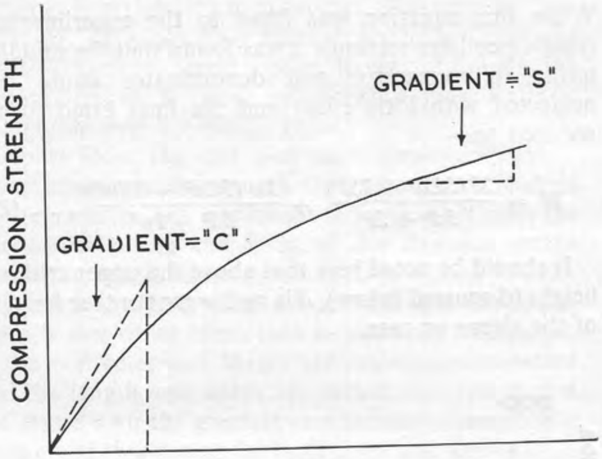


Fig. 1 (*top*)—Relationship between compression strength and height (Vollmer)

Fig. 2 (*bottom*)—Relationship between compression strength and perimeter



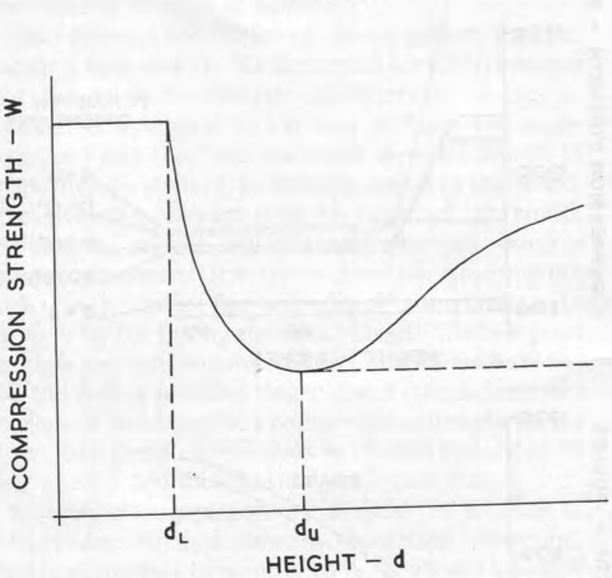
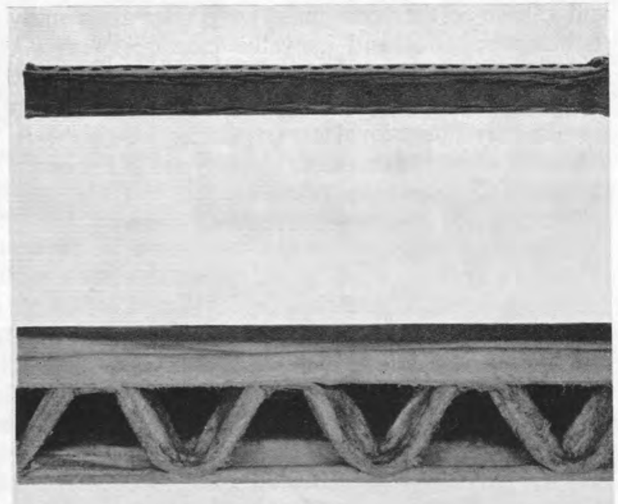


Fig. 3 (*top*)—Change of gradient of compression strength against perimeter relationship

Fig. 6 (*bottom*)—Variation of compression strength with height



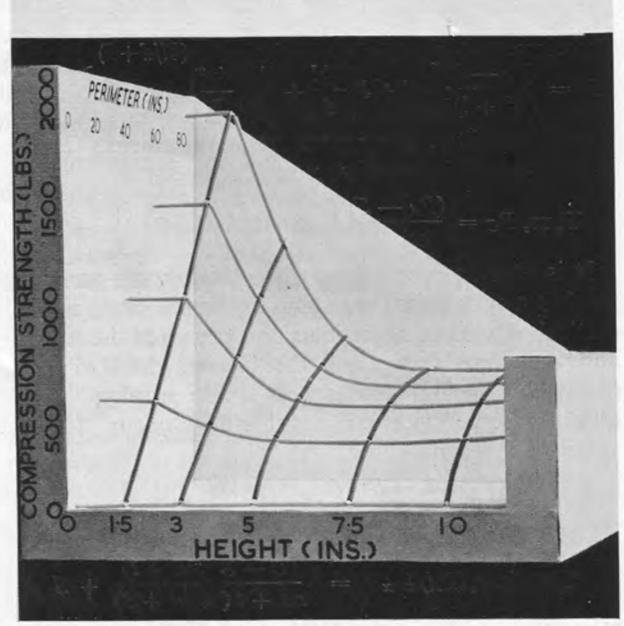


Fig. 5 (*top*)—Half inch vertical crush samples showing the 'concertina' type of failure

Fig. 7 (*bottom*)—Three-dimensional graph showing complete strength against dimensions relationship calculated using typical data for *B*-flute sleeves

Preliminary examination of the equation

CONSIDER first a square sleeve for which $l = w$ and therefore—

$$W = \frac{4l\,(5Cd^2 + 2Sl^2)}{5d^2 + 2l^2}$$

If the height d remains constant, when l is very small compared with d—

$$W \text{ is approximately equal to } \frac{4l\,(5Cd^2)}{5d^2} = 4lC$$

This means the strength is the product of perimeter and corner strength C and the sleeve is 'all corner'—an expected result. Similarly, when $l \gg d$—

$$W \text{ is approximately equal to } \frac{4l\,(2Sl^2)}{2l^2} = 4lS$$

and the sleeve is 'all panel'. This variation is shown in Fig. 3, which obviously resembles Fig. 2 inasmuch as the gradient decreases monotonically from the origin.

The variation of W with height for a single panel can now be considered. It is a well known result that the linear pressure required to cause a strut of height d to buckle is given by—

$$S = \pi^2 F/d^2,$$

where F is a quantity known as the flexural rigidity of the strut. In this particular instance, both S and F refer to a strut of unit length (length being in the machine-direction of the paperboard components—*see* Fig. 4). As the height of the strut decreases, S does not increase indefinitely. Instead, it reaches a maximum value and at this point the board no longer buckles before failing, but collapses in a 'concertina' fashion (Fig. 5). At lesser heights, the failure occurs in the same manner and the maximum load is independent of height. It was felt that this maximum value of S might be equivalent to C, the corner strength, since both relate to the failure of board without prior bowing. During the fitting of the compression equation (*2*) to the experimental data, this was assumed to be so and the good agreement obtained justified the assumption.

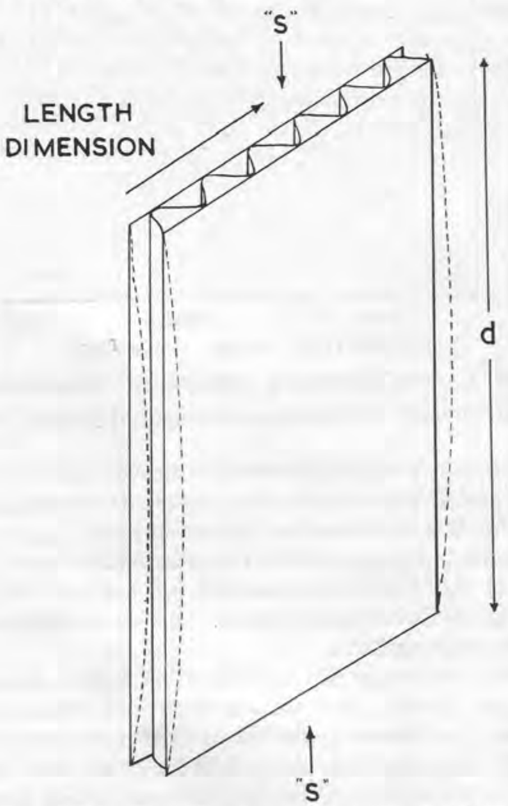


Fig. 4—Compression of a strut (corrugated board)

Since the maximum possible value of S is C, the greatest value of W is 4 lC and the height (called the lower critical height d_L) at which this occurs is given by—

$$C = S = \pi^2 F/d_L^2$$

$$\text{Therefore, } d_L = \pi\sqrt{F/C}$$

Below this value, the compression strength is independent of height and the general shape of the complete curve is shown in Fig. 6. In the region to the right of the minimum point, the theoretical curve predicts the strength assuming the panels to bow in a simple fashion. At these heights, however, the bowing is multiple (as described by Kellicutt and Landt[7]) with a 'wavelength' equal to the height at the minimum strength point and the case behaves like a number of cases of this height with the strength once again independent of height (horizontal broken line, Fig. 6). The value of this upper critical height (d_u) is found by partially differentiating equation (*2*) and equating to zero, which yields—

$$d_u^2 = \frac{\pi^2 F}{C} + \sqrt{\frac{\pi^4 F^2}{C^2} + \frac{\pi^2 F l^2}{2{\cdot}5\ C}}$$

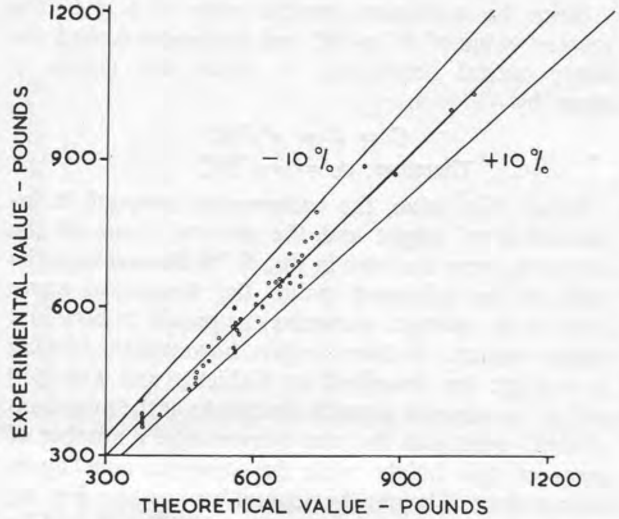
The complete dimensional variation of compression strength is shown in Fig. 7, a photograph of a model that was constructed using typical values for B-flute sleeves.

The determination of the strongest shape at constant perimeter can be carried out by substituting for W the value (constant $- \, l$) in equation (*2*), differentiating with respect to l and equating to zero. This gives two solutions, $l = w$, which is the required one and $C = S$, the significance of which is that when S is equal to C the compression strength is the product of perimeter with C and is independent of sleeve shape—that is, the sleeve is 'all corner' as before.

Quantitative comparison between theory and experiment

A TESTING programme, designed to explore fully the strength versus dimensions relationship, was devised using two qualities of board—one, A-flute (coarse) and one, B-flute (fine). About 600 sleeves and 500 cases were made in a wide range of sizes, from 5 in. square by 25 in. high to 20 in. square by 1 in. high, including many non-square shapes.

Five sleeves and five cases of each size were tested. The sleeves were hand-cut with a sharp knife in order to minimise damage to the horizontal edges. Both sleeves and cases were conditioned at 68°F, 65 per cent. R.H. for 48 hr. before testing.



