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The Modern Paper Machine Headbox

Richard N. Alger
Western Michigan University

THE MODERN PAPER MACHINE HEADBOX

by

Richard N. Alger

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CONTENTS

INTRODUCTION

The headbox and associated equipment, such as the slice and inlet header, are the most important items on a paper machine since what this equipment does or does not do at the wet end determines the quality of paper the machine will produce. The purpose of this project is to examine the historical background and the development of this equipment and ultimately design a new headbox for the fourdrinier pilot machine at Western Michigan University's Department of Paper Science and Engineering. The present headbox does not allow sufficient head to be developed due to the low speed of the machine.

HISTORICAL BACKGROUND

Ever since the development of the modern paper machine, there has been a need for a means of delivering a slurry of pulp, mineral additives and water from a round pipe of some limited diameter and spread that flow in uniform quantity and consistency with equal velocity across the paper machine.

The early headboxes were simple flow spreaders which had a header to split flow from the single pipe at the fan pump into several smaller pipes which were fed into the back or bottom of of the headbox. Early headbox designs were quite

simple as machine speeds were slow and thus little head was needed.

As machine speed was increased, there was a definite need for some improvements. One of these improvements was the development of the closed pressurized box to hold the liquid pond down to a level where the stock flow could be controlled at a desired velocity through the headbox. The older three-pass headbox was good enough for 300 to around 700 ft./min. machine speed, but when speeds of over 1000 feet per minute became a reality, a change was found necessary. Along with these changes it was realized that considerable knowledge of fluid mechanics would be necessary to design a headbox which would give the desired results.

In design of newer types of headboxes, four problems were recognized:

1. The mixture of water, stock, additives, and usually some percentage of air, is not a perfect liquid and consequently does not perfectly obey the laws of hydraulics.
2. The design cannot be based on one single, unchangeable volume of flow.
3. The flow from the fan pump and cleaning equipment more than likely has a lot of residual eddies and flow complexities which must be corrected.

4. From the manifold an abrupt 90 degree turn is made into the tubes. This sets up additional flow complexities which must be allowed to decay.

These problems, coupled with the fact that fiber slurries have a great tendency to flocculate, make the design job quite complex.

The techniques used in the investigation of the problem of fiber flocculation are of two distinct types; some investigators have examined fiber suspensions, while others have examined the sheet under controlled conditions. The actual work employing either of these methods falls into three schools:

1. The additive school (i.e., those who have added materials into the suspension of fiber and observed the effect).
2. The mechanical entanglement school.
3. The dynamic sheet forming school.

In this review, the subject is considered as a whole, and the additive school will not be considered.

The best work in this field is that of Mason's [1] corresponding to number two above. He considers suspensions of cellulose fibers as in many ways similar to colloids, but without the definite point of flocculation and deflocculation

that colloidal systems possess; the mechanical conditions of the suspension are taken as of major importance with regard to flocculation. Mason finds that the factors affecting mechanical entanglement are:

1. The characteristics of the fiber: its geometry, surface form and irregularities, and its flexibility.
2. Fiber concentration.
3. Fluid variables: rate of shear, time, amount of turbulence and viscosity of the medium.

Mason established that in accordance with his theoretical predictions, the amount of flocculation was directly dependent on the concentration of the suspension and the fiber length, and inversely dependent on the shear rate. He assumed that the fibers move independently between collisions [2]. From this "collision theory for fibers" Mason deduced a critical concentration above which flocculation can always be expected since unrestricted movement of the fibers is no longer possible. In practice, the actual operating consistencies of paper machines are always much higher than the theory predicts should be possible without flocculation

(0.2 percent to 0.6 percent or more compared with a predicted maximum of 0.125 percent)[3,4].

Shear motion will disrupt fiber clots or flocs if sufficient time is allowed. The formation and destruction of fiber clots is in dynamic equilibrium and an increase in shear rate will give a shift in the equilibrium to the floc destruction side. The theory assumes laminar flow to be the rule and clearly acknowledges the limitations of this assumption. The fact that on a paper machine, both in the headbox and slice, the motion is largely turbulent probably accounts for this discrepancy between theory and practice.

The work of Mason and his school seems to have definitely established that the flocculation effect of added chemicals is of minor importance; and Mason himself considers any attempts to explain the small flocculation effects that are observed as due to a reversal of zeta potential, as highly speculative.

PRINCIPLES OF TURBULENT MOTION AND VARIOUS HEADBOX DESIGNS.

