# colour two-sideness of paper sheet in high speed paper machine

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*Ununiform distribution of fillers and fines across sheet thickness is mainly responsible for the vexing problem of colour two-sided-ness. High machine speed and mixed furnish of long and short fibres aggravate it. Nature of the dye used and its varying affinity for fines, fillers and fibres greatly influence the result. The techniques behind sheet formation on on machine wire and depletion of fines and fillers at the wire side of the sheet are discussed. Steps to minimise the colour two-sideness by controlling operational conditions and taking advange of modern designs at the machine are indicated.*

Two-sidedness of paper quality is a common defect with all types of paper. The degree of this defect depends on a number of factors, such as the type of pulp fibres, the mode of operating the various unit operations of paper making and more particularly, the details of the design of the paper machine.

Two-sidedness of paper quality can exist in various forms. It can be structural two-sidedness, topographic two-sidedness or distributional two-sidedness. Colour two-sidedness is mainly a result of distributional two-sidedness. It is common experience that the wire side of a paper sheet made on a conventional paper machine invariably shows to contain less fines than the felt side. Similarly the filler content of the wire side of a loaded paper sheet is lower than that of the felt side. Thus, the distribution of fillers and fines across the sheet thickness is not uniform.

The non-uniformity of distribution of various components of the filler-fibre system exists in papers, irrespective of whether they are made on low speed or high speed paper machines. With low speed machines, this defect may not always call for so much close attention of the paper-maker as when high speed machines are used, in which case the relative difference between the two sides of the paper sheet is in greater magnitude.

Defects connected with distributional non-uniformity of paper can be aggravated by using a blend of different types of pulp fibres. The paper industry throughout the world shows an over-increasing demand for utilisation of pulps from diverse fibrous raw materials. Blending of fibres of widely varying nature has become a necessity in many countries due to scarcity of one type of pulping raw material and availability of new raw materials at a cheaper rate. Better knowledge of fibre strength properties as well as deeper understanding of the mechanism of sheet formation have made the practice of blending of pulps more and more popular amongst papermakers. This is specially true for long and short fibres.

The degree of affinity of fibres for a certain dye varies depending on the morphological character. One can well anticipate the complexity of making coloured paper from a blended stock on a high speed paper machine.

## CAUSE OF COLOUR TWO-SIDEDNESS:

*Non-uniformity in fibre and fillers distribution across sheet thickness.*

In order to understand as to why a paper sheet shows distributional two-sidedness, it is necessary to know the mechanism of sheet formation on a Fourdrinier wire part.

When a jet of fibre-water suspension is spread over the wire, water, and along with it a portion of fibres

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and fillers, are drained through the wire. At the beginning of sheet formation, the wire forms the filtering medium. The first layer of fibres on the wire forms a bridge over the pores of the wire mesh and it is on this layer of fibres that further filtration takes place. As further dewatering takes place, water, fibres and fillers have to pass through the already formed initial layers of fibre mat.

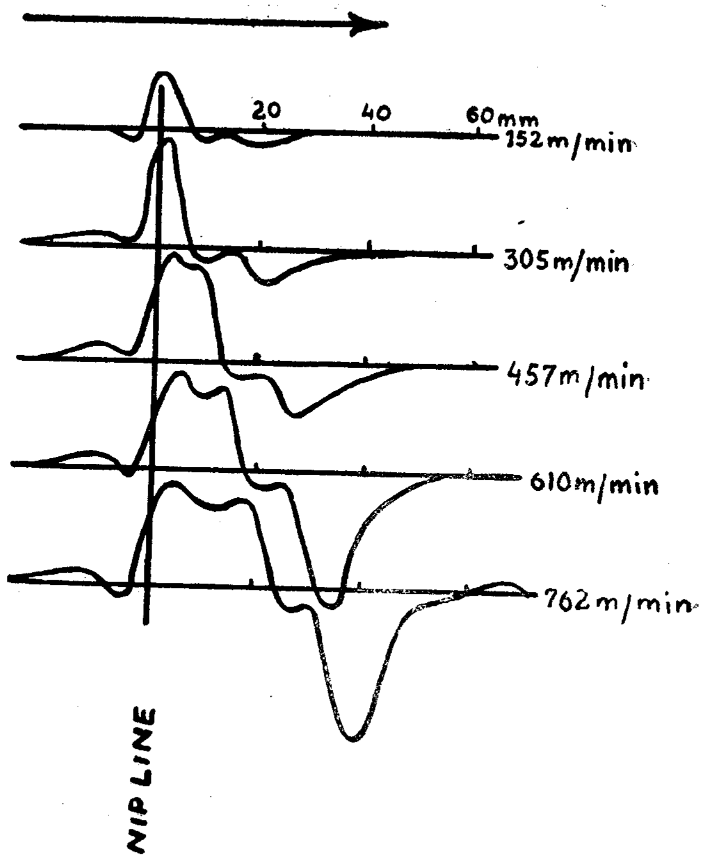
In a multi-component fibre-filler inhomogeneous system, like the paper machine, stock, the efficiency of the fibre components in collecting the filler particles is different for different layers.