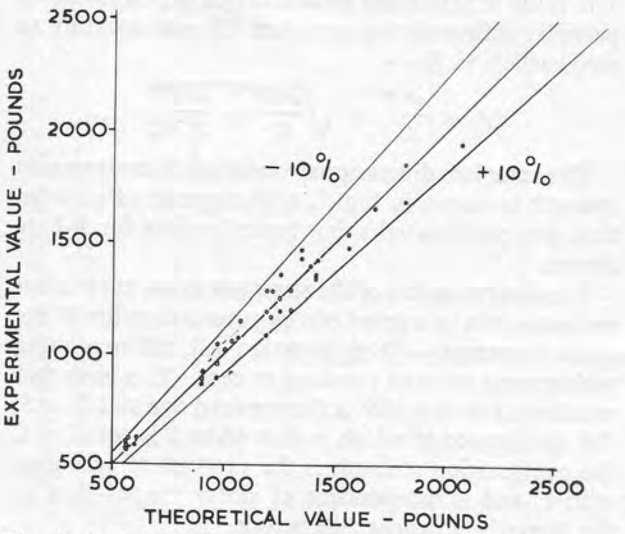
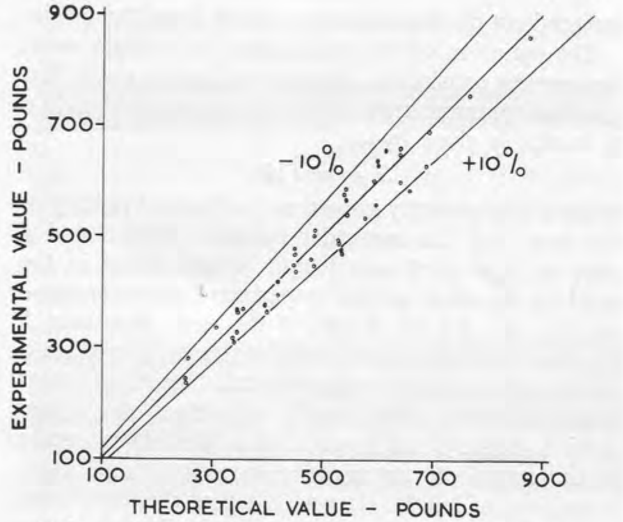


Fig. 8 (*top*)—Compression strength of B-flute sleeves
Fig. 9 (*bottom*)—Compression strength of A-flute sleeves



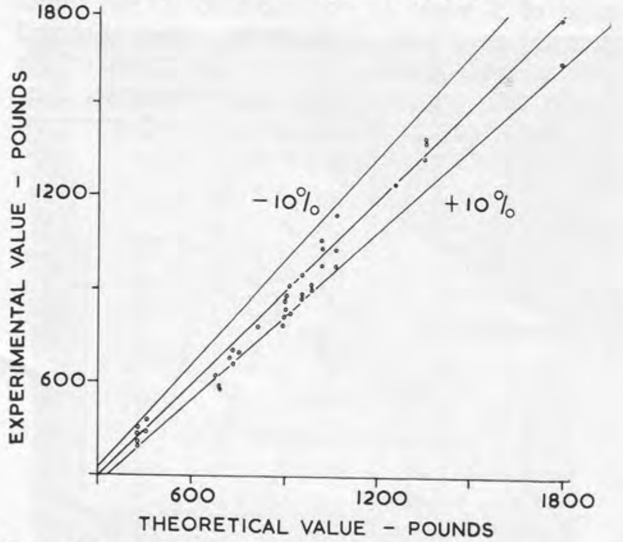


Fig. 10 (*top*)—Compression strength of B-flute cases
Fig. 11 (*bottom*)—Compression strength of A-flute cases

For the actual compression testing, the sleeves were held in the correct shape until the tester platens made contact with the sleeve. Cases were taped top and bottom before insertion in the tester.

In order to fit the equation to the results, S and C were first measured by compressing long and short struts respectively and the best values of a and b found by comparison with the data. As previously mentioned, it was found that certain terms in the equation could be neglected without significant error, which resulted in an equation with only one unknown constant (a/b) and further fitting of the equation was then straightforward. The degree of agreement between theory and experiment for sleeves is shown in Fig. 8 and 9, where each point represents the average value for five experimental determinations.

In order to fit the equation to the strength values for cases, it was found necessary to use a figure for S that was less than that for sleeves. This was anticipated for two main reasons.

Firstly, the load is not applied to the vertical panels of a case directly, but via the flaps and horizontal creases. The line of application of the load does not pass through the neutral axis of the panel and this results in an additional bending moment which gives a lower value of S.

Secondly, as the flap is pressed downwards, there is a rolling action at the horizontal crease, which itself tends to make the panel bow, again resulting in a lower value of S.

The appropriate value of S was determined by compressing struts with creased flaps top and bottom to simulate the conditions in a case panel. This creasing resulted in a reduction in S by about 15 per cent. on average, but the exact reduction (hence, the reduction in compression strength) in a commercially produced case will depend on the conversion efficiency.[8]

The agreement between theory and experiment for cases is shown in Fig. 10 and 11, each point again representing the average of five results.

The strength of sleeves of other board qualities

HAVING investigated the dimensional variations, the next stage was to examine a number of different board qualities. Attention was confined to sleeves of only two sizes (12 in. × 9 in. × 15 in. high and $9\frac{1}{4}$ in. × $8\frac{1}{4}$ in. × 7 in. high) and three different samples of double-wall board were included in the programme. When the individual paper components were available, the prediction of sleeve strength was made from measurements on these components. As would be expected, this led to a wider spread of results compared with predictions based on measurements on the combined board. The results of this part of the work are shown in Fig. 12.

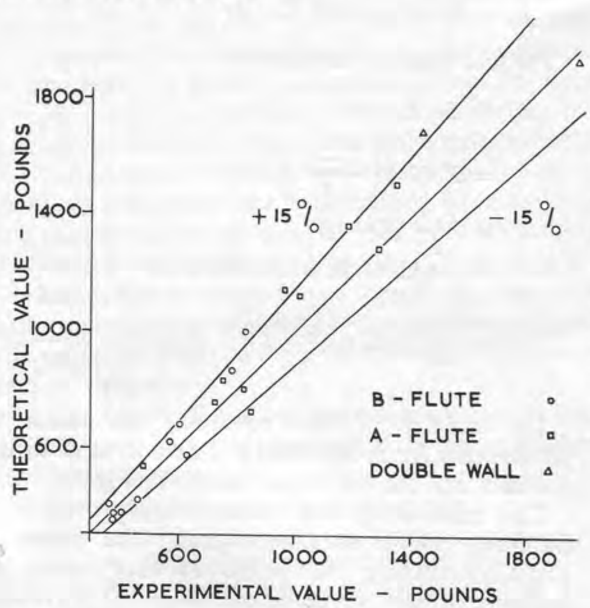


Fig. 12—Relationship between experimental and theoretical compression strength values for various board qualities

Compression strength of non-rectangular shapes

IN deducing the compression strength equation, the assumption is made that the vertical edges of the individual panels remain vertical throughout the compression test until the failure point is reached. This assumption will be valid for many shapes other than rectangular and to test the validity of the equation in this context, triangular, hexagonal and octagonal sleeves were constructed from both the A-flute and the B-flute board. The B-flute sleeves were 10 in. high and the A-flute 15 in. All sleeves had a perimeter of 40 in. and each shape was regular (all panel lengths equal). For such regular polygons, the compression equation assumes the form—

$$W = \frac{nl\,(5Cd^2 + 2Sl^2)}{5d^2 + 2l^2}$$

where n = number of panels of length l.

The agreement for these sleeves is shown in Fig. 13, where strength is plotted against number of panels. In all eight instances, the results are within ± 10 per cent. The horizontal dotted lines represent the limiting values for each board, which are approached as the number of panels (at constant perimeter) becomes infinitely large (that is, perimeter × C).

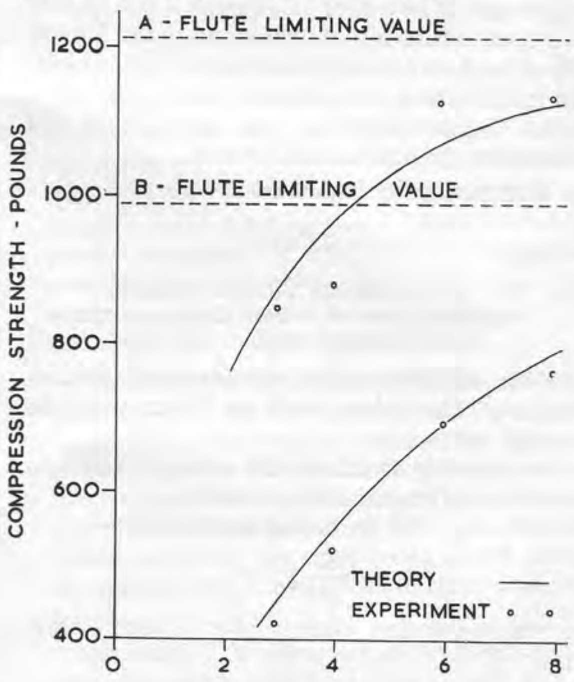


Fig. 13—Agreement between theory and experiment for non-rectangular sleeves

Prediction of strut strength S and corner strength C

THE compression strength equation gives the compression strength in terms of two board strengths—S, the strut strength and C, the corner strength. These two quantities can be determined directly from board or their values may be predicted from appropriate strength measurements on the individual components.

As previously mentioned, the strut strength is given by the relation—

$$S = \pi^2 F/d^2$$

and, in order to predict S from the properties of the paperboard components, it is therefore necessary to derive an expression for the flexural rigidity of combined board. For this purpose, two assumptions are made.

Firstly, it is assumed that the board is symmetrical (has two identical outer liners). It has subsequently been found that the final equation provides ample accuracy where this is not so, if the 'strengths' (product of Young's modulus and thickness) of the two liners are averaged and the board assumed to have two liners of this mean strength.

Secondly, the fluting is assumed to have a sinusoidal shape with a take-up (length of fluted component per unit length of board) of 1.5, though it will be seen that the contribution of fluting medium to the flexural rigidity of the board is only about 25 per cent. or less, assuming all three components have the same 'strength'. Departures from these assumptions will not, therefore, produce serious errors.

The flexural rigidity is defined as—

$$F = E\Sigma a\, y^2,$$

where E is the appropriate Young's modulus,
y is the distance of a small element of area a from the neutral axis.

Since two different moduli are involved, the contributions of the fluting and the liners must be determined separately.

In the following equations, the suffix (*1*) refers to the liners and (*2*) to the fluting medium.

For unit length of the fluting alone, then—

$$F_2 = \frac{E_2}{\lambda} \Sigma\, a\, y^2,$$

where the summation extends over λ (one 'wavelength').

Since the fluting is assumed to be sinusoidal—

$$y = \frac{(T - 2t_1 - t_2)}{2} \sin \frac{2\pi x}{\lambda},$$

where x = distance along the neutral axis (Fig. 14),
T = thickness of the combined board,
t_1 = thickness of one of the liners,
t_2 = thickness of the fluting medium.

$$\text{Therefore, } F_2 = \frac{(T - 2t_1 - t_2)^2 E_2}{\lambda} \int_0^{\lambda/4} a \sin^2 \left(\frac{2\pi x}{\lambda}\right)$$

Also $a = t_2.ds$,
where ds is a small length of the curve.

$$\text{But} \quad ds = dx \left[1 + \left(\frac{dy}{dx}\right)^2 \right]^{\frac{1}{2}}$$

$$\text{and} \quad \frac{dy}{dx} = \frac{\pi(T - 2t_1 - t_2)}{\lambda} \cos \frac{2\pi x}{\lambda}$$

Therefore,

$$F_2 = \frac{(T - 2t_1 - t_2)^2 E_2\, t_2}{\lambda} \int_0^{\lambda/4} \left[1 + \frac{\pi^2 (T - 2t_1 - t_2)^2}{\lambda^2} \cos^2\left(\frac{2\pi x}{\lambda}\right)\right]^{\frac{1}{2}} . \sin^2 \left(\frac{2\pi x}{\lambda}\right) dx$$

This integral can be evaluated numerically using the expression for the take-up—

$$1{\cdot}5 = \frac{4}{\lambda}\int_0^{\lambda/4} \left[1 + \frac{\pi^2 (T - 2t_1 - t_2)^2}{\lambda^2} \cos^2\left(\frac{2\pi x}{\lambda}\right)\right]^{\frac{1}{2}} dx$$

and leads to

$$F_2 = (T - 2t_1 - t_2)^2 E_2\, t_2/2\pi$$

For unit length of the liners —

$$F_1 = E_1 \Sigma\, a\, y^2$$

$$= E_1 (2t_1) \left(\frac{T - t_1}{2}\right)^2$$

$$= \frac{E_1 t_1}{2} (T - t_1)^2$$

For unit length of the board, therefore —

$$F = F_1 + F_2$$

$$= \frac{1}{2\pi} [\pi E_1 t_1 (T - t_1)^2 + E_2 t_2 (T - 2t_1 - t_2)^2] \quad \ldots\ldots (3)$$

The validity of this equation was tested experimentally for A-flute and B-flute boards of various qualities and the results are shown in Fig. 15.