This section will consider several headbox designs including the most advanced types built today, and discuss them from the point-of-view of the hydro-

dynamics of turbulent motion. The initial section comprises a simplified exposition of hydrodynamic principles for paper makers; the principles developed in this section are referred to in the later discussion.

In considering the relationship of the hydrodynamic principles it should be born in mind that transportation of bodies by a fluid moving with respect to boundaries results in a mixed substance that may no longer be regarded as either homogeneous or as completely fluid.

At low velocities, fluids tend to flow without lateral mixing and adjacent layers slide past one another like playing cards. There are neither cross-currents nor eddies. This regime is called laminar flow. At higher velocities, turbulence appears and eddies form resulting in lateral mixing.

Turbulent flow consists of a mass of eddies of various sizes coexisting in the flowing stream. Large eddies are continually formed. They break down into smaller eddies, which in turn evolve still smaller ones. Finally, the smallest eddies disappear. At a given time, and in a given volume, a wide spectrum of eddy sizes exists. The size of the largest eddy is comparable with the smallest

dimension of the turbulent stream; the diameter of the smallest eddies is about 1 mm. Small eddies are rapidly destroyed by viscous shear. It has long been known that shear forces much larger than those occurring in laminar flow exist in turbulent flow where there is a velocity gradient across a shear plane. The mechanism of turbulent shear depends upon the deviating velocities in an isotropic turbulence. Turbulent shear stresses are called Reynolds stresses. When a liquid flows along a pipe, the walls exercise a retarding effect and create a shearing stress on the flowing liquid.

Boundary-layer separation occurs whenever the change in velocity of the fluid, either in magnitude or direction, is too large for the fluid to adhere to the solid surface. It is most frequently encountered when there is an abrupt change in the flow channel, like a sudden expansion or contraction, a sharp bend, or an obstruction around which the fluid must flow. However, separation may also occur from velocity decrease in a smoothly diverging channel. Most often, separation is minimized by avoiding sharp changes in the cross-sectional area of the flow channel and by streamlining any objects

over which the fluid must flow. In the immediate neighborhood of the boundary itself, the effect of viscous action becomes appreciable, and a marked modification of the flow pattern is therefore to be expected. As the boundary layer development involves both mass acceleration and viscous shear, the conditions of motion are appropriately designated by a characteristic Reynolds Number.

In fact, the velocity distribution curve from the boundary outwards includes a film of purely laminar flow, a region in which the turbulent process is fully developed, and a transition zone between the two in which the flow is neither completely laminar nor completely turbulent [5].

FLOW AROUND IMMERSED BODIES

The actual resistance caused by the immersed body will depend only on the Reynolds No. characterizing the motion, and on the geometrical form and orientation of the body. The "dead water" behind the immersed body is set in motion by the shearing forces, separating from the boundary and forming pairs of vortices which detach themselves. If the rate of formation of vortices is sufficiently rapid they lose their identity, and a region of extreme

turbulence or wake extends behind the body.

FLOW IN CLOSED PIPES

There are two differences between flow around a single immersed body of given form and flow through a geometrically analogous closed conduit, where the walls are close.

1. Such confinement causes noticeable differences in the corresponding dynamic patterns.
2. Boundary layer growth begins at the leading edge of an immersed body.

In bends, vortices form from either side as a result of boundary layer growth. The secondary motion may here be eliminated by suitably placed vanes around the bend, or to use a Venturi bend which has a lower resistance than a normal bend. The Venturi bend will not catch fibers as vanes may do.

FLOW IN OPEN CHANNELS

Under normal conditions of flow, the geometrical considerations are usually such that not only is motion definitely turbulent but the Reynolds No. is well above the range of appreciable viscous influence. Although such channels are sometimes very smooth, a boundary layer can still exist. Boundary roughness is what usually

determines the magnitude of wallshear. The velocity distribution in an open channel is dependent on the relative magnitude of channel width and channel depth and the intensity of boundary shear cannot be assumed constant over the walls and floor of the channel. The distribution of shear is a function of the Reynolds No. of the flow, the geometry of the cross section, and the relative roughness of the boundary.

The velocity distribution causes a definite variation in the total pressure from the top to the bottom of the section. At some depth, the specific energy is at a minimum value and the depth and velocity which correspond to minimum specific energy are designated as critical. Under conditions of critical flow the discharge per unit area is a maximum. (The hydraulic gradient is of great importance here).

