# Limitation to satisfactory operation of wet end of paper machine

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SUMMARY

The aim of satisfactory wet end operation is to achieve a uniform basis weight profile in MD and CMD, a good formation, stratified orientation of fibres, a sufficient wet web strength and ability of wet web to withstand hydraulic and compressive pressure during pressing. The basis weight profile is discussed with the consideration of some controlling factors like proportioning, mixing deaeration of white water and thick stock and headbox pulsations. The main part of the paper inevitably deals with the forming zone i.e. from headbox to the suction couch. In this brief comments are made covering rectifier rolls headboxes and a reference is made to noval micro turbulent headboxes. Selected aspects of machines using twin wire former are compared with those using conventional fourdrinier. The reason for the development of foil and vacuum foil, as static drainage devices are briefly discussed. Differences in vacuum profiles between foils and table rolls are shown. The action of the foil is explained. An evaluation of parameters, related to drainage/drag of flat boxes that will improve performance for maximum drainage with minimum effect on the forming medium, is done. Factors affecting the sufficient wet web strength to withstand imposed stresses in open draw, are discussed. A few limitations, such as application of pressure, to the water removal on presses are also discussed in this article.

The intention of this paper is to focus attention on the limitations to the wet end operation of the paper machine that can largely determine the economic viability of machines production.

The efficient wet end operation during paper making process is of primary importance to production rate and cost efficiency of the process.

Factors affecting the efficiency of the wet end operations are :—

1. Basis weight profile M.D. and C.M.D.
2. Drainage, Formation and sheet structure.
3. Wetweb strength.
4. Water removal limitations on presses.

## BASIS WEIGHT PROFILE :

The uniformity of Basis weight distribution as determined by basis weight profie in machine direction (MD) and basis weight profile in the cross machine directions (CMD).

In order to obtain uniform distribution of basis weight, the approach flow system must ensure a constant flow rate at constant pressure and a constant consistency to the head box throughout the period of production.

Deviation in the flow rate and pressure affects the basis weight profile in the machine direction, Flow rate and pressure deviation may have their origins in mal-function of control loops, in pulsation or flow disturbances. It is well known that consistency deviation in the stock approach system show up as similar scale basis weight variations in MD. Short term consistency deviations result in an unstable profile in CMD.

Functions of stock approach system are :—

(a) Constant proportioning (particularly of thick stock and white water).

(b) Constant mixing of thick stock and white water.

(c) Constant feeding of mixing stock to the Head Box.

(d) Deaeration of mixed stock before entering the Head Box.

The main problem with thick stock proportioning is consistency control. Thick stock control is much easier if the control valve position is well below the

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thick stock level and white water tower. The difference in height between the thick stock level and white water level should be more than 2 meters and the thick stock level is kept very constant by maintaining an overflow. The white water flow rate is easily kept constant by a constant level in the white water tank maintaining an overflow. The white water should also be deaerated before entering the tank.

The continuous and smooth mixing of thick stock and white water is done so that the consistency over the pipe cross section becomes constant.

Steady feeding of pulp suspension means a constant flow rate to the Head box at a constant pressure. Through puts and pressures prior to the head box have to be adjusted to suit the production range of the paper machine. This may cause instable pumping condition depending upon the characteristic curve of the pump and production range required. In addition, a pump which is not functioning at optimum conditions can generate more pulsations. Through-put and pressure should be adjusted by a combination of rpm control of fan pump, by pass and/or main stream throttling.

Control of throughput and pressure under steady operating conditions should be under taken by rpm control of fan pumps since bypass control causes consistency variation due to the change in flow rate of the bypass and thus in the proportioning conditions.

The air in stock effects the basis weight profile both in machine direction and cross machine direction. Before the paper stock finally enters the headbox it should be well deaerated to avoid any basis weight fluctuation. This is done by passing the stock through a Deculator system, ahead of the head box. In the Deculator process the stock is introduced into a receiver in which a high vaccum is maintained. The stock is sprayed into the receiver, through the large nozzles, which whirl the stock at high velocity and discharge in the form of spray against impingement areas. thereby separating the individual air bubbles from the fiber and wa er.

On the low production machines, deaeration of stock is successfully done either by installing Educators or connecting the top of the centricleaner nozzles to common reject header and separator/receiver connected to a small vacuum pump.

In the modern practice, pressurized screens are used ahead of the head box. The pressurized screen eleminates the possibility of addition of air to the stock after complete deaeration and at some time it removes all lumps and strings.

## HEAD BOX PULSATION

The pulsation in head box effects the basis weight profile in machine direction and in cross machine direction.

All hydraulics head boxes developed so far are susceptible to pulsations passing from the stock supply system to the headbox. As a result, an essential quality feature of the paper-uniformity of the basis weight—distribution in the machine-and to some extent in the cross machine direction of the sheet—can be adversely effected.

Disturbances due to pulsation—As a rule, these cause the greatest problems. They result from periodic excitation in the stock approach flow system and are propogated with the speed of sound. They can be produced by pressure screens, fan pumps, or external sources, whose distrubances are conveyed to system from outside.

The pulsations reaching to headbox can be prevented by two measures :

(1) Preventing development of a disturbance (modifying design and control of approach flow system).