The movement of a filler particle towards the fibre surface depends on the crossing the lines of fluid flow around the fibre to fall within the capture distance. The capture distance is a function of diameter of the filler particle and the fines sorption. Probability of crossing the lines of fibre surface depends on the frequency of flow disturbances, on the flow rate and the particle movement towards the fibre surface. Thus, more compact the mat and more the disturbance, longer would be the flow path and a greater probability of close approach and of being collected.

Thus, the collection efficiency, which is a measure of the probability of filler particles reaching close to the fibre surface to allow cohesion, depends on the diameter of the filler particles, ratio of length of path of flow to the mat thickness, the porosity of the mat and the volumetric rate of flow of the fibre—water suspension. Fig. 1. shows two schematic pictures indicating the path a filler particle must have to traverse in a fast formed flocculated mat and in a slow formed dispersed mat. In the latter case, a filler particle has to travel a longer path and the probability of its coming within the capture distance is greater.[1]

With rapid formation of mat, the time for relative movement of the fibres would be less, and hence a greater non-uniformity of the porocity distribution would result. Uneven porosity encourages channelling of filler particles through the fibre mat in regions of lower porosity.

This mechanism of retention of filler particles holds good also for fibre fines, since they are in general heavier than the long fibres.




In actual practice of sheet formation on a Fourdrinier machine, there exists disturbances. The lower formed layers are disturbed partly by continuous pressure fluctuations caused by the wire shake and mostly by the rotating table rolls. As a result of these suction-pressure fluctuations, there is a preferential removal of easily detachable fines and filler particles, from the wire side of the paper sheet.

AFFINITY OF DYES FOR FIBRE FINES AND FILLERS:

A pulp sample consists of a spectrum of widely varying fibre lengths. When a pulp is dyed, the dye uptake is different for different fibre dimensions. This is usually true for long fibres and fine fibres. In the following discussion, the fines are defined as that portion of fibres which passes through a 60 mesh sieve.

Fines take up more dye than the long fibres. This is partly due to their larger surface area. However, the differences in colour intensity of fines and longs are not explained by the surface area effect. Had this been so, the ratio of lose. Acid and basic dyestuffs have in general, higher values of Df Dl than direct dyestuffs.

With direct dyestuffs the two-sidedness can further be reduced when the dyes are added to the fibres before rosin and alum addition. Addition of some electrolytes (sodium chloride for example) can further reduce the dye uptake by fines and thus reduce two-sidedness. This, of course, is not always practicable.

When dues have more affinity for filler particles a small quantity of dyestuff of the stilbene class is added to the stock in order to minimise the two-sidedness.[3] Colour two-sidedness can also be controlled to some extent by using a combination of two or more dye-stuffs, one having affinity for fibres and the other for fillers. Another method is to make a paste of dyestuffs and fillers and then add the paste to the fibres.

By use of beater additives of the type Naphthalene-Sulphonic Acid-Formaldehyde condensation products, dye uptake distribution is made less non-uniform.

(b) *Method of beating the pulp fibres*:

Method of beating should be such that least fines are produced.

When two different pulp fibres are used for the paper machine, furnish, blending of pulps may be carried out before or after the beating. In case of separate beating (pulps beaten to desired freeness and then blended), it is best to dye the short fibred pulp first, since the fibre length distribution of short fibred pulp is broader in range.

However, mixed beating (pulps blended before the beating) should be preferred to separate beating from stand point of least colour two-sidedness. This is because mixed beating produce less fines.