INLET TO THE HEADBOX

Headbox inlets can be classified into four main types:

1. Branching of pipes.
2. A gradually expanding pipe to the entire width of the machine.
3. An inlet from the base of each of two triangular boxes, each the width of the machine and

tapering so as to fit together, see Figure 1.

4. Delivery to the box by a weir following an expanding pipe.

It is well understood that irregularities introduced at the stock inlet to the headbox can persist right through to the slice. Much of the paraphernalia of rolls, baffles and flow eveners of the older type of headbox were installed in an effort to damp or eliminate fluctuations due to the inlet.

Headboxes with large Reynolds No. may, in fact be turbulent only at the center and edges of flow eveners etc. The boundary layer, however, gets larger as the headbox is traversed.

Based on the fact that irregularities introduced at the stock inlet may persist through to the slice, the most modern of headbox designs seems to be the Voith-Allis flow nozzle where the inlet consists of many very small pipes coming from the large stock header.

HEADBOXES

The headbox types in use today and those which recently became obsolete, can be divided into three main types:

1. Headboxes with baffles and perforated rolls.

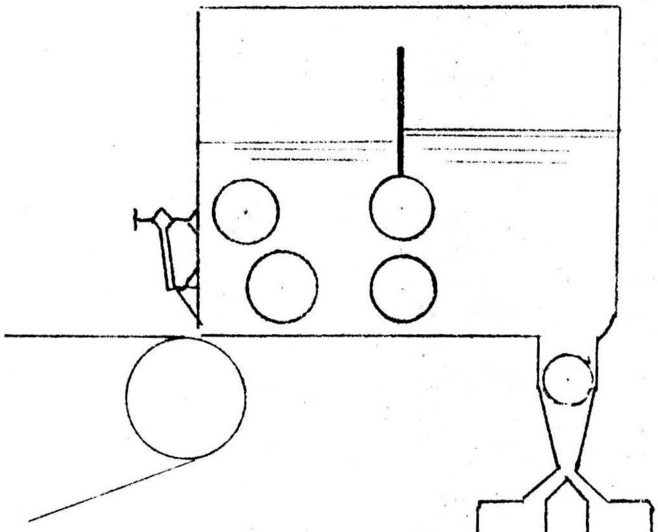


FIG. 1

2. Headboxes with a weir.
3. Headboxes with a totally enclosed flow nozzle.

The above three types may be fitted with either a straight or projection-type slice. Slices are to be discussed later.

HEADBOXES WITH BAFFLES AND PERFORATED ROLLS

This type of medium speed headbox, common until recently, consisted of a large box containing baffles and perforated rolls and/or flow eveners by which the imperfections in distribution and velocity of the stock inlet stream were corrected.

The perforated rolls can be considered either as acting as screens, or as a means of putting in more turbulence thus giving better mean velocity distribution. The last roll often placed immediately before the slice is for evening out the velocity distribution across the box. Care must be taken when using perforated rolls as to the amount of open area and the placement and rotation within the headbox [6].

Flow eveners are sound in principle since they act as a honeycomb. If placed too close together, they may act like a Venturi nozzle and create turbulence of small scale. The effect of

passing the stock under baffles and through narrow gaps is to speed the flow up and so increase the rate of shear. In the gap itself there is reduced turbulence, but turbulence is recreated after the baffle as in figure 2.

FLOW NOZZLES

Flow nozzles may be classified into two main types:

1. Flow nozzles where the stock velocity at the slice is created in a small pond by air pressure where the air pressure is used to hold the liquid level at some predetermined height.
2. Flow nozzles where the stock velocity comes directly from the pump and without use of the air pressure.

Actually, the stock velocity is dependent on the flow rate in both cases, except where as in some of the types to be mentioned later, there is an arrangement for a continuous overflow. In the other case, the air cushion above the stock in the box serves only to even out capacity differences of the pump, due to power frequency variation or oscillations.