(2) preventing further effect of a disturbance by isolation of hydraulic path and the mechanical path.

In most cases it is impossible to eliminate all disturbancees by first measure then it is necessary to rely on pulsation damping in order, to reduce the effect of the disturbance.

Pulsation Damping--pulsation damping, in the main achieved by three physical conditions:

1. Damming- Damming means, that tha pulsation is impeded by dam. This can be done by concentration of mass, by resistance element, by reflectors, at disturbance points.

2. Damping—Converting the pulsation energy into another form of energy(heat).

3. Interference—Interference means elimination by super imposing another pulsation of the same frequency and amplitude of the first pulsation, displaced, however, by half a wave length.

Pulsation dampers with vertical approach flow and with horizontal apprach flow are shown in the Figure (1).

Also the frequency spectrum before and after Eysher Wyss Pulsation Damper, is shown in Figure (2).

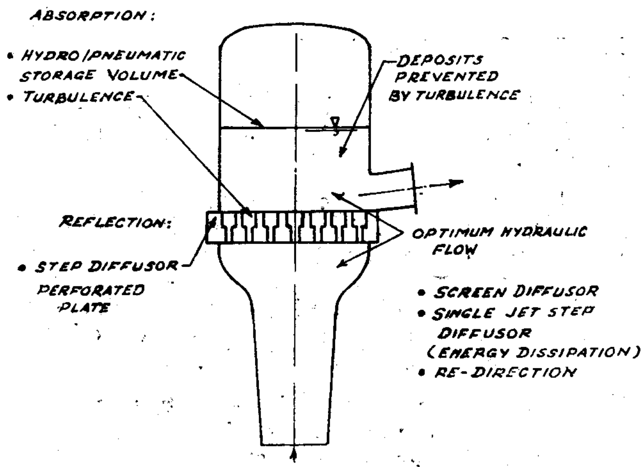
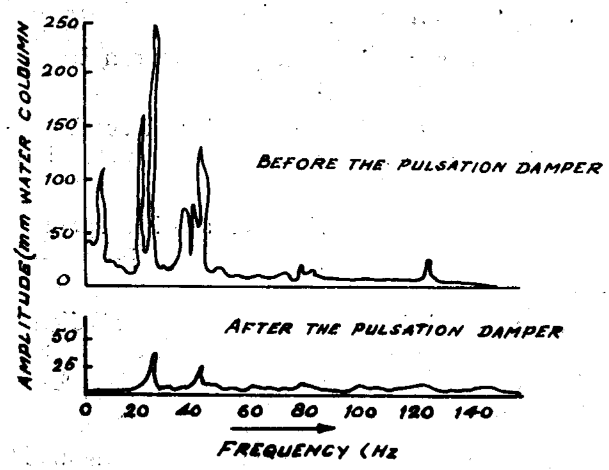



**FIG. 1—Pulsation Damper with Vertical Approach Flow (Ref. 9)**




**Tig. 2—Frequency Spectrum Before and After an Escher Wyss Pulsation Damper (Ref. 9)**

## II. DRAINAGE, FORMATION AND SHEET STRUCTURE

Formation is equivalent to small scale (or high frequency) basis weight variation. Wild formation not only weakens the sheet through the uneven stresses caused but it can also have significant import on printing quality as thick and thin spots leads to show-through or strike-through. Poor formation to the point of pin holes in the sheet is indicative of very poor operation and is not usually fault of furnish. The sheet structure is also critical for many end uses particularly in printing grades. The sheet structure i.e. the orientation of the fibers is more a characteristic of former effect or former design than a furnish effect. So, the optimum formation depends upon the design and setting up of the head box, type of former, forming fabric, and other ancillaries.

## THE HEAD BOX

The head box may be considered to be the most important part of a paper machine. The head box affects sheet formation and grammage, which together with fibre properties are the main features influencing the paper produced.

The perfect head box should be one which continuously delivers completely uniform dispersoin of fiber to a former a perfect former would then instantly freeze that uniformly dispersed fibres into a sheet of wet paper, whilst it might be difficult to achieve this in practice. However it is difficult to see how the freezing process can be made to take place sufficiently quickly to prevent the reformation of the flocs. Untill such time, as this is practicable, former generally have to introduce disturbances to prevent reflocuiation.

In general we classify the head boxeses :

(1) Conventional type--rectifier roll head boxes.

(2) Modern headboxes--Micro turbulence headboxes.

## RECTIFIER ROLL HEADBOXES

With various modifications, such as number of rectifier rolls, placement and type of rectifier rolls etc., these boxes are being used satisfa ctorily on our paper machines running upto a speed of 300 M/Min. but beyond this speed these headboxes can be used with a logical extension of their design, to place an air tight cover on headbox, keep the liquid level in the headbox at some optimum height and used air pressure in the open space above the stock to give the required total head.

To determine the characteristics of Rectifier roll headboxes following components are to be considered.

(1) The bundle of small diameter tubes feeding the headbox from the distributor.

(2) Its cavernous space.
(3) The rectifier rolls and
(4) The slice zone.

The smaller diameter of the tubes feeding headboxes produce a large number of discrete flow, with well dispersed fibres and fine scale turbulence.