This relationship has subsequently proved to be extremely useful for investigating the effects of partially crushing the board as may occur, for instance, at the printer-slotter stage of conversion.

The board thickness may subsequently recover almost completely, but a decrease in rigidity is found

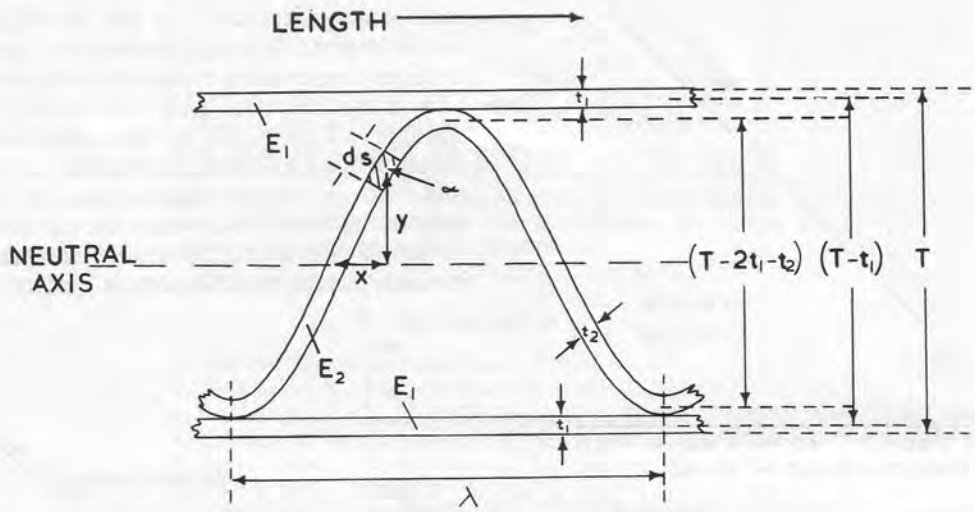


Fig. 14—Section of corrugated board

on flexing. This is due to the damaged fluting being compressed by the liners and the board thickness decreasing during the flexing. Such a mechanism is thought to explain the loss in compression strength known to result from such conversion treatment.

It has already been pointed out that, when the height of a sleeve is below the lower critical height, failure occurs by a concertina-like folding action and the strength is merely the product of perimeter and C. This fact led to the test that is now used to measure C on board. The normal type of ring stiffness tester is used with flat platens and strips of board are cut 4 in. × ½ in., with the flutes running parallel to the ½ in. dimension. The strip is held in the tester with the flutes in a vertical direction and crushed, the test value being the maximum load it can sustain. The figure C is a quarter of this value, of course, since the strip is 4 in. long (both C and S are strengths in lb./in. length).

The manner of failure in this test (crushing without bowing) led to the consideration of the ring stiffness test on components in the cross-direction as a means of predicting C.

It was found that a test piece size of 4 in. × ⅜ in. gave the most consistent results and the best prediction of C was given by—

$$C = 1{\cdot}5\,R_2 + 0{\cdot}72\,(R_1 + R_1'),$$

where R_2 = ring stiffness/in. of the fluting medium,
R_1 = ring stiffness/in. of the first liner,
R_1' = ring stiffness/in. of the second liner.

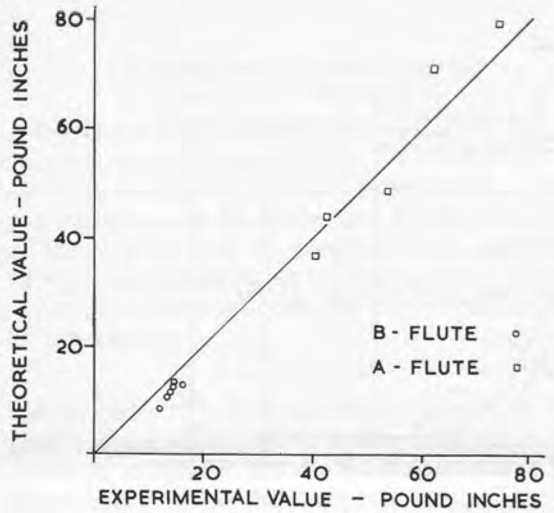
The results are shown in Fig. 16. The agreement in this case is poorer than for flexural rigidity and further investigation on the prediction of C from component tests may well prove profitable.

Relative importance of elastic and plastic properties

THE strut strength S is an elastic property of the board, whereas C is a plastic one, involving irreversible deformation. The question arises—which is the more important of the two quantities? This can be carried even further by considering the relative importance of elastic strength (Young's modulus) and plastic strength (ring stiffness) of a single component. Another question that fits automatically into this context is the relative importance of fluting and liner strengths. The complete picture is obviously very complex, since the answers to these questions depend on the case size and shape and the type of flute.

Firstly, it must be appreciated that, other things being equal, S (or F) depends on the depth of flute. For A-flute, F is approximately three to four times greater than for B-flute; for double-wall board, it is two to three times larger again. The value C, on the other hand, is independent of flute type, although it is greater of course for double-wall board, because of the greater total length of material in unit length of board.

Secondly, C is obviously more important than S when the panel lengths are small and the relative importance of S steadily increases as the lengths increase.



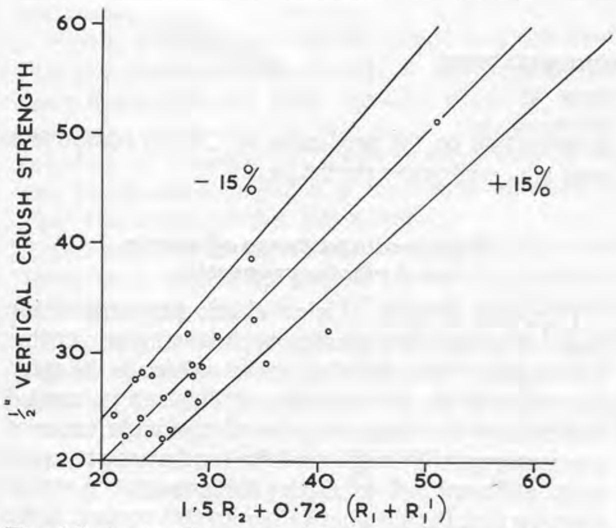


Fig. 15 (*top*)—Flexural rigidity—comparison between theory and experiment

Fig. 16 (*bottom*)—Relationship between component ring stiffness (4 in. × $\frac{3}{8}$ in. samples) and vertical crush strength of board

Fig. 17 shows both of these tendencies. The strengths have been calculated for the same board qualities that were used in the main series of experiments described earlier, except for the double-wall board. The contribution of *S* to compression strength is shown for the different flutes and its variation with panel length (square sleeves).

As far as the relative contributions of liners and fluting are concerned, assuming all three components have the same relevant characteristics (*Et* and ring stiffness, cross-direction), the fluting contributes approximately 25 per cent. of the *S* strength and 50 per cent. of the *C* strength. Since *C* is in general more important than *S*, it will be realised that the elastic strength (Young's modulus) of the fluting is of negligible importance compared with its ring stiffness. This is not the case with the liners. Their elastic strength will probably be less important than their ring stiffness for B-flute (depending on basis weights and case or sleeve dimensions), of about equal importance for A-flute, whilst, for the two outer liners in double-wall board, the elastic strength will almost certainly be the more important quality.

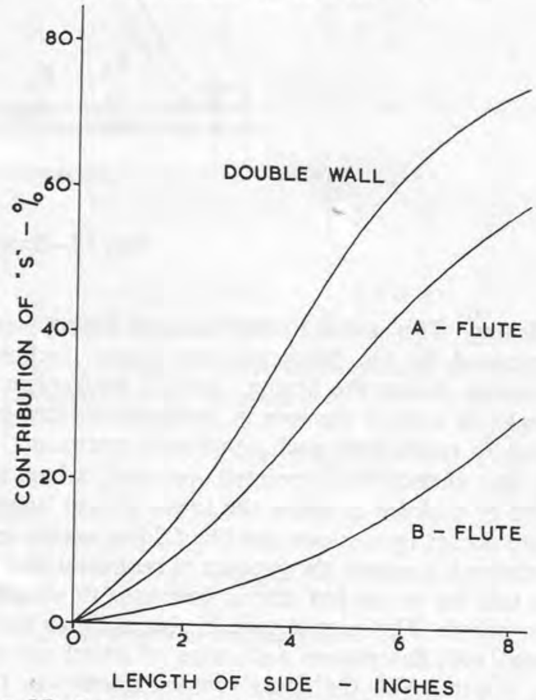


Fig. 17—Contribution of strut strength *S* (elastic strength) to total compression strength for square sleeves

Conclusions

An equation capable of predicting the top to bottom compression strength of corrugated cases and sleeves has been established and it has been shown how this strength depends on two strength characteristics of the component papers. The relative importance of these characteristics depends on flute type and on case size and shape and can be assessed in any given instance.

The two relevant board strengths can also be determined and comparison with values predicted from component strengths could be used as a measure of combining efficiency. Similarly, comparison between compression strength predicted from board strength and that obtained experimentally could be used as a measure of conversion efficiency.

Acknowledgements

The author gratefully acknowledges the valuable advice and assistance given by members of the staff of Bowater Packaging Limited, Fibre Container Division and of the Packaging Department of the Bowater Research and Development Company Limited, without which this work would not have been possible.

REFERENCES

1. Vollmer, W., *Verpackungs Rund.*, 1956, **9** (5), 37
2. Neuhäusser, R., *Allg. Papier-Rund.*, 1956, (10), 485
3. Maltenfort, G. G., *Fibre Containers*, 1956, **41** (7), 44
4. Kellicutt, K. Q. and Landt, E. F., U.S. Dept. of Agriculture Forest Service: *Forest Products Lab. Report No. D 1911* (Nov. 1951)
5. Dagel, A. Y., *Svensk Papperstidn.*, 1957, **60** (6), 211.
6. McKee, R. C. and Gander, J. W., *Tappi*, 1957, **40** (1), 57
7. Kellicutt, K. Q. and Landt, E. F., *Tappi*, 1952, **35** (9), 398
8. Carlson, T. A., *Fibre Containers*, 1941, **26** (3), 28, 32, 35

Acknowledgments

The author gratefully acknowledges the valuable advice and assistance given him by members of the staff of Bowater Packaging Limited, Fibre Container Division and of the Packaging Department of the Bowater Research and Development Company Limited, without which this work would not have been possible.