One example of the flow nozzle type former is the Baie Comeau which has been first

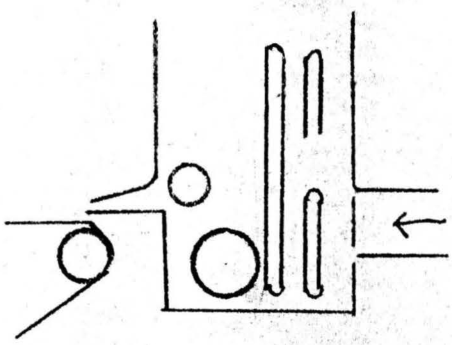


FIG. 2

Common early form of medium speed
headbox

described in the literature [7,8]. An earlier version of this appears to be the headbox at Powell River [9]. These are shown in diagrammatic form in figures 3 and 4. The Powell River box is described as being divided into three distinct zones:

1. A deceleration rectification zone containing one or more perforated rolls to make the stock slurry turbulent.
2. A still pond area over the saddle.
3. A final acceleration area.

For an even discharge of stock on to the wire headboxes of this type depend on an even discharge from the last pump. Pumping variations to some extent are absorbed by the air pressure.

The original Voith nozzle [10], is similar in conception to figure 4, where the stock is turbulent and delivered to the slice. This was the first slice to be totally inclosed but it is not now manufactured possibly because of difficulties with cross streams and the boundary layers. Figures 5 and 6 show successively later versions of the Voith flow nozzle. Figure 7 shows the latest version of the Voith-Allis flow nozzle type.

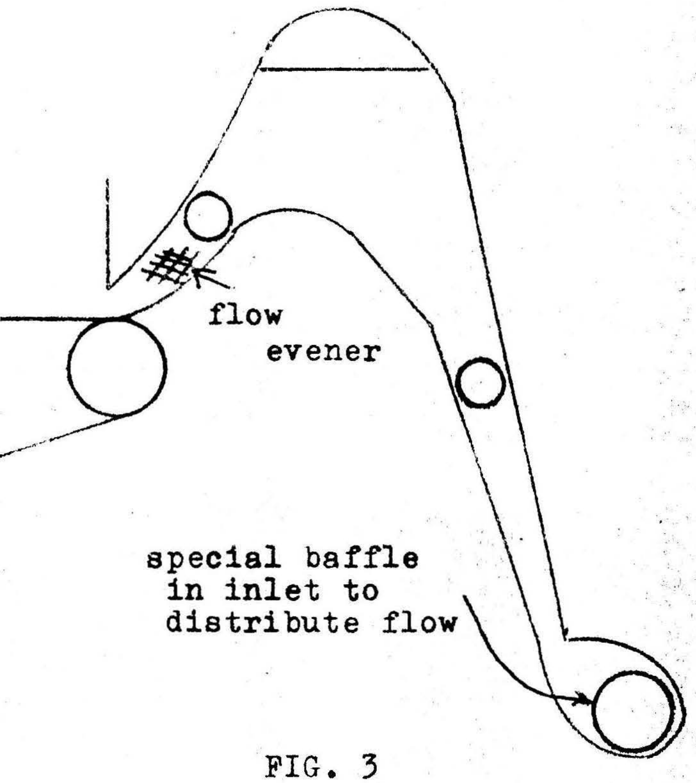


FIG. 3

Diagrammatic of Baie Comeau.