The cavernous space or volume of headboxes combines the separate flow from the distributor tubes into a single unified flow, but proper care must be taken that it does not provide more time (in order of magnitude) than is required, for the stock to flocculate severely. One can look through the window on the side of most such headboxes and see the large flocs floating leisurely by.

To destroy the flocs or to reduce their sizes these headboxes are equipped with one or more rectifier rolls with varying placement and type. These rolls because of their relatively large diameters of holes (2—3 cms) can only marginally reduce the size of flocs. They certainly never redisperse the fibres to the degree of uniformity that existed on entering the heabox

The important functions of the rectifier rolls are :

(1) The rolls are the only significant resistance to flow within the headbox. Thus they reduce gross misuniformities in flow and minimize the larger cross currents.

(2) The second effect of the rectifier roll is the production of regularly spaced medium or fine scale flow disturbances across the width of the discharge. These disturbances appear to be flow streaks conforming to a single row of the holes of rectifier roll just behind the slice with the turbulence created by rolls causing cross flow within the jet.

When a stock flow with these rectifier rolls, induced cross direction flow disturbances are deposited properly on the wire, the repetitive vortexing, which deflocculate a fibre suspension on the wire during dewatering, is initiated. This action on the discharge of rectifier rolls appears to be causing the very effective small scale redistribution of fibre during the drainage process.

The rectifier rolls behind the slice is not the only source of turbulence in the discharge of rectifier roll headbox. Since the liquid level in the headbox is much higher than the slice opening, the acceleraation of the stock originating at different locations at different heights behind the slice varies. These different stock acceleration create considerable shear within the stock, an effect which also tends to orient the fibres preferentially in the machine direction, which is a form of turbulence that assists in deflocculating a fibre suspension.

The more severe the contraction of flow behined the slice the more oriented shear is introduced into the stock and greater the degree of machine direction bias in the fibre orientation distribution. Thus 90° slices produce more oriented shear and more turbulence – than do 30° projected slices.

## MICRO TURBULENCE HEADBOXES

The prevention of the flocculation of the stock in the headbox has been a particular point of interest. The evener rolls have for a long time proved a general solution to this problem for low and medium speed machines. But on modern high speed machines, to produce higher production with further improvement in quality of paper, it becomes necessary to introduce a new system of stock discharge with high turbulence in the flow to give a good formation and sheet structure.

The efforts made on this have led to the development of the headbox which does not incorporate any rectifier roll and it led to such a solution as plates with holes, rows of tubes or partition walls, all of which generate shear forces, and thus turbulence either by uncontrolled eddies or wall friction.

The underlying principle is based on utilizing tube lattices or orifices to subdivide a total flow into individual flows which later reunite. Inside the tube lattices, frictional forces create intense turbulent motion in the vicinity of the wall, thus transforming flow energy into turbulence energy. In general, a turbulent flow may be regarded as an eddying motion in which temporary and locally innumerable eddies of different magnitude occur in a random orientation. Therefore in addition to the mean velocity such eddies impart, to each element of the fluid velocity, fluctuations in all axial directions.

The velocity fluctuations in fluid create the shear forces in the water which help to decompose the fibrous net work and prevent flocculation.

The high turbulence headboxes step diffusor type, Duoformer (Honey comb, Bunch tube, Nozzle type) and many others are synthesis of well proven principle of high turbulence generation. The function of recently developed step diffusor one of the high turbulence headboxes, is discussed here.

The step diffusor is a parallel sided chambers one which increases in cross sectional area in a series of steps (Figure 3). An intense micro turbulence is created by generating a controlled eddy behind each step.

The functions of step diffusor are :

(a) To turn the suspension entering the headbox from the side to the machine direction.

(b) To distribute the fiber suspension evenly over the full machine width.

(c) To generate cotrolled intense micro turbulence for breaking up fibre flocs.

(d) To give a rectangular velocity profile at the outlet of step diffusor.

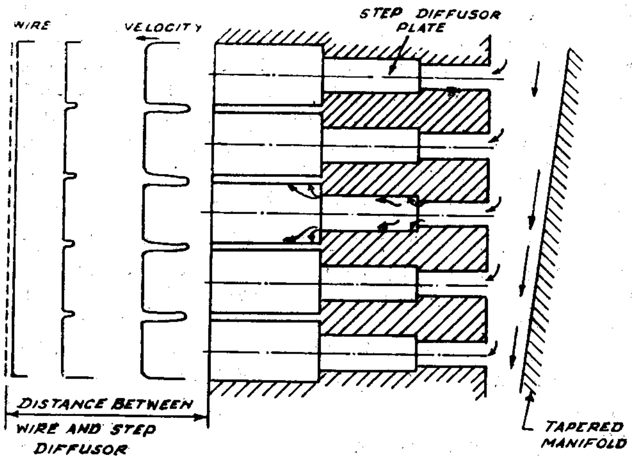



**Fig. 3—Velocity Profile After Step Diffusor Plate (Ref. 6)**

The stock approaches to the headbox through a rectangular tapered distributor with a rectangular cross section which provides equal pressure across the width. In step-wise increase of cross sectional area a intense micro turbulence is generated by generation of eddy currents behind each step. In the rapidly converging slice of headbox a quick and uniform fusion of individual flows from the step diffusor takes place which prevents reflocculation of the fibres and secondary flows.