In order to study the effect of mixed and separate beating on the generation of fines, a long fibred pine pulp and a short fibred birch pulp were beaten mixed and separately in a conical refiner. The fibre classification and the fibre composition of separate and mixed beatings have been compared in table 1, which shows that less fines are produced in case of mixed beating.[4]

| | Retained by screen No., % | | | | |
|---|---|---|---|---|---|
| | 20 | 35 | 65 | 100 | Fines (by difference) |
| **Seperate Beating** | | | | | |
| Pine ... ... | 69 | 14 | 10 | 1 | 8 |
| Birch ... ... | 2 | 42 | 41 | 5 | 10 |
| Blend ... ... | 46 | 20 | 21 | 2 | 11 |
| % birch in fraction ... | 6 | 35 | 65 | 93 | -- |
| % birch on whole pulp ... | 8 | 7 | 23 | 0 2 | 7 |
| **Mixed beating :** | | | | | |
| Blend ... ... | 48 | 21 | 20 | 2 | 9 |
| % birch in fraction ... | 21 | 36 | 50 | 50 | — |
| % birch on whole pulp ... | 10 | 7 | 11 | 1 | 2 |

Table 1. Fibre classification of pulp mitxures from separate and mixes beating.

Pulp blend consisted of 70 of pine and 30 of birch by weight. Fibre classification performed in Bauer-McNett Fibre Classifier.

*Methods based on machine design details* :

One main factor governing the non-uniform distribution of fibre and filler in the sheet thickness is the rate of drainage of the diluted stock. By a gradual drainage the formation can be increased and better will be the distribution of porosity structure and the permeability of the fibre hat to the fines and fillers.

the permeability of the fibre mat to the and fillers. Considerable progress has been made by design engineers to develop gradual and milder dewatering devices in the wire part of the end of a Fourdrinier machine,

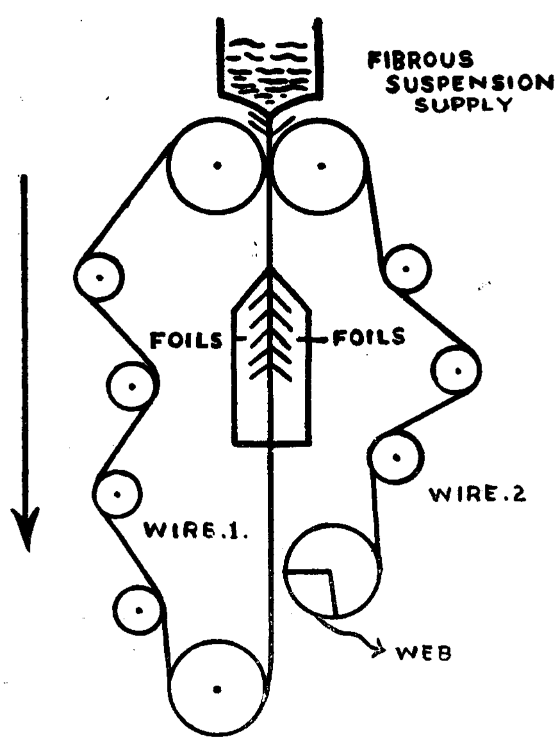
*Drainage by table rolls* :

In a slow speed conventional paper machine the wire part consists of a breast roll, table rolls, suction boxes behind the table rolls and a couch.

For very slow speed machines, the primary function of the table rolls is to support the moving wire to

Dyes on fines, Df
Dyes on longs, Dl should be constant and independent of concentration of dyes used. This ratio varies from 2.5 to 60 for a given pulp.

Hinton and Quinn[2] have determined and shown that the surface charge (Zeta-potential) on fines and longs are different. Thus, for example, fines have a Zeta-potential of—28 mv, while the longs have a value of—7.5 mv. Hence they concluded that the differences in surface charge are the major cause for differential dye uptake. Dyes show varying degrees of affinity for a given fibre depending on the nature of the dye ion (charge, distribution of charge, shape colour two-sidedness to a gveater extent. Direct dyestuff show relatively uniform behaviour towards the fibre fines and the longs.




VERTIFORMA

Besides the preferential dye uptake of the fines, the fines absorb dyes quicker than long fibres. Fig. 2 shows a correlation between dye uptake concentration and the period of dyeing by the longs and fines.[2] The fines and longs of a purified cellulose (bleached pulp) shows less difference in dye uptake of direct dyes.

Two-sidedness occurs to a lesser extent in unsized paper, probably due to the nature of the electric charge of the rosin-alum precipitate.