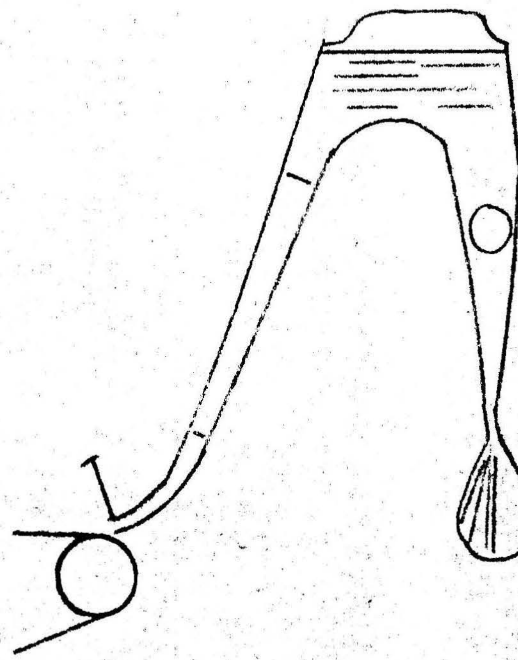


FIG. 4

Powell River headbox
Canadian Pat. 466720

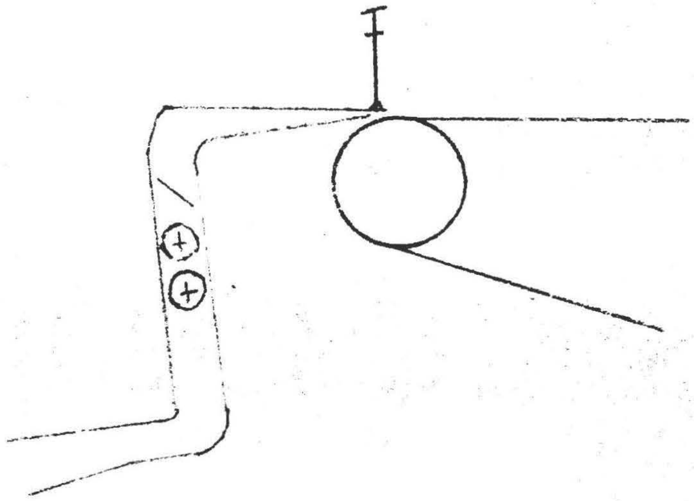


FIG. 5
Voith flow nozzle (old type)

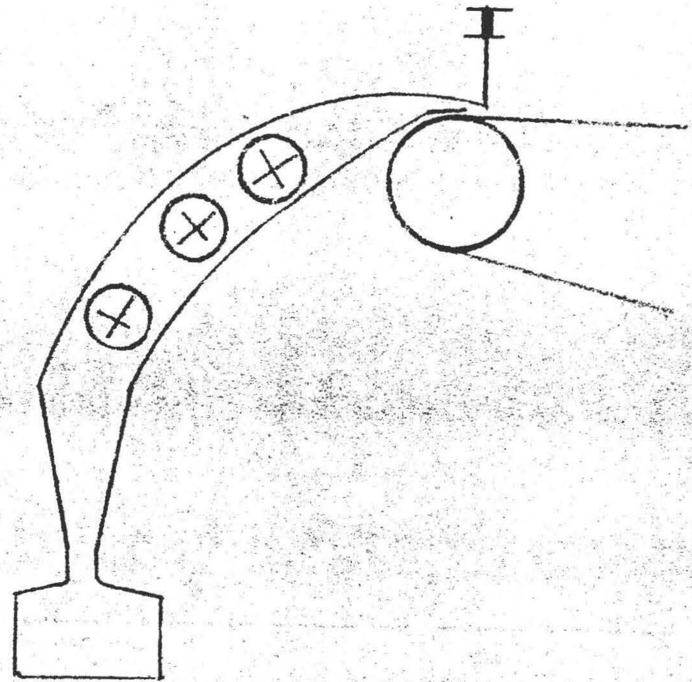


FIG. 6
Voith flow nozzle (newer type)

SLICE DESIGNS FROM PAPERMAKING ASPECT

If a paper machine without a flowbox of some type is ever invented, the operators will no longer know on what to blame the faults in the paper. As long as the flowbox and slice are tools of papermaking, it is not likely that paper will be produced without faults. There are two types of fault in the finished sheet that can be traced back to the slice. These are differences in the basis weight on an absolutely dry basis, and a non-ideal orientation of the fibers.

The efflux from a slice should be not only at constant velocity, but also with the suspension in a constant direction, this direction being the machine direction. If these two conditions are not fulfilled, the fault may be either in the headbox or on the slice. Two sorts of deviation from the normal jet plane may be observed.

1. Deviations at a constant position.
2. Deviations which wander from one edge of the machine to the other.

The deviations referred to in number 2 above are the result of large scale turbulence

in the headbox, causing the flow to reach the slice with an uneven velocity. This is quite likely to happen when the front wall of the headbox is vertical and the tendency can be lessened by giving the front wall an angle of approximately sixty degrees.

The deviations at a constant position are slice faults and include:

1. Dirty places on the slice lips.
2. The ends of the slice lips not sharp.
3. Irregularities of the form of the slice plates.

THE JET ON THE WIRE

The jet should strike the wire over the whole machine width exactly the same distance from the centerline of the breast roll at the same angle with the wire and parallel to the counterline of the machine. An even thickness of jet is also essential. If the jet does not strike the wire in this manner, the result is an earlier dewatering at the points where the jet strikes first. At these points the stock layer on the wire becomes thinner and the stock from the sides flows into them, resulting in a thicker place further down the wire.