**WEB FORMERS :**

**Twin wire forming :**

It is determined that after the discharge from head box repeated vortexing, which introduces turbulence to deflocculate the undewatered portion of the stock throughout the forming zone, is the best way to form a uniform sheet. But, if the stock can be formed into a sheet before reflocculation sets in, all is well and good and then no further turbulence is required to deflocculate in the forming zone.

Twin wire formers do not have a free surface to energise flocculation or disturbances. Moreover they have ability to rapidly drain the suspension before it fully reflocculates. In this for a better initial dispersion, headboxes, that produce highly turbulent discharges, can be used.

Advantages—The prime advantage is increased drainage capacity and hence larger machine capacity and speed. Less two sidedness is achieved. The question of sheet structure seems to be debatable as are the question of cost, power and ease of adjustment of the equipment.

The disadvantages are lower filler retention, a more open sheet a more three dimensional sheet (which is not generally required in paper making).

It is difficult to see how the filler retention, openness and structures of the sheet made on twin wire formers can be made to match those of the fourdrinier. It is for this reason that some people consider that the twin wire former will not, without basic redesign, produce some of the quality papers. However, when one considers the proved quality requirements in production today (Newsprint, light weight directory, coating base, printings and writings, liner board, tissue, filler, grease proof, fine papers board, sack kraft, towelling, offset papers), it seems little pessimistic to say that future uses for the twin wire former are restricted.

At this point one could make preference to twin wire forming for tissue making, which also seems likely to increase because of the lower cost of the equipment compared to high speed suction roll formers, improved formation and profile and quality and last but not least, speed limitation of suction formers (As suction formers are difficult to run at a speeds greater than about 1500 M/Min due to high shear, closeness of the slice to the forming roll, and difficulties in pick up and roll former).

The paper characteristics and machine performance for selected grades of papers produced by machines using twin wire formers and by those using conventional fourdriniers were compared by TAPPI Four drinier Paper makers committee. In the committee report it was indicated that machines twin wire formers produce better printing sheets with reduced linting characteristics. The Machine direction and cross machine direction tear indexes were higher for sheet made on twin wire formers. Many twin wire formers are producing the sheet with comparable retention and lower horse power requirements and in less space than machines in the same will with flat fourdriniers.

Machines with twin wire formers had lower couch moisture levels than did machines in the same mill with flat fourdriniers, but many machines were running over 81% couch moisture content. The machines with twin wire formers generally had lower press moisture level and higher reel moisture level than machines with fourdrinier. This puts a smaller load on drying part of the machine. So the sheets made on machines with twin wire formers are easier to dry.

On the average the machines with twin wire formers had lower efficiency. Machines with twin wire almost always had more breaks/day than machines with fourdrinier in the same mill with same stock conditions.

Some former operating variable were also considered in the comparision. Headbox consistency is the same for both the formers. Fabric life was almost similar on both the machines. It took less time to change both fabrics on a twin wire machine than to change a single fabric on a flat fourdrinier. The forming horse power/ton was much less for twin formers than for fourdrinier. For twin wire former it was about 0.41 HP/ton and for fourdrinier 2.13 HP/ton. The rush ratio was reported higher for twin wires.

Looking at twin wire formers in more detail, the question which type will succeed is more difficult to predict. The different formers have been admirably classified recently by schmidt and Norman.

## SCHMIDT CLASSIFICATION

(1) Twin wire but with no pre-drainage (for example vertiformer, papriformer, duoformer).

(2 Fourdrinier with top wire (e g. symformer, ultra twin former).

(3) Twin wire with pre-drainage (for example the speed former, acrufomer).

Figure (4) illustrates basic differences between thesc formers.

## NORMAN CLASSIFICATION

He classifies them as :

(1) Dewatering (Smooth or pulsating, one sided or two-sided drainage).

(2) Jet [directly into the nip (i.e. no pre-drainage) or some preforming].

## HIGH CONSISTENCY FORMING

In this sheets are formed from consistencies between 2.5 and 3.5%. The 3.5% is practical upper limit at this moment. The sheet is basically different from a fourdrinier sheet, being felted rather than layered.

The principal advantage over conventional forming is that water volume required in the wet end is reduced by upto 80%; the lengths of forming and pressing sections can be considerably reduced. This results in the capital cost being about 80% of the normal. The felted sheet is more 'square', that is increased porosity which could mean lower drying costs. It produces high Z-direction strength and good bulk. The retention seems to be as good as with the fourdrinier sheet.