It is also known that fillers and fibres do not have the same affinity for a certain dyestuff. This differential dye absorption of fillers and fibres,—coupled with the fact that there exists an uneven distribution of filler in fibre mat,—is responsible for the intensified two-sidedness behaviour of loaded coloured paper.

The wire side of a coloured paper sheet has a lighter shade in case the filler absorbs more dyes than the fibres and vice versa.

### Methods of Controlling the Colour Two-Sidedness:

Methods of controlling the colour two-sidedness can be grouped into

(1) factors involving operating variables and
(2) factors depending on machine design details.

### Methods Based on Operational Factors:

(a) *Selection of dyestuffs and their mode of addition*:

To be able to bring the colour two-sidedness of a sheet under control, dyes with least two-sided behaviour should be used. A laboratory method of evaluating the two-sided behaviour of a dye is to determine the ratio of Df Dl where Df is the dye concentration on fines and Dl is the dye concentration on long portion of fibre. An ideal dye with complete absence of two-sided behaviour should have a ratio of unity. The degree of deviation of this ratio from unity would be the parameter of the two-sidedness. Greater the deviation, more will be the two-sidedness of paper dyed with the dyestuff.

Direct or substantive dyestuffs show least two-sidedness, since direct dyes have more affinity for celluprevent sagging. Water removal is by gravity in the initial period of formation.

For medium and high speed machines, the drainage of water from the fibrewater suspesnion is due to the suction created by the relative movements of the wire and the rotating surface of the breast roll and the table rolls. The amount of water drained by the table rolls can be expressed by the equation Thus, the drainge rate is proportional to the third power of the machine speed and to the first power of the table roll diameter. Since at higher speeds the table roll must have to withstand greater magnitude of mechanical stresses, the diameter of the table rolls is made larger for high speed machines. Thus the drainage rate of the diluted

$$Q = f \cdot \frac{P^2 \cdot V^3 \cdot R}{K^2} \qquad (5)$$

where Q — amount of water drained per unit width

Q — density of water

V — machine speed

R — the diameter of table roll

K — coefficiant of resistance of fibre mat and

f — a constant.

stock is more rapid at higher speeds. Although the high drainage rate is beneficial from standpoint of water removal, it does not help in getting a sheet with good formation and least two-sidedness.

In a rotating table roll, a thin film of water is carried around the roll by the centrifugal forces. This film of water is carried upto the nip of the wire and the table rolls on the underside of the wire, and is pressed through the wire into the wet sheet of fibre mat. This works as a washing of the fines and fillers. Further, there exists an air film along the nip line of the table rolls. Determination of pressure distribution in a table roll nip shows that there exists pressure fluctuations at and near the nip of table rolls. Figure 3 shows the pressure-vacuum fluctuations around the nip of a table roll at various machine speeds.[6]

The pressure-vacuum impulses give rise to instability of wire surface. The underpressure creates a sag of the wire, while the overpressure gives a kick to the wire. Thus, the surface instability disturbs for-

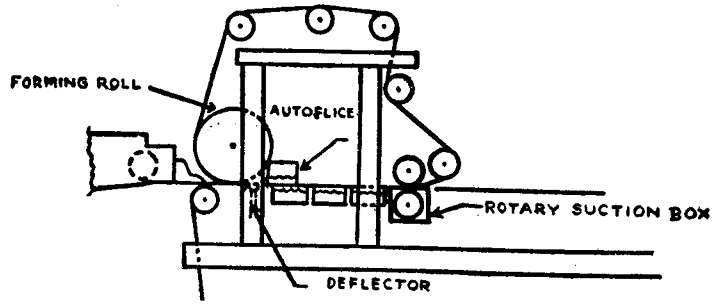



Fig. 3. Pressure — Vacuum fluctuations along the nip of table roll at increasing speeds.

mation and loosens the sheet structure, resulting in removal of fillers and fines from the underside of the sheet. Higher the speed of the machine, greater will be the disturbance on the surface. At higher speeds not only the amplitude but also the range of such impulses is increased.

## GROOVED TABLE ROLLS :

One method of reducing the rapid drainage of the diluted stock with the view to increase the length of flow path of the fillers and fines, is to install grooved table rolls in place of plain rolls. Grooved rolls do also supress the pressure fluctuations. The shape and depth of the grooves are detedmined by the quality of paper desired. The grooves should be deep enough to allow the deposition of fines and fillers.