REFERENCES

1. Villiers, W., *Verpackungs-Rund.*, 1956, 9 (7), 57
2. Neubronner, R., *Allg. Papier-Rund.*, 1956, (10), 453
3. Maltenfort, G. G., *Fibre Containers*, 1957, 42 (7), 66
4. Kellicutt, K. Q. and Landt, E. F., U.S. Dept. of Agriculture Forest Service; *Forest Products Lab. Report No. 1911* (Nov., 1951)
5. Dagel, A. Y., *Modern Packaging*, 1957, 69 (9), 211.
6. McKee, R. C. and Gander, J. W., *Tappi*, 1957, 40 (1), 57.
7. Kellicutt, K. Q. and Landt, E. F., *Tappi*, 1951, 35 (9), 398
8. Carlson, T. A., *Fibre Containers*, 1941, 26 (7), 28, 32, 35

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Interrelationships between degree of swelling and strength properties of strawpulps and their mixtures with woodpulps

Communication from the Institute for Cellulose Chemistry in conjunction with the Wood Research Centre at the Technical College, Darmstadt

GIVEN AT THE SECOND EUCEPA SYMPOSIUM HELD AT NOORDWIJK, HOLLAND IN JUNE 1959

Introduction

IT is becoming increasingly recognised that the strength properties of the dry sheet of paper are determined primarily by the *degree of swelling* of the fibrous mass *before* sheet formation takes place.[1–3] If only one component had to be dealt with, then the relationships would be quite apparent. For example, there is a linear relationship between the *degree of swelling* as found from the water retention value (WRV) of the swollen fibres and the tensile strength of the sheet expressed as *breaking length*.[4,5]

The relationships are considerably more complex with mixtures of different fibres, especially in the cases of short- and long-fibred pulps. Although in practice most papers are made with mixed furnishes, there is relatively little data available in the literature and so it has not been possible to predict the behaviour of mixed furnishes on a sound theoretical basis.

Van Nederveen and Hellenberg[6] carried out systematic studies on the beating of strawpulps and also investigated the properties of mixtures. If beating of the pulps was carried out *separately* and they were mixed after beating, it was found with a mixed softwood/strawpulp and varying the proportions of the two pulps that there was a linear relationship for tearing strength and fold number, while the degree of wetness was generally somewhat lower. The same authors got better results, however, when the pulps were first mixed and *beaten together* to approximately 50° S.R. Here, it was observed that the beating time necessary to reach a given wetness was always less than that required when the pulps were beaten separately to the same final wetness; beating was thus improved, since more long fibres survived the beating process and as a result the beaten mixed pulp had a higher tearing strength than the constituent pulps. The values for breaking length and fold number showed no increases over the average value for the constituents and gave a practically linear relationship with the composition of the mixture.

Brecht and Globig[7] investigated the same problem and used 50/50 mixtures of spruce, beech and straw chemical pulps and spruce groundwood pulp *beaten separately* to 45° S.R. It was found that the actual values for breaking length, bursting strength and initial wet strength were somewhat better than the calculated values, but the fold number was considerably lower.

In these investigations on mixtures, they always used dried pulps, but also studied the changes taking place in the components when they are dried before beating. With undried, unbeaten pulps in the moist condition, they always found higher WRV readings and a change in behaviour on beating, which resulted in the observed differences becoming smaller with increasing beating time, but without ever disappearing completely. According to them, drying gave decreased wetness, a reduction in the initial wet strength, reduced bulk and decreased tearing strength, bursting strength and fold number.

Brecht and Jacobs[8] continued these laboratory experiments on a mill scale. In this case, too, dried pulps were beaten separately to 45° S.R. and then mixed. The pulps used were a bleached straw sulphate and a bleached spruce sulphite in mixtures containing in turn 22 per cent., 50 per cent. and 74 per cent. of the straw component. With increasing strawpulp content in the machine-made papers and at constant bulk, there were increases in breaking length, the fold number was substantially unchanged and tearing strength was reduced.

Vámos and Merö[9] investigated a 50 per cent. bleached strawpulp/50 per cent. wet bleached woodpulp mixture under various beating conditions. A comparative examination was made of beating separately and together with beating times of 20, 40 and 60 min. With this procedure, the strawpulp is naturally more resistant to beating than is the woodpulp. After 20 min., for example, the relative wetnesses were 68° S.R./28° S.R.; after 40 min., 88° S.R./64° S.R. They confirmed that the wetness of the mixture in both cases (that is, when beating is carried out separately or together) is higher than the arithmetic mean for the components. Beating together improves breaking length and bursting strength, while, under the conditions of this investigation, separate beating gives increased tearing strength. The low, absolute values for fold number show that only dry pulps were used.

In this work, the effect produced is always dependent on the degree of beating. In our opinion, this value is simply a measure of the freeness of a pulp suspension, the sheet strength being determined by the WRV figure,[3] so it appeared both desirable and necessary to re-examine the whole problem experimentally, with greater emphasis on the degree of swelling of the fibres. In obtaining a clearer relationship than had hitherto been achieved, there was also the prospect of developing a new method of determining the WRV figure of wet-beaten pulps that would give accurate and reproducible results.[5]

Experimental procedure

A. WRV[5]

0.1–0.2 g. of a pulp that has been allowed to swell in water are put in a plastic centrifuge tube equipped with a small nickel gauze plate and centrifuged for 10 min. at 3 000 *g*. The weight of the sample is determined before and after drying. Thus, the water retention value (WRV) of the pulp is given by—

$$\frac{(\textit{Moist weight after centrifuging} - \textit{dry weight}) \times 100}{\textit{Dry weight}} = \textit{WRV per cent.}$$

B. Experimental procedure

The rest of the experiments, with certain exceptions, were carried out according to the German standard methods. By mixing pulps before or after beating in the Jokro mill, two groups of pulps were obtained—those beaten together and those beaten separately and then mixed. The pulps were treated in the disintegrator for a short period.

In order to avoid any possible secondary beating effect, mixing was carried out at high dilution in 10 litre tanks. The division of the test sheets formed on the Rapid-Köthen sheetmachine is varied, since tearing strength is determined by Brecht-Imset and Elmendorf testers. The variations in the lignin and hemicellulose contents of the bleached and unbleached pulps, their wide range of fibre lengths with extreme morphological differences and the differences in the swollen condition of moist and hornified material leads, with closely controlled percentage composition and combination of different beating conditions, to a large number of variations; here, only some of the most important results can be given.

Results

1. Freeness, swollen condition and strength properties of strawpulp mixtures in the unbeaten condition

In order to achieve the clearest possible relationships, the first investigations were carried out with mixtures of *unbeaten* pulps. Dried, bleached and unbleached softwood pulps were used along with unbleached and bleached, dry and moist strawpulps. The percentage of strawpulp varied within the wide range of 10–80 per cent.

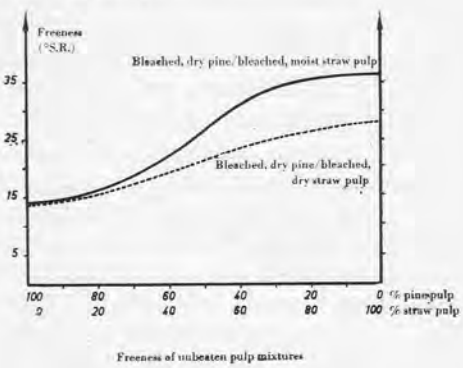
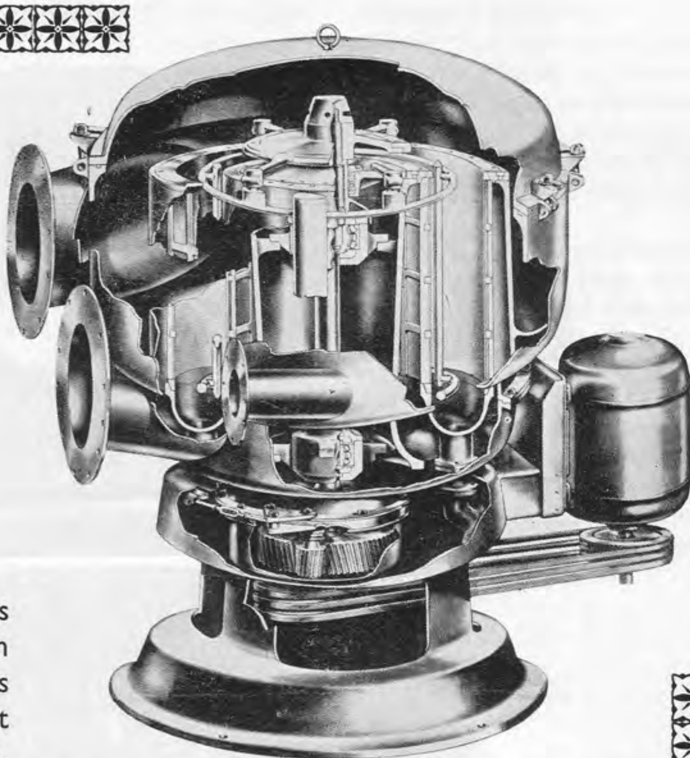


Fig. 1

Freeness (°*S.R.*)—Fig. 1 shows the freeness values for unbeaten, dry, bleached pine pulp and bleached strawpulp, the latter in both the moist and the dry states. It can be seen clearly that initially the wetness changes little up to a mixed pulp composition of approximately 80 per cent. pine/20 per cent. straw, there is then a more rapid increase and, finally, the curves flatten out again; in other words, considerable amounts of strawpulp, up to 20 per cent., can be added to a softwood pulp without having any pronounced effect on the drainage properties.

(*continued on page 549*)



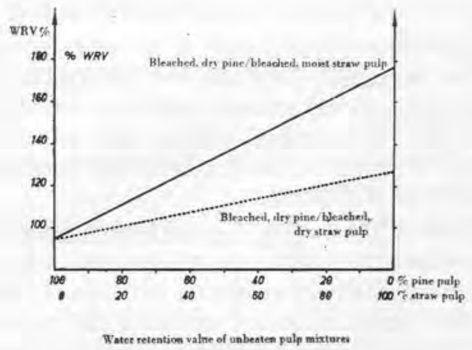


Fig. 2

On the other hand, in mixtures containing large amounts of strawpulp, the poor water drainage properties of the strawpulp exert a dominant influence.

A comparison of both curves shows in addition that it is more difficult to remove water from the bleached, moist, undried strawpulp, so that mixtures containing this have always a higher wetness. In this case, too, the effect is scarcely evident with a mixture containing 20 per cent. strawpulp.

Water retention value (WRV)—The WRV figures were determined with the same mixed, unbeaten pulps.[5] The results are given graphically in Fig. 2. From this, it can be seen that, in contrast to the Schopper-Riegler values, the WRV readings are closely related to the percentage composition of the mixture.

The values were found to be on straight lines. Thus, the WRV figures of mixed, unbeaten pulps are easily calculable from the percentage composition of the mixture. In this case, too, the undried, moist sulphate strawpulp gave considerably higher values, so that all mixed pulps containing it had higher values than those containing dried strawpulp.

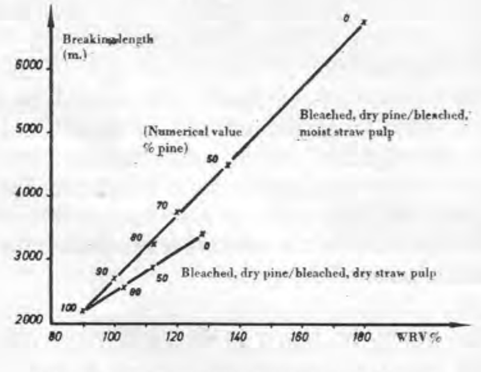


Fig. 3

Tensile strength expressed as breaking length (m.)—It was previously established that there was a linear relationship between the WRV and the breaking lengths of single, beaten pulps. It was now necessary to test if this relationship was true for mixed pulps. The results are given in Fig. 3. The graph shows that the relationship holds also for the mixed pulps under investigation.