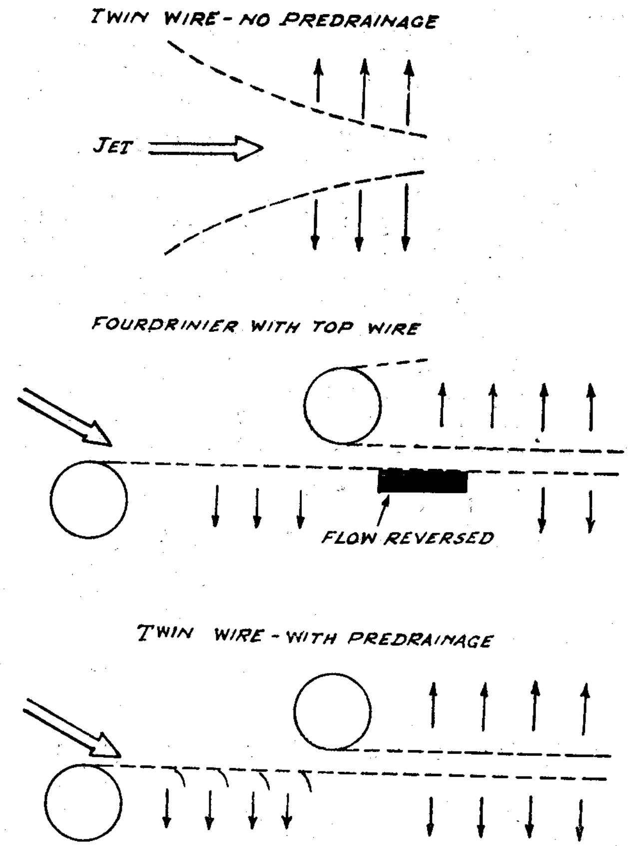



**Fig. 4 Basic Types of Twin Wire Former (Schmidt) (Ref. 3)**

The two main disadvantages are, as a result of the felted structure, the sheet appears to have tensile and burst significantly lower (by at least 30%) and secondly there is a problem of cleaning and screening high consistency pulp prior to forming.

## ANCILLARY EQUIPMENTS

Forming board--At least one quarter and usually third to one half of the sheet forming process is completed by the end of the forming board. The amount completed on any given fourdrinier can be estimated readily and quickly by comparing the thickness of the stock layer on the wire at the end of the forming board with the thickness of stock hitting the wire i.e the headbox discharge. For example, if the former is 0.3 cm. and the later 0.5 cm. than 40% of the water has been removed from the stock and 40% of the sheet is formed on the forming board.

The portion of the sheet formed by the end of the present day forming boards reflect the flocculate state of the headbox discharges for two reasons:

(1) There is no fiber dispersive turbulence introduced before breast roll dewatering, when this type of dewatering is present, it removes a very large portion of the headbox discharge.

(2) The second problem is that, since sheet forming on the fourdrinier is a filteration process in which the sheet is built up in layers, it is highly unlikely that the turbulence generated beyond the forming board more than marginally disturbs the initially for portion of the sheet.

Table rolls and foils--The vacuum profiles developed by various types of dewatering element are shown in figure (5). The points of most importance are the comparison between the

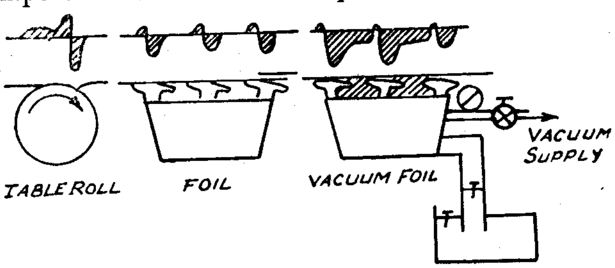



**Fig. 5—Vacuum Profiles of Dewatering Elements (Ref, 8**

positive pressure drop across the wire (dp) developed by the table roll before the top dead centre of the roll and the minimum positive dp developd at the leading edge of the foil table. It is this difference which gives the foil blade such an advantage, in terms of absence of two sideness in the finished sheet and in total loading and fine fibre retention. The intense short duration dp across the fibre mat which is developed by the table roll is replaced by a much less intense but longer duration dp curve in the divergent nip of the foil blade. This means that the rate of flow of water through the formed mat is lower, which in turn means that retention is generally improved,

Action of the foil Blade--The action of a foil is shown in exaggerated form in figure (6). The

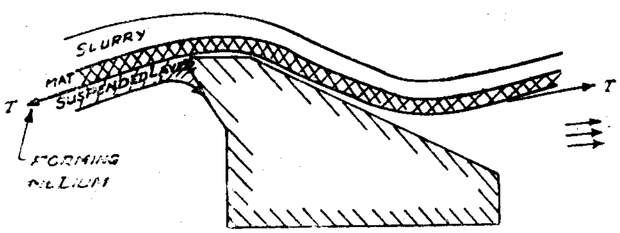



**Fig. 6—Action of Foil (Reg 8)**

foil blade consists of a straight horizontal section followed by a straight section at an angle to the horizontal (the nip). It is assumed that all foil surfaces are flat and unworn The wire comes into contact with the foil first at its leading edge. Immediately upstream of the leading edge of the foil blade, the wire has three independent layers parallel to it and moving uniformly with it These are, a layer of white water suspended under the wire, a layer (the mat) of relatively dense fibres and fillings supported directly by the wire and; a layer of stock at approximately headbox consistency (the slurry) located just above the mat.

The consistency of the mat is greater than the headbox stock. As the layer of white water suspended under wire comes in contact with leading edge of the foil, a portion is deflected up in to the sheet whilst the remainder is doctored off and runs down the face of the foil blade.

As the wire passes over the nip, the diverging passage reduces the hydrostatic pressure between the foil and the wire and causes the wire to attempt to follow the surface of the foil blade. The degree to which this ocours is governed by the wire tension. If severe deflection takes place it can cause disruption of the sheet.