In high speed machines, when the wire shake is ineffective in conducing formation, disturbances of the nature caused by the table rolls are sometimes desired. Hence only a first few table rolls are grooved, so that the drainage is milder and spouting eliminated. Plain table rolls are used at a point where the consistency of the stock is such that spouting does not occur, but at the same time it is low enough to allow free movement of fibres in the layers above the primary bottom-most layer.

*Deflectors* : In high speed machines, the draining water is carried around the table rolls in a thin film or ring by the centrifugal forces. The water ring carried by a table roll strikes the following roll and causes spouting and reduces the draining capacity of the affected roll. Hence deflectors are used in between the rolls to prevent water spouting. Figure 4 shows the schematic view of haw spouting takes place and how it can be eliminated by installation of a deflector between the two adjacent table rolls.

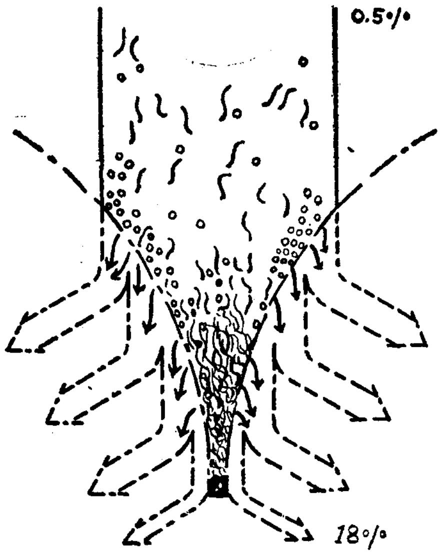



**Fig. 4 Elimination of table rolls spouting by means of deflectors in high speed paper machine.**

In order to maintain uniform drainage along the whole width of the wire, a constant clearance has to be kept betewen the wire bottom and the tip of the deflectors. If the clearance is not uniform either due to wire sagging or improper positioning of the deflector tips, the drainage rate will vary from point to point across the sheet.

*Drainage Foils* : In order to completely eliminate spouting in the wire at higher speeds, drainage foils are used in place of table rolls. It has been shown by Dunlop and Gardner (7) that the pressure fluctuations are remarkably suppressed when the drainage foils are used. Figure 5 shows comparison of the nature of pressure fluctuations caused by use of table rolls in one case and by use of drainage foils in another case.

One notices here that the suction created by the foils is gradual and gentle, i.e. the suction at a gven speed is lower but more extended. Overpressure is completely absent.

Drainage rate across the foils can be regulated by adjusting the foil angle (the angle the slope of the

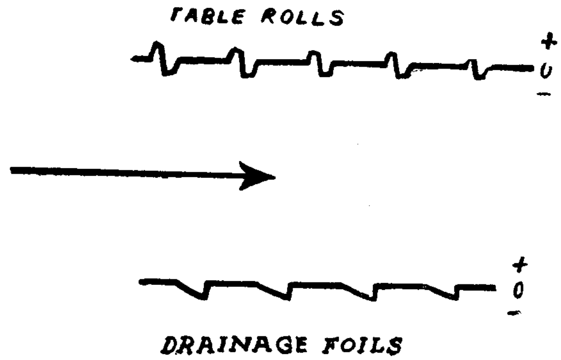



**Fig. 5. Nature of pressure fluctuations by the use of table rolls and drainage foils (7) respectively.**

foil makes with the wires); by use of foils, spouting can be eliminated even at higher speeds.

One disadvantage of the foils is the wearing away of the materials. If the wear is not uniform, there will be a sheet with uneven moisture profile. Plastic materials are wear-resistant, but have a high coefficient of friction. Some of the synthetic materials of construction like Teflon or Micarta would be of use for the tips of the boxes.

*Wet Suction Boxes* : One of the most effective means of reducing the distributional two-sidedness of the sheet is by use of wet suction boxes. A wet suction box can be defined as a suction box in the wire section of the wet end without any air flowing through the sheet. These boxes are erected at a point, where the fibres are still mobile, i.e. between the forming board and the dry suction boxes of the wire.

The drainage across the wet suction boxes is smooth and gentle. This is indicated in the clarity of white water flowing from the wet boxes. The drainage rate depends on the number of slots in the box and the suction head.