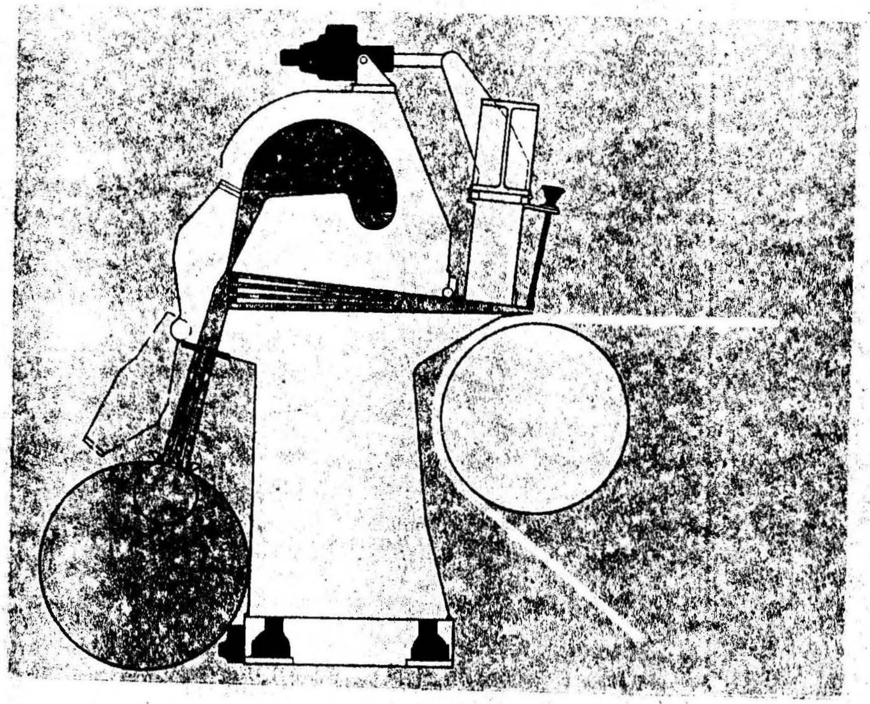


FIG. 7

Voith-Allis High Turbulence Headbox

It is equally important that there is no distortion of the top lip and it is thus of the utmost importance that operator correction of the slice opening be kept at a minimum. The practical result of this is that for a slice with a flexible top lip, the point of bending must be as far back as possible and the rest of the top lip must be stiff.

EXPERIMENTAL PROCEDURE TO BE USED

Since it would be impossible to design and build more than one headbox from both the standpoint of economics and time, only one headbox will be designed. This headbox will be designed with the best features found in the foregoing sections of this paper. This headbox will be one in which several options may be used so that the best possible combination of entry header, flowbox proper, use of perforated roll, and slice design.

Due to the slow speed of the pilot machine, a pressure type unit using negative pressure, i.e. vacuum, will be designed. By doing so, the box will be able to develop enough liquid level in order to make efficient use of the perforated roll.