As the wire and surface of the foil blade part, the reduction in pressure created by the diverging nip causes a pressure gradient to be set up from the area under the wire through the mat to the slurry. The amout of water which passes through the mat will depend upon the flow resistance, the pressure drop across the wire, mat and slurry, dp,and the length of time over which the pressure is applied (effecrive nip length). The amount of water which will flow through the wire can be altered, for instance, by increasing the foil blade or by increasing the effective nip length.

The water which flows to the under side of the wire may flow down the foil blade or remain on the underside and be doctored off by the following foil blade.

If we follow this pattern down the length of the machine we can see that, at each foil blade, there will be an increase in the thickness of the fibre mat and a corresponding redauction in the thickness of the slurry above the m t. As this occurs, there will be an increase in drainage resistance due to the thickness of the mat increasing so that, if dp remains constant at each foil blade the amount of water removed at each foil blade will reduce. This means in turn, that drainage becomes progressively more difficult down the machine and so the angle blade, of and the number of blades per unit area, must increase towards the dryer end of the machine table.

One of most restricting characteristics of foils with regard to slow running paper machines is the fact that at speeds below 100 M/min. insufficient pressure drop develops in the nip to dewater the sheet sufficiently. This means that there have to be auxiliary drainage devices (which are generally vacum assisted) to cause sufficent drainage to take place in the space available.

Suction foil units—The requirement for small, low speed, machines to have a suitable type of foil led to the development of a suction foil unit. The type of vacuum profile developed differs from that developed by simple foil box.

In this vacuum assistance is given in between after the foil nip and the leading edge of the next blade-the dp across the sheet is maintained by the pressure difference between the interior of the box and atmosphere.

Drainage on the forming table of the fourdrinier steadily decreases with increased sheet consistency to a point where self drainage inducing equipment such as hydrofoils and table rolls are no longer effective. External vacuum is then appiied to increase sheet consistency to a level where sheet strength is sufficient for transfer to the first press. This vacuum induced drainage is performed primarily by flat boxes and then by couch vaccum.

Flat boxes—The simplicity of the flat box and ease with which its performance can be adopted to various production requirements has made it a universally accepted piece of equipment. However, there are short-comings inherent to the flat box, such as continuous abrasion of the forming medium and covers, drag load created by the boxes, problems with drainage uniformity, pin holding and wire marking.

In all cases drainage of the flat boxes increased proportionally with the level of vaccum applied. The consistency of the white water is relatively low compared with that of the other forming zone. The white water consistency decreases with increased vaccum. The movement of the forming medium over the stationary flat box covers creates a drag force. The magnitude of which is greatly influenced by the level of vacuum applied to the boxes. This drag or friction from the flat box cover constitutes a significant part of the overall power consumed by the fourdrinier drive motor and also adversely effects, the life of the forming medium. Drag of a flat box was found to be primarily function of applied vacuum, sheet consistency entering the box and surface finish.

Performance of a bank of flat boxes—The sheet consistency leaving the last flat box increased with an increase in cumulative vacuums applied to the flat boxes. But the final sheet consistency highly depends upon the vacuum schedules employed. The higher sheet consistencies are obtained when vaccum on the flat boxes was graduated in such a manner as to increase from the wet to the dry end, rather steeper increase from wet to the dry end gives much higher sheet consistencies.

Drag of a bank of boxes, like drainage, is seen to increase with an increase in the total vaccums applied but is highly dependent upon the vaccum schedule employed. The highest drag loads are obtained when vaccum schedules which resulted in the highest drainage also resulted in greatest amount of drag load.

Maximum drainage and minimum drag load can be achieved only by successively dropping flat boxes and redistributing their vaccums among those remaining.

Initially assuming the maximum no. of flat boxes in a bank is eight. Now the figure (7) shows the drag load of the bank of the flat boxes and the sheet consistency leaving the last flat box when successive flat boxes were dropped and their vaccums redistributed among those flat boxes remaining in the operation.

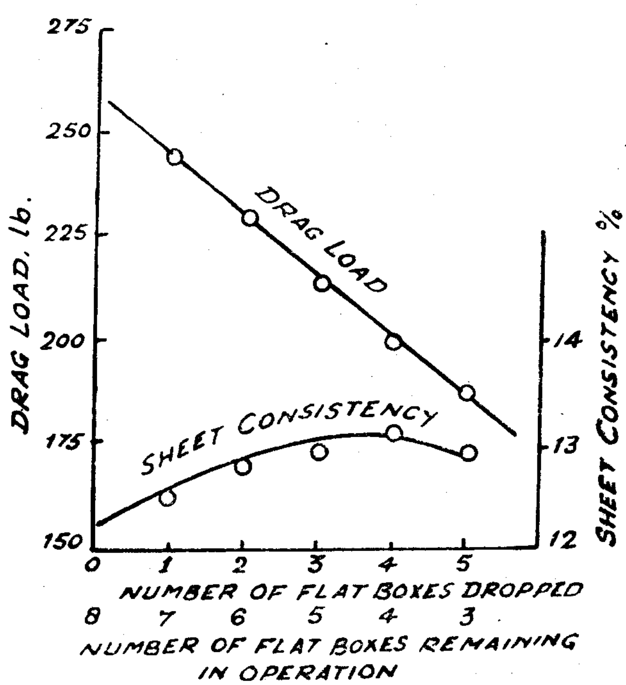



Fig. 7 (Ref. 13)

The reduction in the drag load noted when fewer flat boxes are used, is a direct result of the decrease in flat box cover area in contact with the forming medium.