In order to study the effect of the replacement of the table rolls by the wet suction boxes on the transverse distribution of fines and fillers in the paper sheet, an interesting experiment has been conducted by the Swedish paper research institute in Stockholm.(8) The wire section of the wet part of an experimental paper machine was arranged in the following two different ways :

(1) Between the breast roll and the couch of the wire section, a forming board, twenty table

rolls and six dry suction boxes were installed. The dry suction boxes consisted of 2 sections, each with a series of three boxes. The top portion of the diagram in figure 6 shows the arrangement.

(2) In the same machine, the table rolls have been replaced by four wet suction boxes, of which two had nine slots each and the other two six slots each. The boxes are in staggered position. The dry suction boxes are similar to arrangement no. 1,—bottom portion of figure 6.

In order to study and compare the filler distribution across the sheet thickness, the sheets were split into layers and the ash content of each layer was determined. In the diagram of the figure 6, the ash contents at various points have been expressed as percentage of the average ash content of the sheet.

Similarly, the transverse distribution of fines has been evaluated by measuring the drainage resistance of the layers of the sheet.

A comparision of the top and bottom diagram shows clearly that the arrangement No. 2 is the superior arrangement. Thus, by use of wet suction boxes in place of table rolls, the distributional two-sidedness can be controlled to a great extent.

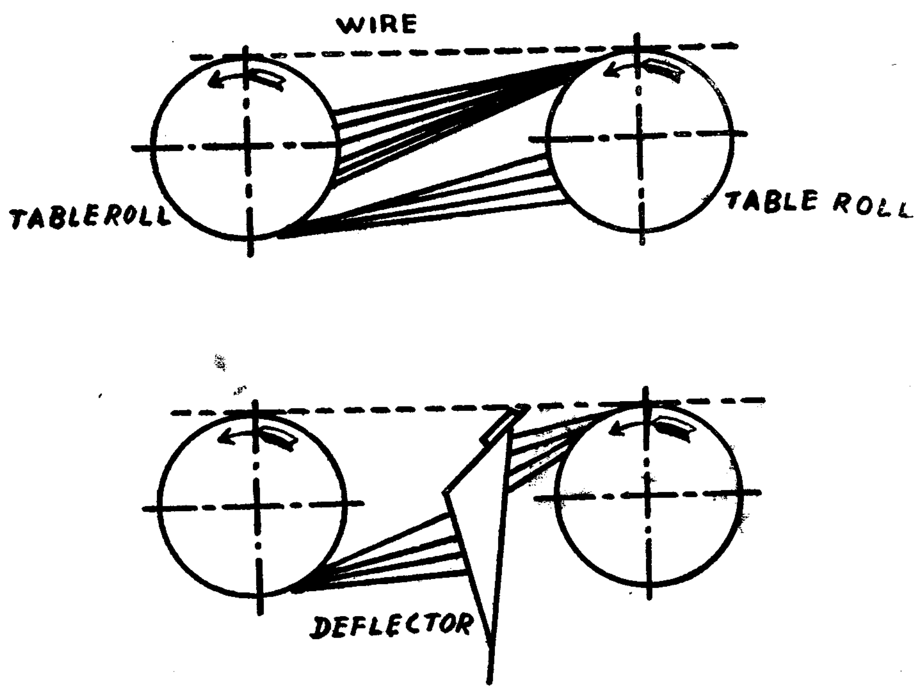



Fig. 6. Comparision of effects of table rolls as against those of wet suction boxes with regard to transverse distribution of fines and fillers in the sheet.

All the above mentioned devices of the wire part of a conventional wet end cannot completely eliminate the colour two-sidedness. They are, however. very effective in minimising the colour two-sidedness to a considerable extent, since they are to render the drainage more smooth and gradual.

*Methods based on achieving symmetrical drainage on both sides of the sheet*

In order that the paper can be made completely free from the two-sided colour behaviour, the distribution of fibre fines and fillers on both sides should be as symmetrical as possible. A few major newer concepts are mentioned and discussed below :

*Multiwire machine* :—The multiwire machine, as the name implies, consists of two wire parts for forming two different wet sheets and then joining the sheets before the press section.

*The Inverform machine* :—The idea of draining from the diluted fibre suspension from the both sides (top and bottom) has been materialised by the development of the so called "INVERFORM" machine. The Inverform machine originally developed by St. Anne's Board Mill, Bristol, Great Britain, consists of two wires : the bottom wire and the top wire. The diluted stock is made to flow and drain through the two wires. On the top side, water passes up a slopping blade (autoslice) and is collected in a tray. The drainage rate is regulated by adjusting the position and the pressure of the slopping blade. Further dewatering takes place by means of suction boxes. A small rotary suction box at the bottom side holds the sheet on the bottom wire. Figure 7 shows a digrammatic sketch of the original inverform machine.