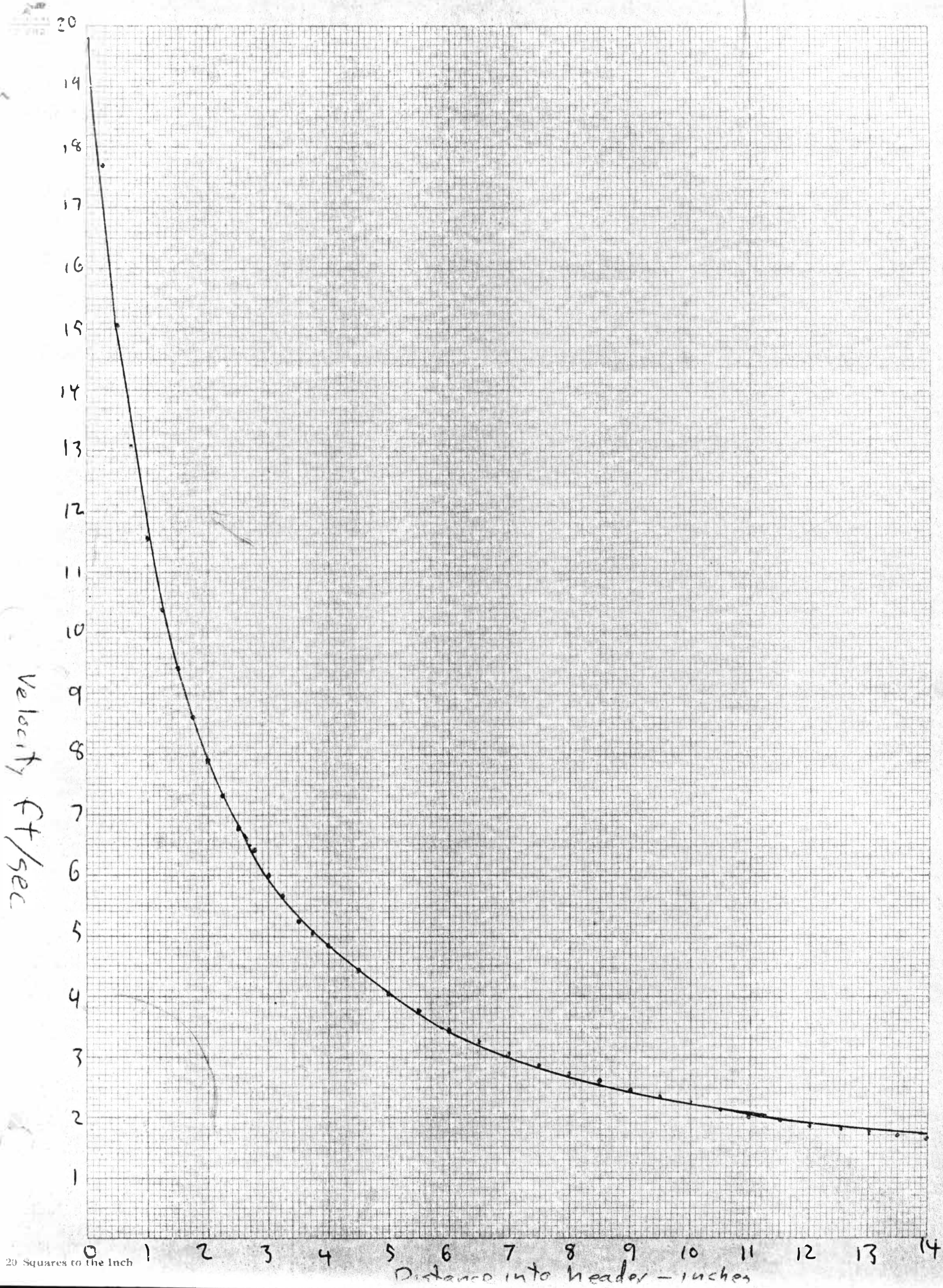
DESIGN PROCEDURE

Once the basic design ideas have been formulated, the first step in the design procedure was to measure up and sketch the area of the wet end of the machine around the headbox. The main reasons for this first step are as follows:

1. To find the space limitations in the area to be changed.
2. To assure proper fit of the headbox and associated equipment to the machine once it has been constructed. The best equipment is of little value if it does not fit.

The next step in the procedure was to make sketches of the selected design types to which of the types best fitted the space and would best suit the machine conditions to be encountered. These sketches will not be included in this paper. It was known from the start that the design selected must accomplish the following:

1. To improve the velocity profile through the headbox in order to keep the stock from flocculating. See graph 1.
2. To move the perforated roll down to a point where it would be more in the mainstream of stock flow or to move the stock flow to the area where the perforated roll is to be, or a combination of both.


20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Velocity ft/sec
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Distance into header – inches

Since space limitations did not allow moving the perforated roll completely into the stock flow it was decided to move it down far enough to make for the most simple and easiest installation of the drive components for the perforated roll, then to close the headbox and use a vacuum to get enough head to completely cover the roll during operation. Now that it was known that a vacuum must be used and that the velocities would be slow, it was decided that the stock should have to flow through the perforated roll in making its way to the slice opening and that the distance between the roll and the slice opening be as short as possible.

The third step in the procedure was to draw up a set of scale drawings of the headbox, its individual components and the perforated roll drive mounting. A complete set of blueprints of these drawings is included in this paper while the original drawings will be on file with the Director of Pilot Plant Operations. Please see drawing index.

The final step is to decide on the materials for construction. Since the machine is experimental in nature, it would be a logical choice to use a material that would allow it to be known what is going on inside the headbox while it is in operation,

thus clear acrylic plastic i.e. plexiglas was chosen with all seams cemented together with acrylic cement. The existing slice adjustment assembly was found to be the most economical consideration since it both operates correctly and will fit the installation quite well with few modifications. The perforated roll drive mounting is to be fabricated of mild steel - welded construction.