Higher final sheet consistencies were obtained, even with fewer flat boxes, because steeper vaccum schedules realised when the vaccum of the boxes which were dropped were redistributed among those remaining in operation.

## III. WET WEB STRENGTH

The study of the load extension behaviour of wet paper, the work done in stretching the wet paper (area under the load extension curve) and the relationship of the load extension curve to various paper making parameters and to paper rupture is termed as wet web strength.

The operating problems start at wet end. The important factor in determining the paper machine runability is an adequate wet web strength to withstand stress imposed on the wet web in the open draws of the machine.

The stresses of wet webs are imposed by three factors :

1) Peeling tension
2) Momentum and
3) Stability

The effect of first two of these factors are summarised by stripping tension equation given by Mordon and Short This shows that adhesion to press roll is major factor compared to the wire adhesion and changes in adhesion can greatly effect machine operation.

The stability factor in the tension required in excess of the stripping tension to maintain a stable draw. For a given set of conditions this factor can be estimated by determining the actual tension predicted by the stripping tension equation.

For an example on a paper machine running at about 600 M/Min. the tension in the first open draw after the second press was determined to be approx. 64g/cm$^2$ while stripping tension equation accounted for only 40g/cm$^2$. Thus instabilities in draw, formation and moisture content, adhesion etc. forced to run at tension level 60% higher than the minimum required.

It is hypothesized that the magnitude of stability factor is directly proportional to the degree of system instability. Increasing variation in basis weight, moisture content, draws, formation, consolidation etc. create the need for higher sheet tension. Should the stability of the system be improved thus less tension be required, then the wet web strength of the sheet can be lowered and improved stability usually translates into higher and/or efficiency.

Hence the wet web strength depends upon :

1) Basis weight
2) Formation and sheet structure
3) Sheet moisture content
4) Furnish composition
5) Consolidation of web

Variation in the basis weight can be critical because they are usually accompanied by moisture and structural variations, which causes uneven stresses, upon the sheet and thus directly effect the stability factor.

Above a critical minimum level the absolute level of basis weight is no longer a limiting factor in wet web strength because most wet web strength parameters increase in proportion to an increase in basis weight or vice versa.

Formation is equivalent to small scale (or high frequency) basis weight variation. Deteriorating formation not only weakens, the sheet through the uneven stress caused, but it can also have significant impact on other properties of paper.

Sheet structure i. e. the orientation of fibres has significant effect on wet web strength properties. As the webs become more orientated in machine direction it is more able to withstand the tensile forces imposed. However, a sheet that is too strongly oriented in one direction may not have sufficient cohesion (resistance to sheet delamination) to overcome the adhesion of the sheet to the press roll surface and picking will then become problem.

Sheet mixture content is also an important factor affecting wet web strength on the machine. Wet web strength increase with dryness and is fairly linear upto 40% and above 40% solids content it increases exponentially.

It is anfortunate that certain action taken to increase wet web strength e. g. refining of the reinforcing pulp, will have the corresponding effect of the reducing drainage and increasing sheet moisture on machine. In certain instances the increase in moisture content will be the over-riding effect and the net result will be a decrease in actual wet web strength on the machine.

So the furnish used must either have water removal properties equal or superior to those of control furnish otherwise reduction in machine speed and/or efficiency must be anticipated. Of course increase in moisture has a double effect, it not only weakens the web but it also increases the stress by increasing the mass in the $MV^2$ term of the stripping equation.

The wet web consolidation at or before the couch roll is an important factor in improving wet web mechanical propertles. Pressing, producing a greater degree of consolidation, is superior to suctions. The water removal by pressing (as it might be applied at the couch) vastly improves wet web mechanical properties when compared to those obtained by water removal by suction. Pressing tends to produce wet webs of initial moduli 2-3 times those produced by suction. Other mechanical properties are also much higher for pressed sheets than for suction treated sheets.

The difference in the stress strain values of wet web produced by pressing at couch and those produced by suction is due to the difference in the thickness of the wet webs. The suction treated sheets range in thickness between 0.40 and .360 mm, while pressed sheets show thickness values of 0.30 to 0.24 mm i.e. pressed sheets are roughly 1/3 thinner than suction treated sheets. Thus consalidation appears to be the overriding factor in determining the mechanical properties of the wet web.

## IV LIMITATIONS OF WATER REMOVAL ON PRESSING

The importance of wet pressing or water removal on presses, to the economics of paper making is well recognised. The limit of water removal on presses is normally governed by consideration of paper quality, cost and the inability of the system to remove further water. The important factor preventing higher water removal is rewetting of the sheet on the outgoing side of the nip. The other factors which effect the limit to the amont of water we can remove, are press type, felt speed etc.

The very essence of pressing is application of pressure. In the recent years high pressure is used with the use of high intensity presses, harder roll covering etc. But there are several factors which impose limits on the maximum pressure used.