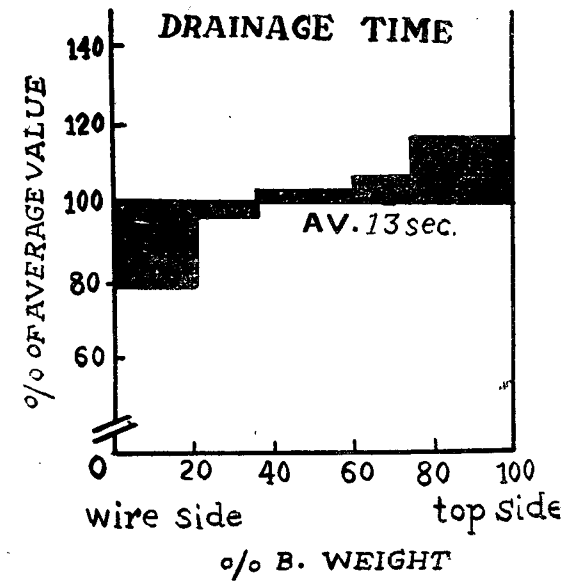



Fig. 7. Sketch of an original Inverform machine.

The original Inverform was meant for making paper boards at higher speeds. The Beliot Iron Works, U.S.A. in collaboration with their British counterparts have modified the arrangement, in which the forming roll and the autoslice have been replaced by an inverted suction box. This modification, it is claimed, allows the wires in the forming zone to gradually increase the pressure between the wires and thereby reducing the developments of shear gradients of high magnitude in the diluted stock.(9)

One main advantage of the Inverform paper machine is the improved distribution of fines and fillers and, therefore, the less two-sidedness.

Further, since the fibre suspension is drained between the two wires, i.e., no free surface in the forming zone, a higher turbulence can be imparted to the stock. Due to the greater degree of turbulence permitted in the Inverform machine, higher stock consistencies can be maintained without deterioration of formation. It may be stressed that higher stock consistency improves filler and fines retention and distribution, besides other operating advantages. In the conventional fourdrinier machine, consistency must be kept below a certain maximum in order to avoid flocculation. Satisfactory results have been obtained from an Inverform trial even at a machine speed of 1500 m/min. for newsprint paper.(10)

*The Vertiforma Machine* :

Instead of having two horizontal wires running one over the other, arrangement can be made to drain the diluted stock in between two vertical endless wires running parallel to each other.

This idea has been tried in the so called "Vertiforma" machine by the Black Clawson Co. of U.S.A. Figure 8 shows the sketch of a Vertiforma.

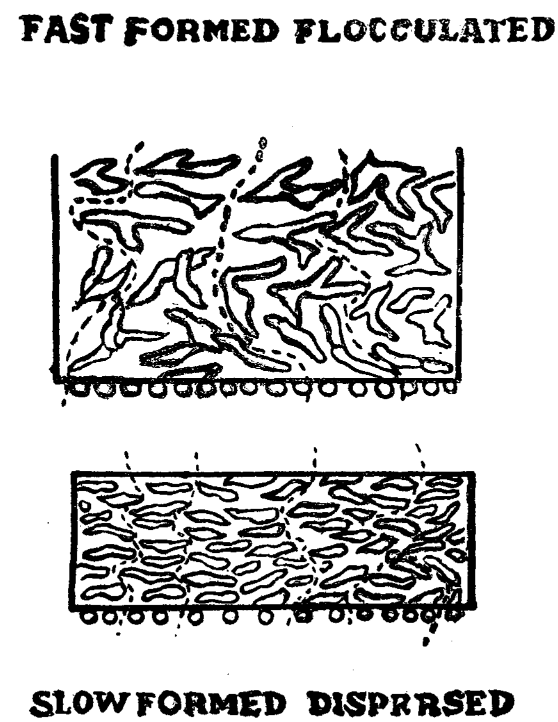



Fig. 8. Sketch of a Vertifoıma.

The drainage in the Vertiforma is symmetrical on both sides mainly due to the equal level of the fibre suspension, and, therefore, symmetrical filtration. The principle of filtration and sheet formation is shown in the diagram[9]. Fltration takes place here by gravity at the beginning of sheet formation.