Fig. 3 shows also that the use of a moist strawpulp in the mixture gives considerably higher tensile strength than can be attained using dried strawpulp.

Thus, for example, at a WRV of 120, there is an increase in breaking length of approximately 600 m. If dry strawpulp is used, then this WRV figure is attained with a pine pulp fraction of 25 per cent.; with a moist strawpulp, on the other hand, the pine pulp fraction is 70 per cent. However, the mixture containing 25 per cent. pine pulp and moist strawpulp had a breaking length some 2 500 m. higher, corresponding to a WRV of almost 160 per cent.

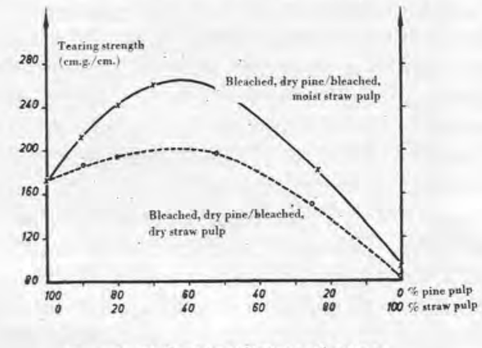
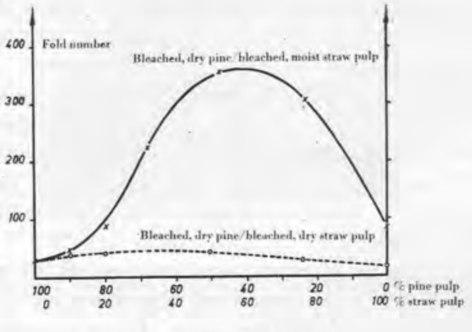


Fig. 4

Tearing strength—Fig. 4 shows the values for the tearing strengths of test sheets made from unbeaten mixed pulps. The considerable increases in tearing strength are extremely prominent. These have a pronounced maximum at a mixture composition of 60 per cent. pine/40 per cent. straw, when moist strawpulp is used. In this case, too, the short fibre length of the strawpulp is not the sole decisive factor.

We know that there are two distinct factors involved in the measurement of tearing strength:[10] firstly, the work necessary to separate one fibre from another and the effect of the associated frictional forces. It is evident that, with these mixture proportions, the increased WRV and the associated higher adhesive power of the strawpulp cells cause bonding points to be formed between the fibres and so increase the tearing strength. Only when the strawpulp fraction exceeds 40 per cent. does the considerably shorter fibre length of strawpulp begin to have an obvious effect.

In accordance with theory, mixtures containing moist strawpulp show significantly higher values, as well as a pronounced maximum.



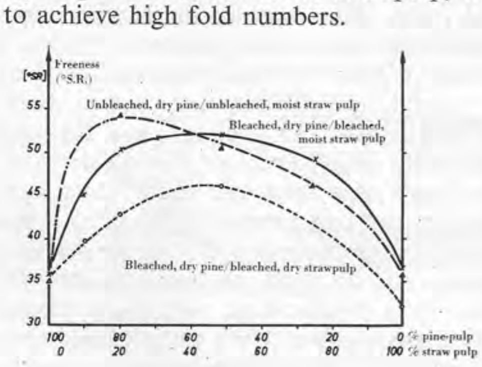
Fold number of unbeaten pulp mixtures

Fig. 5

Folding endurance (fold number)—Fig. 5 shows the very interesting values for the fold numbers of sheets made from unbeaten pulps. Here, the difference between dried and moist strawpulp is particularly obvious. While increasing the percentage of dried strawpulp in the mixture has scarcely any effect on the fold number, the use of moist strawpulp gives very pronounced increases in this value.

It is interesting to note that a strawpulp fraction of 60 per cent. gives a maximum that is considerably higher than either the fold numbers of each of the components or their mean value. At present, it is not possible to give a theoretical explanation for this. This subject is at present being investigated at the Institute for Cellulose Chemistry and the results will be published later.

In addition, Fig. 5 shows most clearly that it is especially important to use moist strawpulp, if one wants to achieve high fold numbers.



Freeness of pulp mixtures beaten separately

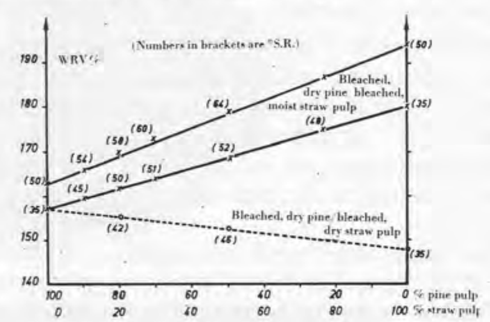
Fig. 6

2. *Separate beating of the components before mixing*

The pulps used in this part of the work were beaten in the standard German beating apparatus, the Jokro mill, in accordance with the recommended procedure,[11] then mixed and, as previously described, sheets were made on the Rapid-Köthen sheetmachine, conditioned and tested.

Wetness (°S.R.)—Fig. 6 gives the wetnesses for three different mixtures when the components were beaten separately. Many investigators have already noted the fact that the wetnesses of various mixed pulps are in many cases rather higher than the values calculated from the composition of the mixture.

Fig. 6 shows this effect most clearly and it is especially pronounced when the wetnesses of the woodpulp and the strawpulp are approximately the same. It can be seen from Fig. 6, for example, that when the two components are beaten separately to about 35° S.R. the resulting mixture has a much reduced water drainage as is shown by the large increase in wetness to almost 55° S.R.



Water retention value of pulp mixtures beaten separately

Fig. 7

This unexpectedly large increase in wetness is at a maximum in different mixtures, according to the components of the mixture, when the strawpulp fraction has a value between 20 and 50 per cent. This fact is not very important by itself, but, as will be shown later, it plays an important part in the evaluation of other investigators' work and enables their conclusions to be examined in quite a different light. As was expected, Fig. 6 shows also the pronounced increase in wetness of the mixture when moist strawpulp is used in place of dry pulp.

Water retaining capacity (WRV per cent.)—In addition to Fig. 6, Fig. 7 gives the WRV readings for various pulp mixtures when beating is carried out

(*continued on page 555*)

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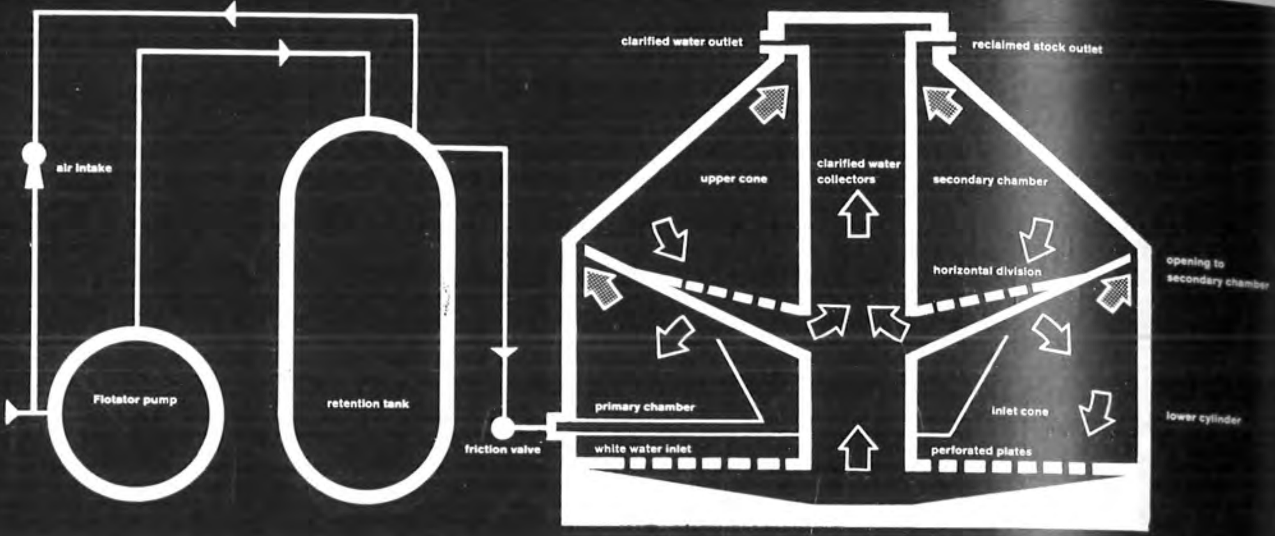

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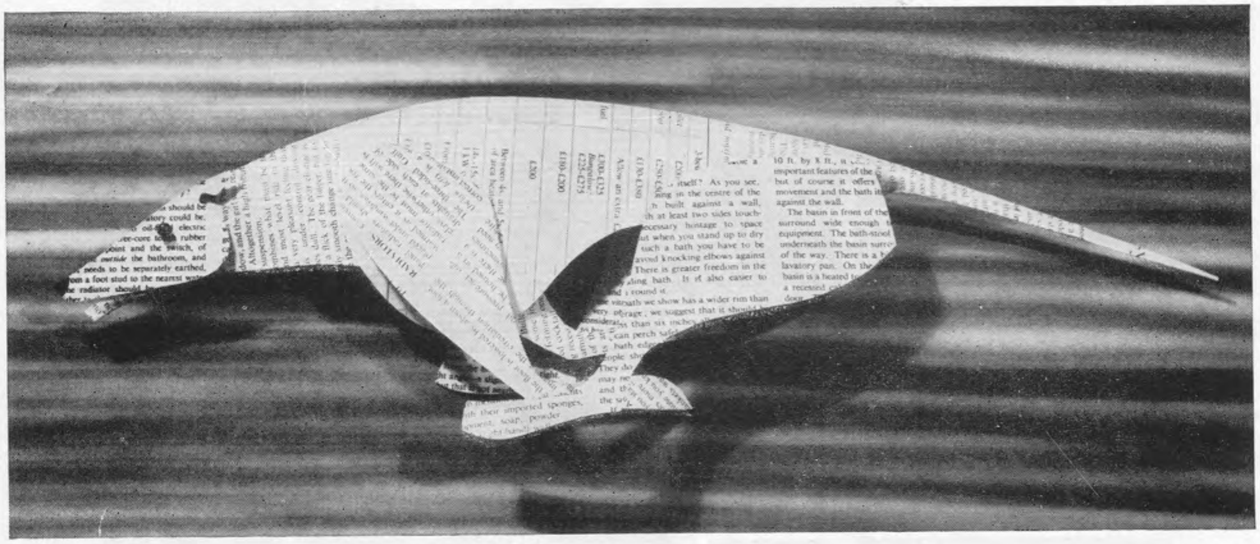

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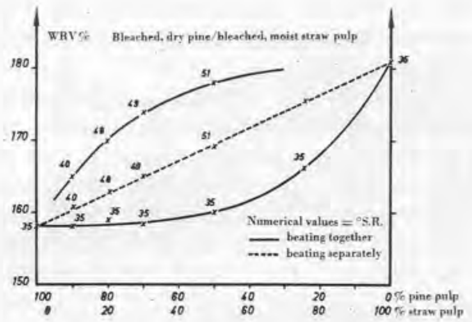


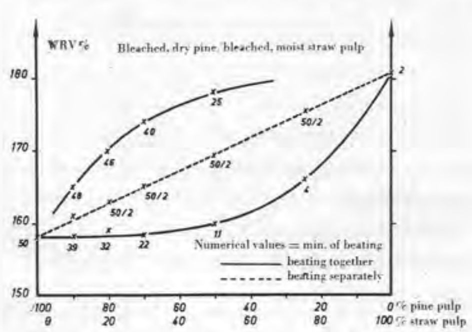
Water retention value of pulp mixtures when beaten separately and together

Fig. 8

separately. In complete contrast to Fig. 6, there is a close linear relationship, which makes it possible to calculate the WRV of mixtures. The figures in brackets in Fig. 7 represent the corresponding Schopper-Riegler values at these points. As in Fig. 6, the volumes were found to be higher than those for the individual components. Here, the large amount of data was used to choose mixtures in which both components had the same wetness after beating separately, for example, 35° or 50° S.R.