Mentioning the press construction the older presses especially those equipped with weight and lever system, are severely restricted in the range of pressure that can by applied. The incorrect camber and misalignment of rolls are two common occuring faults which results in poor sheet moisture profile due to uneveness of pressure app ied.

As press loading is increased this simultaneously increases the hydraulic pressure both in felt and sheet and also the compressive loading on the felt. An increase in hydraulic pressure leads to a higher flow of water through the felt. However an increase in compressive pressure leads to a decreased water flow. Increasing the speed of the machine, the felt is not compressed to same extent due to shorter dwell time. So the effective permeability of the felt and pressure for maximum water removal reduces.

Degradation of paper properties is a more serious limitations to increasing pressure. The increased pressing not only reduces sheet moisture content (see figure 8) but also sheet bulk. This bulk value is further reduced at calenders which does not result in a corresponding increase in smoothness. Like this other properties of paper are also affected by pressing which limit the water removal on presses.

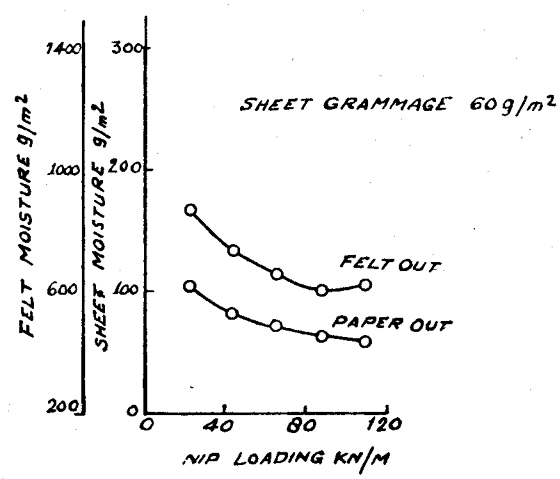



Fig. 8

Ultimately the increase in pressure is the onset of crushing which sets the upper limit of the pressure application. Crushing is due to the rate of change of hydraulic pressure in the sheet being too great. The resulting water flow is then too rapid causing the sheet rupture. Three major variables effect the onset of crushing are speed, loading and nip width.

Considering it impractical to decrease machine speed and loading then the third variable could be modified by decreasing roll hardness or increasing roll diameter.

To prevent crushing the pressure per unit area in the nip can be reduced by altering compressibility characteristics and by increasing permeability of the felt.

The water permeability is goverened by design of the felt. The range of water permeability covered by each generic type of felt is given in the figure (9). Modern felts now have a much greater permeability than possible with the conventional designs.

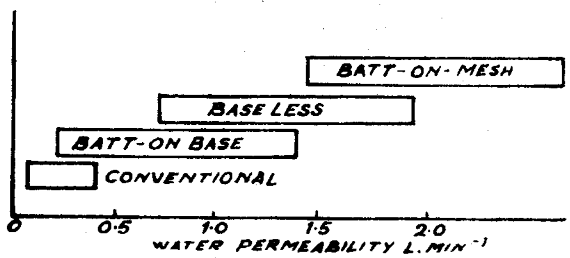



Fig. 9 (Ref. 12)

The line pressure applied is not in itself sufficient to describe the actual pressure distribution and peak pressure found in the nip. The use of smaller diameter rolls or harder coverings result in higher applied pressure for the same pli loading due to smaller nip width. These are more economic in obtaining high specific pressure in this, felt costs are normally higher and paper quality more likely to suffer.

Effect of loading on the cost of running a press is shown in (figure 10). It shows that with the increase of press loading the cost of conditioning remains constant, the cost of power to drive the press increases, the cost of clothing the press also increases due to decresed felt life and the cost of drying decreases, as with the increase in pressure the sheet leaves the presses drier.

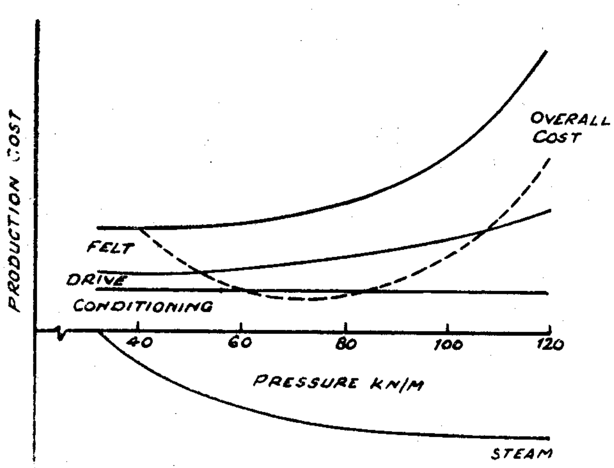



Fig. 10 (Ref. 12)

Thus we obtain the overall cost of running a press, we find that the pressure upto 60 KN/M are results in over all saving. Further increase results in slight increase in cost with loading of approximately 100 KN/M are achieved after which there is a rapid increase in the cost, due to the effect of shorter felt life and increased power requirement.

## CONCLUSION

In the above we have discussed few limitations to the satisfactory operation of wet end. So many other limitations are there which affect its operation. By over-coming through these limitations, with certain. modifications of processes, existing equipments, the paper properties, efficiency of the machine and hence the runability of the paper machine can be improved.

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