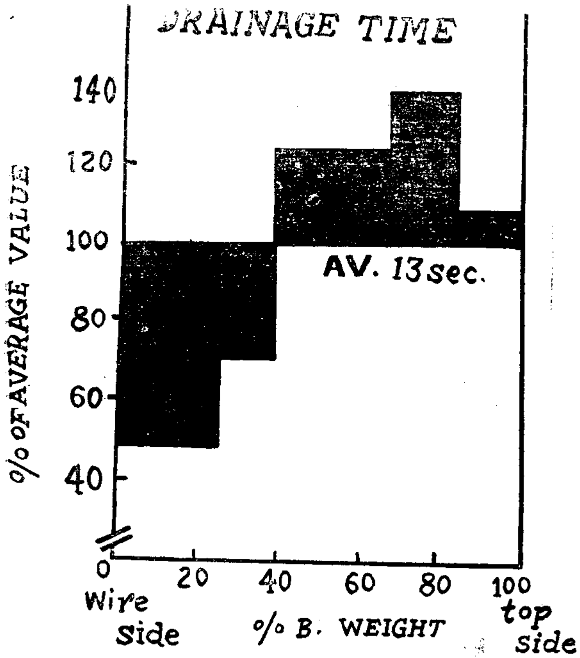
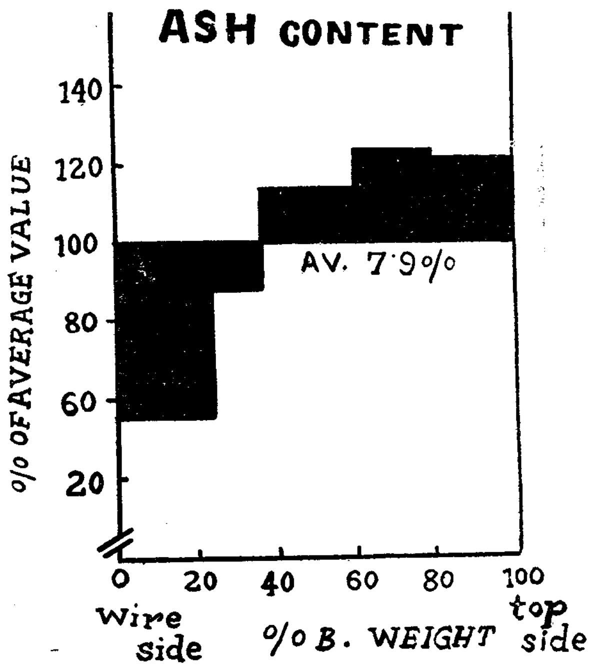
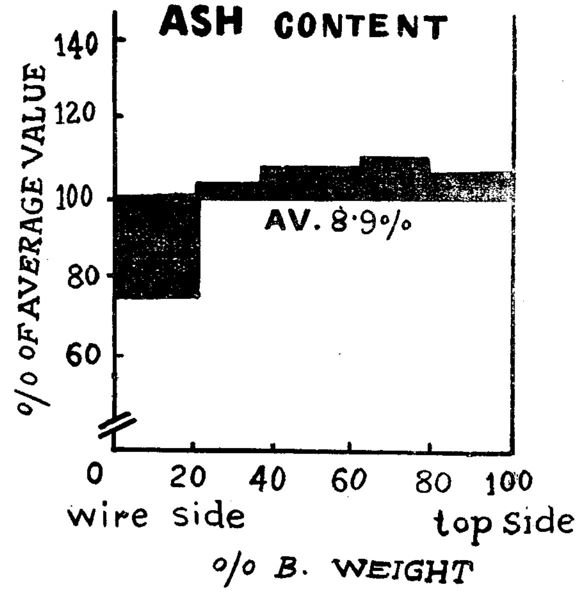



Fig. 9. Symmetrical distribution of fines and fillers as a result of symmetrical filtration on both sides.




Thus, considered from standpoint of elimination of two-sidedness of the paper sheet, the Vertiforma is superior to the Inverform machine. Semi-




commercial trials have shown good results at speed ranges between 900 to 1500 m/min with the vertiforma.(11)

In not a distant future, it would be possible for the papermakers to select their machines from a good number of choices, the selection being on the basis of the desired end product. The trend of having a single purpose paper machine rather than the multipurpose machine has already been noticed in the Indian Paper industry. It is hoped that two-sidedness of paper will be of no problem even at higher machine speeds and with mixed blend of fibre furnishes.

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