3. A comparison of beating together and separately

WRV and freeness (° *S.R.*)—Fig. 8 gives the relationships existing between WRV, °S.R. and mixture composition for beating separately or together. The straight dotted line in the middle represents the WRV readings of pulp mixtures that have a wetness of 35° S.R. when both components are beaten separately.



Water retention value and breaking length of pulp mixtures when beaten together

Fig. 9

As in Fig. 7, on this line are marked the wetnesses as measured for these mixtures, which, as already seen in Fig. 6, are considerably higher than the values for the individual components.

A well-defined basis must now be established in order to compare the two procedures of beating together and beating separately. For purposes of comparison, the results for beating together can of course be given for constant wetness.

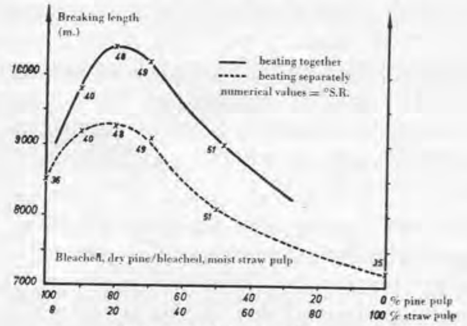
Thus, in Fig. 8, the lower curve is drawn for 35° S.R. In all cases, the WRV figures are lower than when beating is carried out separately. However, if the extreme wetnesses produced by separate beating are converted to a common basis and compared with mixtures having the same wetness and that have been beaten together, then we get the upper curve in Fig. 8. With beating together, this curve is considerably higher than if beating had been done separately; in other words, at a given freeness, if one compares the processes of beating together and beating separately, it is found that beating together always results in higher WRV and consequently in increased breaking length.

WRV and beating time (*min. in the Jokro mill*)—To ascertain the economics of a required beating effect, the beating time also must naturally be taken into consideration as one of the power consumption factors in the process. Fig. 9 gives the results (of course, only of theoretical significance) of our experiments on the relationship between beating time and WRV for beating both separately and together. As in Fig. 8, the straight dotted line represents separate beating. To reach a wetness of 35° S.R., the pine pulp has to be beaten for 50 min. whereas this wetness is achieved after only 2 min. when moist strawpulp is beaten in the Jokro mill. Calculated on a weight basis, a mixture of 50 per cent. pine pulp/50 per cent. strawpulp required an average beating time of 26 min.

On the upper curve for beating together, there is the value for 25 min. beating, at which—as on comparison with Fig. 8—the two mixtures prepared in different ways have the same freeness (51° S.R.). In this case, the advantage of beating together is particularly obvious. At the same freeness, the WRV is considerably higher and thus the breaking length is also increased. Similar relationships can be derived for the other points on the curve, but the proportions of the mixture must be taken into account when calculating the average beating time. When mixtures that have been beaten together to a final wetness of 35° S.R. are considered, then the result is the lower curve in Fig. 9. The values from this curve show that, as expected, when beating is carried out together, the beating time can be reduced by increasing the amount of strawpulp. This results, however, in low WRV figures and correspondingly poor strength properties.

Power is saved, but optimum strength is not reached. This will be made clearer in the next section.

Comparison of breaking length and freeness on beating separately or together—Fig. 10 shows the breaking lengths for various pine/strawpulp mixtures with both methods of beating. The upper curve is for beating together and the lower for beating separately. These results are in line with the others and a comparison shows conclusively the advantages of beating together. As can be seen from the individual values in °S.R., the comparison is made at the same freeness.

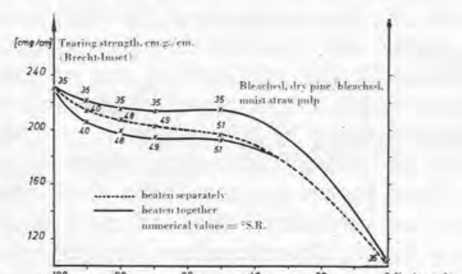


Breaking lengths of pulp mixtures when beaten separately and together

Fig. 10

There is another important conclusion that can be drawn from Fig. 10. When moist strawpulp is used, there is obviously a mixture ratio at which the breaking length is a maximum. In the case under investigation, this optimum ratio is at a moist strawpulp fraction of 20 per cent.

Comparison of tearing strength and freeness on beating separately or together—In the same way, Fig. 11 gives the curves for tearing strength. Here, too, it can be seen that fibre length has a decisive influence on tearing strength. Since beating always produces a

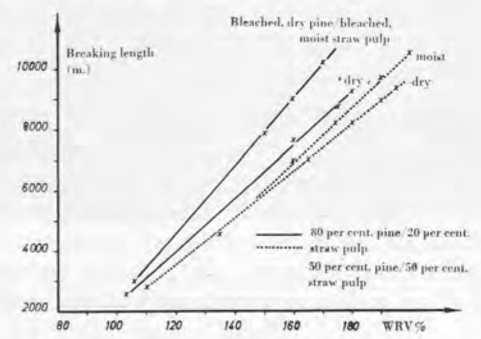


Tearing strength of pulp mixtures when beaten separately and together

Fig. 11

certain amount of fibre shortening, as is generally recognised, the tearing strength will be reduced as beating proceeds.

In Fig. 11, beating together is represented by two curves, the upper being for a final freeness of 35° S.R. and the lower for a wetness similar to that produced by separate beating, that is, 40–51° S.R. (according to the proportions of the mixture). As would be expected theoretically, all tearing strength values are higher at low wetness. The dotted curve results from a consideration of separate beating. These curves are all drawn for mixtures of similar wetness. Here, it is interesting to note the somewhat better results achieved when the components of the moist strawpulp mixtures are beaten separately. This is apparently due to the fact that the pine pulp fibres have a considerably higher resistance to beating than have the strawpulp elements and, when beating is done separately, there is less fibre shortening than when beating is done together, since the pine pulp fibres are subjected in the former case to a longer beating period than is necessary for the strawpulp fibres.



Water retention value and breaking length of pulp mixtures when beaten together

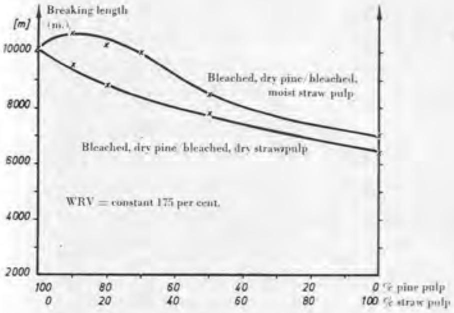
Fig. 12

It can also be seen from Fig. 11 that the size of the strawpulp fraction has relatively little influence on the tearing strength of the mixture up to a mixture ratio of 50 per cent. pine pulp/50 per cent. strawpulp. This is in agreement with the conclusions drawn from Fig. 4.

4. *The variable relationships between WRV, °S.R. and strength properties when beating is done together*

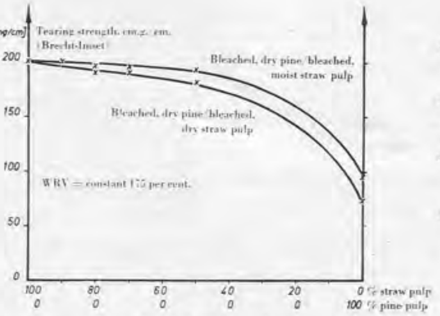
Since the preceding sections have shown that beating together is better in many respects than beating separately, it is now proposed to carry out a closer examination of the relationships between the factors involved in this process.

(*continued on page 559*)



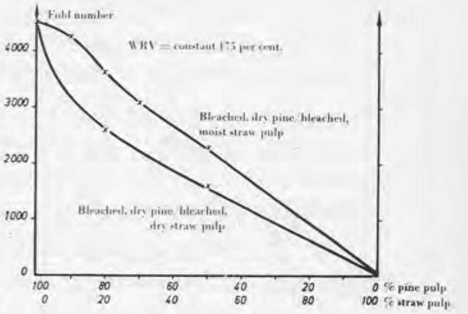
Breaking length of pulp mixtures beaten together and with constant WRV

Fig. 13



Tearing strength of pulp mixtures beaten together and with constant WRV

Fig. 14



Fold number of pulp mixtures beaten together and with constant WRV

Fig. 15

Breaking length and water retention value—The relationships between breaking length and WRV for four different mixture systems are given graphically in Fig. 12. Again, it is clear that the relationship is linear. This gives further proof of the assertions made in the preceding sections that the breaking length is determined only by the WRV figure, whereas the freeness expressed as °S.R. is characteristic only of that property and has no direct relationship to strength properties. Consequently, it will of course be necessary to revise all former theories made about the development of strength properties and its relationship to Schopper-Riegler freeness.

As stated previously, this linear relationship with increasing WRV is valid for one and the same system, but is not an absolute value, for the line is displaced with mixtures of different compositions, as can clearly be seen from Fig. 12.

It is interesting to compare the strength maxima at the same WRV for the mixtures under investigation and we found that, for example, at 160 per cent. WRV, the order of increasing strength was—

50 per cent. pine, dry/50 per cent. straw, dry
50 per cent. pine, dry/50 per cent. straw, moist
80 per cent. pine, dry/20 per cent. straw, dry
80 per cent. pine, dry/20 per cent. straw, moist

Breaking lengths for various mixtures when beating is done together and WRV is constant—Fig. 13 gives the interesting relationships found for various mixtures at a constant WRV of 175 per cent. The slightly curved lower line results from using dry strawpulp and shows that the strength properties in this case correspond to the arithmetic mean.

The results are quite different if moist strawpulp is used (upper curve). In this case, the breaking lengths are much higher than with dry strawpulp up to a mixture ratio of 50 per cent. pine pulp/50 per cent. strawpulp. This effect is so pronounced that, with mixtures containing 10–30 per cent. moist strawpulp, the breaking lengths of the mixture are higher than the values for the pine pulp component by itself. Up to 30 per cent. moist strawpulp can thus be added to the pine pulp, when beating is done together, without causing a reduction in breaking length.

Tearing strength for different mixtures when beating is done together and the WRV is constant—These relationships are shown in Fig. 14. A WRV of 175 per cent. was again chosen as the constant value for the experiments.

It is surprising to find that in this case, too, the tearing strength decreases very little up to a 50/50 mixture ratio and only over this ratio does the effect of the short fibres in the strawpulp become apparent. The effect can also be seen with a mixture of unbeaten pulps (*cf*. Fig. 4) and the theoretical explanation given there can also be applied in this case. Moreover, when beating is done together, the 'adhesive power' of the strawpulp improves the tearing strength and, up to a mixture ratio of 50 per cent. pine pulp/50 per cent. strawpulp, compensates for the reduction caused by the shorter fibres. In this case, too, moist strawpulp gave better results.

Fold number of different mixtures when beating is done together and the WRV is constant—Finally, the values for the fold number are given in Fig. 15 (WRV constant at 175 per cent.). It can be seen that, when dry strawpulp is used in the different mixtures, the fold number figures are considerably below the arithmetic means in each case, but they are almost exactly equal to the arithmetic means when moist strawpulp is used.