ASSEMBLY INSTRUCTIONS

The first step in assembly of the headbox is to construct all parts as detailed in drawings B-2-A through C-11 and B-13. Please note that material for construction of the headbox is to be plexiglas with all seams to be glued while the drive mounting for the perforated roll is steel plate welded.

Once all parts have been fabricated, construction may begin. First assemble the inlet header as shown on drawings C-1-A and C-1-B using the top, bottom, sides, connecting flange, top brace, bottom brace, flow splitting plate and flange braces. All joints should be glued together, being careful to hold to the dimensions shown. Next the rear dam and holey roll housing may be glued in place. After the glue joints

are solid, the end plates should be glued in place, being careful to avoid any gaps in the joints which may cause leaks. The apron board and bottom support may also be glued in place at this time.

The next item to be fabricated is the slice, using the following parts which have already been built; slice,slice brace, slice end seals, front dam and hardware from old slice. The hardware is glued to the slice as shown on drawing C-11 and the slice brace fitted and glued in place. The slice end seals may now be fitted into place and glued with the beveled edges down toward slice and leaving a small slot in which "O-Ring" material size 1/8 inch diameter is glued as to make a seal. Next, the front dam is glued to the back (beveled edge) of the slice and slice brace.

The whole slice assembly with front dam in place may be glued to the headbox assembly being careful <u>not</u> to glue the seal ends of the slice to the end plates. After the slice assembly is solidly in place, the top seal plates (sides and ends) and top hold-down braces may be glued in place, being sure to keep the beveled edges of the seal plates to the outside

of the headbox so as to leave a slot all around the top, in which 1/8 inch "O-Ring" material is to be glued for a top seal.

The headbox is now ready for installation on the machine. The old headbox should be removed along with all associated equipment so that the framework is accessible. The perforated roll, its bearings and seals should be removed from the old headbox and installed on the new headbox. After the old headbox and associated equipment have been removed, the frame should be drilled to accept the new headbox and holey roll drive mounting plate as shown in drawings C-1-B and C-12 respectively, and the new headbox installed. Some shimming may be required to get the apron board parallel to the breast roll and in the proper position. The holey roll drive mounting place may also be bolted into place at this time.

With the headbox secured in place, the piping from the fan pump to the inlet flange may now be field fit into place and the holey roll drive motor and gear box installed. A vacuum pump and piping to the top of the box from the vacuum pump should now be installed using flexible hose so the top of the headbox

may be removed and replaced with ease. A vacuum bleed valve should be installed in an easily accessible location for adjustment of the head in the headbox.

The headbox should now be ready for operation. The operation is basicly the same as before with the exception of being much more versatile.

DRAWING INDEX

REFERENCES

1. MASON, S.G. "Some Factors Involved in the Flocculation of Pulp Suspensions and the Formation of Paper". Pulp & Paper Magazine of Canada, Vol. 51, No. 10, p. 94 (Sept. 1950).
2. MASON, S.G. and HUBLEY, C.E., "Flocculation in Suspension of Large Particles". Canadian Journal of Research. Section B 28, p.770 (1950).
3. MASON, S.G., "Fibre Motions and Flocculation". Tappi Vol. 37, No. 11, p. 494 (Nov. 1954).
4. MARDON, J., O'BLENES, G., and WAHLSTROM, P.B. "The Hydrodynamics of Paper Machine Headbox Approach Piping". Pulp and Paper Magazine of Canada, Vol. 59 No. 4, pp. 139-170, (April, 1958).
5. McCABE, W.L. & SMITH, J.C., Unit Operations of Chemical Engineering, McGraw-Hill, New York. Second Edition., pp. 47-119.
6. FISHER, J.M., "A Study of Holey Roll Streaks and Their Relation to Holey Roll Design and Operation". Mead Research Laboratories, (July 8, 1959).
7. BREWDEN, H.A. & LOCKING, B., "New Developments in Paper Machine Headbox Design & Equipment". Paper Trade Journal, Vol. 144, Nos. 31, 32, 33., pp.36-42, 24-29, 38-44.
8. STEWART, A.E., "New Developments in High Speed Paper Machines". Pulp and Paper Magazine of Canada. Vol. 51, No. 12, p. 131 (Nov. 1950).
9. VanDerMeer, W. "Hydraulics of Flowbox & Slice". Tappi, Vol. 37, No.11, p.502 (Nov. 1954).
10. NEWCOMBE, DOUGLAS P., District Manager, VOITH-ALLIS INC. (Conversation & Voith-Allis Literature)