5. *Detailed study of the interrelationships between WRV, °S.R., beating time and strength properties of various mixtures*

The large amount of experimental data, of which only a part was used in the preceding sections, made it possible to carry out a graphical analysis of the relationships in question.

WRV, °S.R. and beating time—If the WRV readings are plotted against beating time for the different mixtures, the result is a family of curves like those shown in Fig. 16. The first conclusion to be drawn from these curves is that the WRV increases with increases in the strawpulp fraction.

The graph shows also that, as the beating time increases, the initial increase in WRV is rapid and is then followed by a falling off in the rate. The dotted lines on the graph represent the base lines for equal freeness. The base lines show a slight increase below 40° S.R. and fall off in the region above 40° S.R. It is worth noting that, with a wetness of approximately 40° S.R., the WRV is almost constant at 160 per cent.

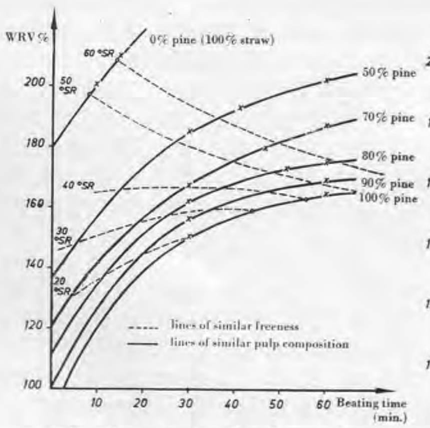
Fig. 17 gives the results for the same mixtures when the WRV readings are plotted against freeness. In this case, too, when beating is done together, the Schopper-Riegler values increase rapidly at first and then the curve shows a tendency to flatten out. An increase in the proportion of moist strawpulp increases the WRV. It can also be seen that, for all the mixtures, except pure strawpulp, the curves intersect in a small area represented by a wetness of approximately 40° S.R. and a WRV of approximately 160 per cent., that is, equal WRV and wetness are practically independent of the proportions in the mixture.

Freeness and beating time for different mixtures at different given WRV figures—The relationships between composition of the mixture and freeness at given WRV are shown in the left half of Fig. 18. Those relationships are certainly complicated, though certain laws seem to be obeyed. At a WRV of 140 per cent., the Schopper-Riegler wetness is increased when the amount of bleached, moist strawpulp is increased; at 160 per cent. WRV, it remains practically constant, as would be concluded from Fig. 16 and 17; at a WRV of 175 per cent., it shows a sharp decrease. This latter result depends on the fact that mixtures containing large amounts of pine pulp have to be extensively beaten in order to attain a high WRV figure.

The relationship between mixture composition and beating time is given in the right half of Fig. 18. Here, all three curves slope down from left to right—that is, at constant WRV, the beating time is always reduced by increasing the amount of bleached strawpulp.

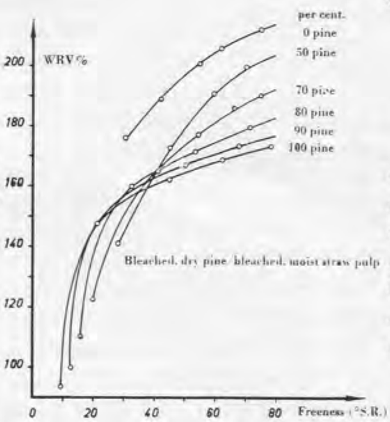
Strength properties of different mixtures when beating is done together and the WRV is constant—The relationships discussed in the three preceding figures are not only of theoretical interest, but can be used to derive the general principle of 'controlled development' of given strength properties. It should always be recognised that an increase in the amount of beating in general gives higher breaking lengths and fold numbers, but tends to reduce the tearing strength. Thus, the maximum average strength is always a matter of compromise and optimum strength is taken as a combination of increasing breaking length and fold number as much as possible, whilst keeping the reduction in tearing strength as low as possible.

(*continued on page 563*)



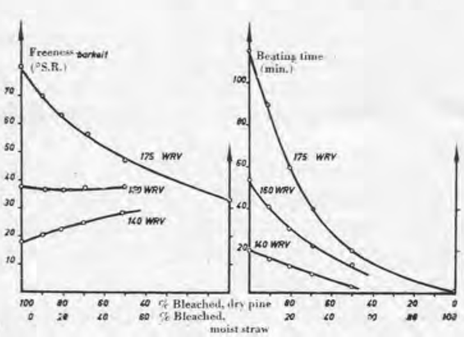
WRV and beating time when pulps are beaten together (Bleached, dry pine/bleached, moist straw pulp)

Fig. 16



Wetness and water retention value of pulp mixtures when beaten together

Fig. 17



Freeness and beating time of pulp mixtures at constant WRV and beaten together

Fig. 18

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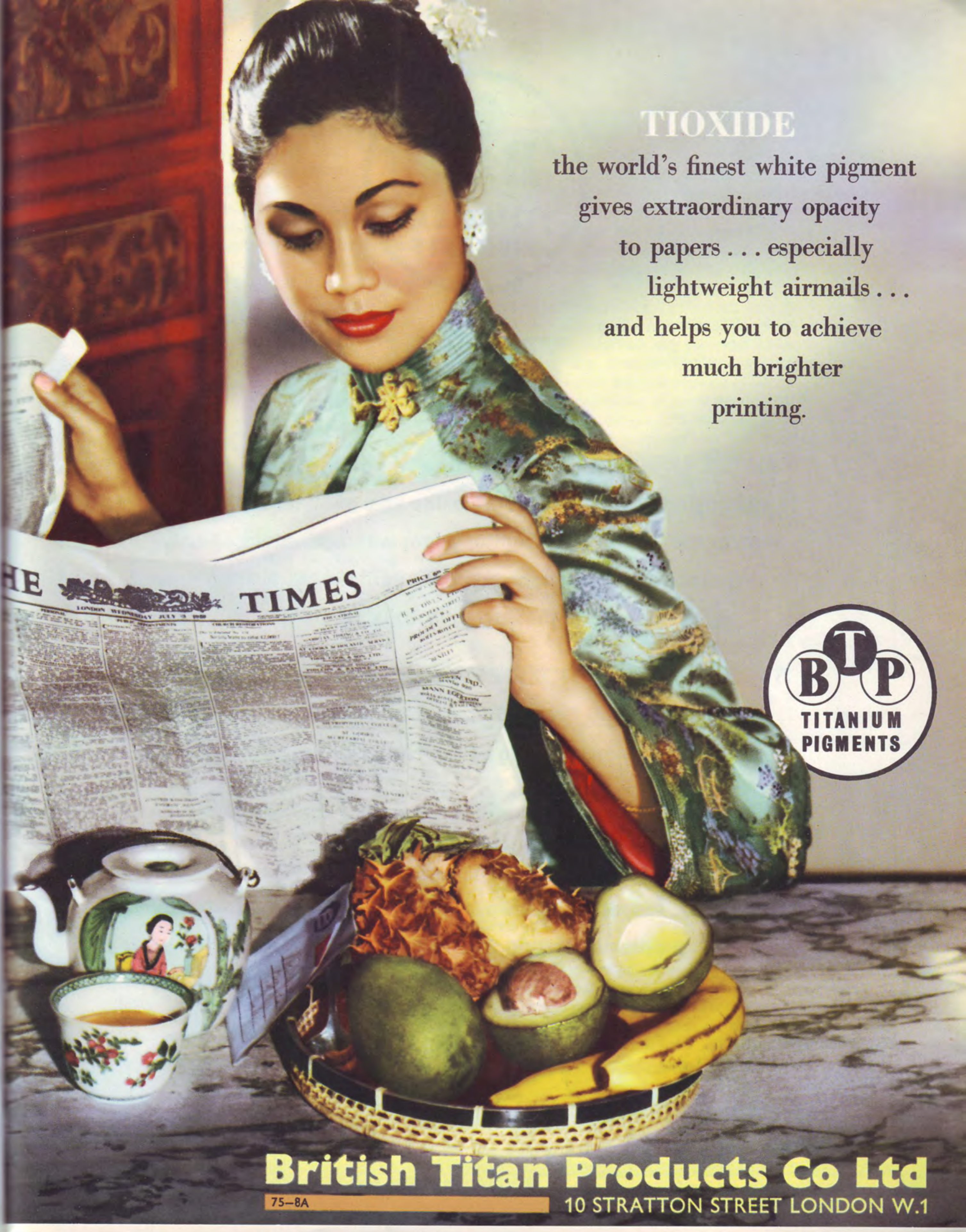


Table 1 gives the appropriate values from the conclusions drawn from Fig. 16, 17 and 18 for various mixtures at WRV levels of 140 per cent., 160 per cent. and 175 per cent. Firstly, considering the values for the tensile strength, it can be seen there is no decrease in breaking lengths—and there may even be an increase —with mixtures containing up to 30 per cent. strawpulp. On the other hand, if the values are considered in respect of increases in the WRV level from 140 to 160 per cent., then there is in all cases a considerably greater increase in breaking length than when the WRV is further increased to 175 per cent.

TABLE 1

Wood fibre fraction, %	100	90	80	70	50
Breaking length (km.)					
First range 140 WRV	7.2	6.8	6.8	6.7	5.0
Second range 160 WRV	9.6	9.4	9.4	9.7	7.0
Third range 175 WRV	10.0	10.7	10.2	10.0	8.0
Tearing strength (cm.g./cm.)					
First range 140 WRV	256	220	230	240	250
Second range 160 WRV	238	215	215	210	210
Third range 175 WRV	200	200	190	190	195
Fold number (double folds)					
First range 140 WRV	2000	2200	2200	1400	400
Second range 160 WRV	4400	3900	3300	2500	1600
Third range 175 WRV	4500	4300	3600	3100	2300

The development of strength properties in the special beating ranges 1-3 when the pulps are beaten together (Bleached, dry pine/bleached, moist strawpulp)

The results given in the same table for tearing strength are particularly significant. If these values are considered relative to increases in the strawpulp content, then, in close agreement with Fig. 14, it is found that the tearing strength decreases but little up to 50 per cent. moist strawpulp in the mixture. As would be expected theoretically, for each mixture ratio, the tearing strengths are highest at the lowest WRV figure. With mixtures containing up to 20 per cent. strawpulp, however, the accompanying decrease is smaller when the WRV level is increased from 140 per cent. to 160 per cent. than when it is increased from 160 per cent. to 175 per cent. As Table 1 shows, to attain optimum strength for all mixture ratios, it is generally best to work for a WRV of 160 per cent.

This WRV level has the following advantages (*cf.* Fig. 18)—

1. At 160 per cent. WRV, the freeness is practically constant for all mixtures.

2. This constant freeness level is very suitable in practice and is in the region of 38° S.R.

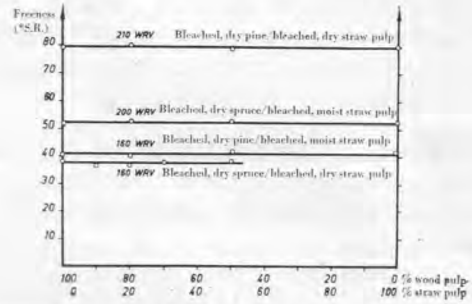
3. The beating time for a WRV of 160 per cent. is considerably less than, for example, 175 per cent. WRV (Fig. 18 right half).

6. Systems with constant Schopper-Riegler freeness and constant WRV

After the conclusions in the preceding sections had been made, it was necessary to investigate whether they were applicable to other systems. On working through the experimental results, it was in fact possible, with all systems when beating was done together, to find definite regions in which WRV and Schopper-Riegler values were independent of the proportions in the mixture.

This is shown in Fig. 19 for four different systems. The lower straight line represents the system examined in Fig. 18 of bleached, dry pine and bleached, moist strawpulps. Fig. 19 shows that other systems also have completely linear relationships.

It is also interesting to examine these WRV levels at which the Schopper-Riegler wetness is constant. Both pine sulphate pulps are in a low WRV region of 160 per cent., whilst spruce sulphite pulp gives higher WRV figures of 200 and 210 per cent. This is in agreement with Jayme and v. Köppen's[12] observations that spruce pulps in general have a higher WRV than have pine pulps.



Specific swelling ranges when pulps are beaten together and with constant WRV

Fig. 19

It is especially significant that moist strawpulp from this point of view gives the best drainage, that is, low Schopper-Riegler values. This is in agreement with the fact that the amount of beating with moist pulps necessary to produce a given WRV is less than with dry pulps.

Summary

1. The experiments were designed to examine the interrelationships between water drainage, beating time and strength properties and their dependence on *swelling degree*, measured as water retention value, with different softwood pulp and strawpulp mixtures in the unbeaten condition and when beating was done separately and together.

2. When mixtures of unbeaten pulps were used, the resultant strength properties showed that the degree of swelling has a decisive influence on strength. In contrast to the freeness expressed as °S.R., the WRV is directly proportional to the ratio of the components in the mixture and so can be calculated from this ratio. There were found to be simple linear relationships between all the static properties (tensile and bursting strengths) on the one hand and WRV and mixture ratio on the other. The use of moist strawpulp that had never been dried gave a considerable increase in strength properties and gave pronounced maxima for both fold number and tearing strength.

3. *Separate beating* of the pulps in the Jokro mill followed by mixing caused a considerable increase in the final wetness over a wide range of mixtures. On the other hand, with separate beating, the water retention value of the mixture is obtained by adding together the WRV readings of the components.

4. *Beating together* gives a different set of relationships and, when the final wetness is equal to the value for separate beating, the WRV is considerably higher and this gives a corresponding increase in strength.

5. It is generally true to say therefore that only the water retention value and not the freeness can be used to estimate the strength properties of a pulp mixture.

6. A comparison of the strength properties of pulp mixtures that have been beaten together, calculated at the same WRV, shows very considerable differences between dried and moist pulps. Whilst the use of dry strawpulp only causes small deviations from the mean values for breaking length and bursting strength, the use of up to 40 per cent. of moist strawpulp in the mixture produces *maxima* for those properties, these values being greater than for the softwood pulp component alone. Dried strawpulp reduces the fold number well below the arithmetic mean, but the fold number with moist strawpulp is almost exactly equal to the arithmetic mean. An important factor in beating together is that the *tearing strength* of the mixture is considerably *higher* than the arithmetic mean, if *moist* strawpulp is used and the strawpulp fraction is not more than 50 per cent.

7. There is also a *linear* relationship between WRV and breaking length for all the mixtures investigated. The breaking length, however, cannot be calculated from the WRV, since the linear relationship is different for each mixture system.

8. The graphical analysis of the relationships between WRV, freeness, beating time and mixture ratio leads to the conclusion that there is a WRV level for each system at which the freeness is constant and is independent of the mixture ratio; for example, for the system dry, bleached pine and moist, bleached straw, beaten together, it is approximately 38° S.R. at 160 per cent. WRV.

9. If the strength properties are compared, it is surprising to see that the *average strength* is an *optimum* in this region of *constant water retention value* and constant Schopper-Riegler freeness, that is, breaking strength and fold number are at an optimum for a relatively short beating time and with good water drainage. These are the conditions for the best breaking length and fold number compatible with a relatively small reduction in tearing strength.

10. It was shown that this interesting region where both WRV and Schopper-Riegler freeness are constant and independent of the proportion of the mixture exists for *every* mixture system. Thus the water retention value is shown to have an even greater importance. This factor not only determines the strength as such, but can be used to find suitable WRV figures and freeness for optimum average strength properties for any mixture.

REFERENCES

1. Jayme, G., *Svensk Papperstidn.*, 1957, **50** (11B), 117
2. Jayme, G., *Tappi*, 1958, **41** (11), 178A
3. Jayme, G., *Tappi*, 1959, **41** (11), 180A
4. Van Nederveen, G., Paper given at Verein Zellcheming conference, Heidelberg, 26th June 1957
5. Jayme, G., Ghoneim, A. F. and Krüger, H., *Das Papier*, 1958, **12** (5/6), 90
6. Van Nederveen, G. and Hellenberg, G. H., *Das Papier*, 1955, **9** (1/2), 1
7. Brecht, W. and Globig, C., *Wochbl. Papierfabr.*, 1954, **82**, 807, 847
8. Brecht, W. and Jacobs, G., *Wochbl. Papierfabr.*, 1955, **83**, 115, 151
9. Vámos, G. and Merö, T., *Zellstoff u. Papier*, 1958, **1** (10), 285
10. Instrumentation studies, *Paper-Maker*, 1944, **42**, 107 (Midsummer special)
11. Merkblätter (Testing methods) of the German Association (Verein Zellcheming), No. V/1-15
12. Jayme, G. and v. Köppen, A., *Das Papier*, 1950, **4** (21/22), 415

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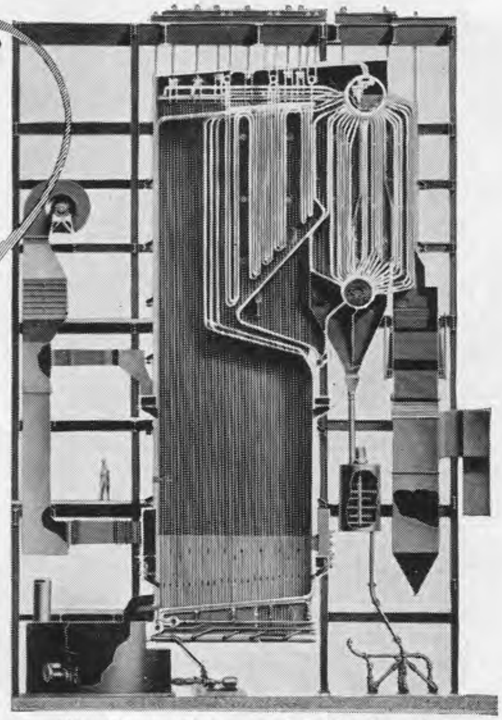

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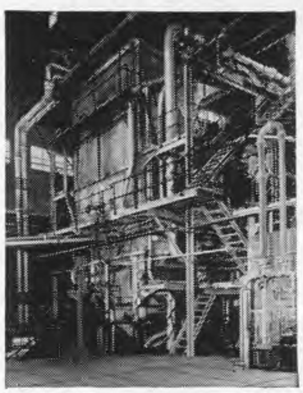

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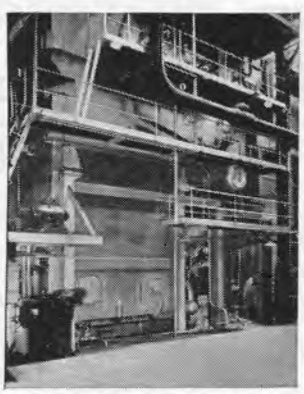

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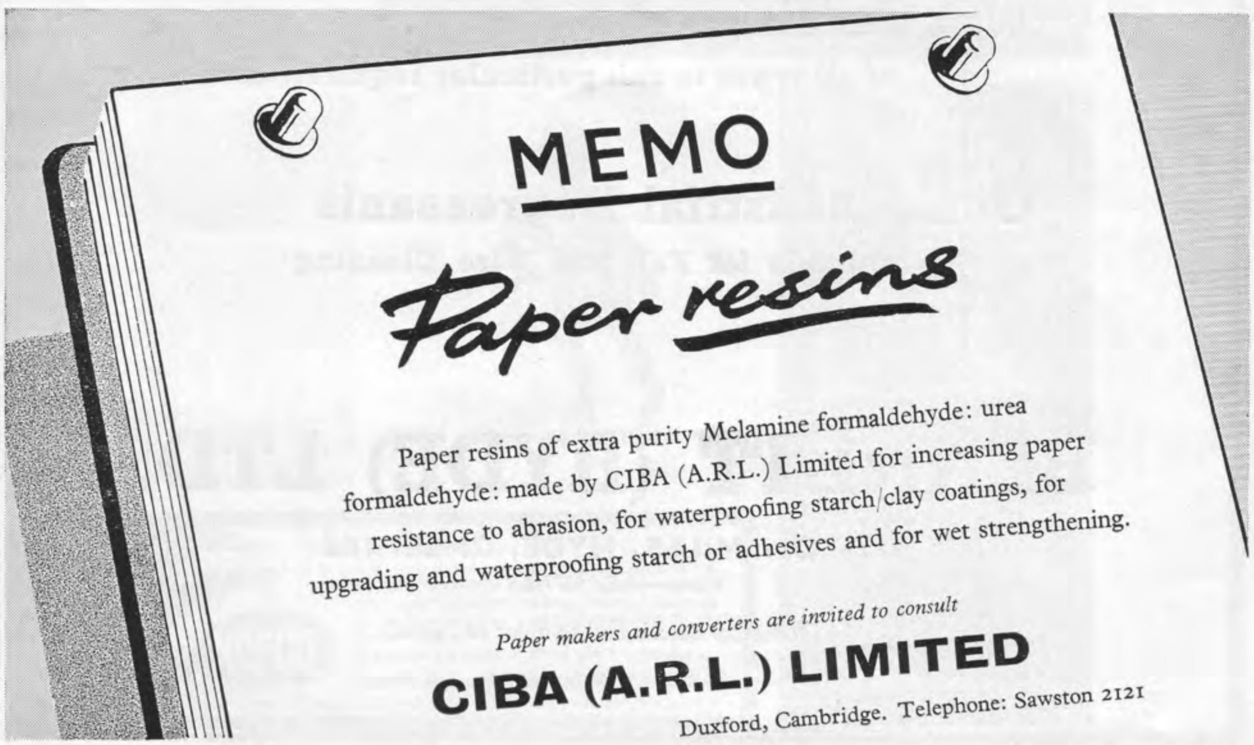
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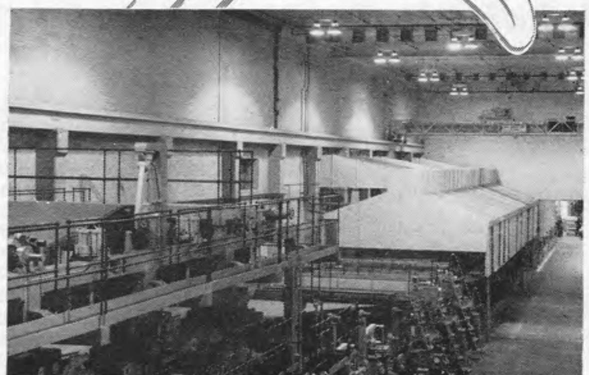

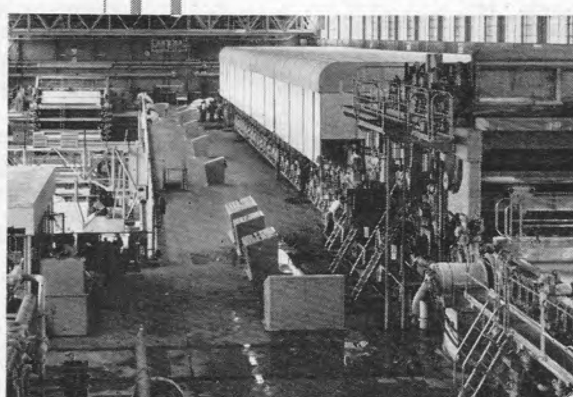

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