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Delekto et al.

[11] **3,802,966**

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[54] **APPARATUS FOR DELIVERING A FLUID SUSPENSION TO A FORMING UNIT**

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[21] Appl. No.: **244,591**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 852,214, Aug. 22, 1969, abandoned.

[52] **U.S. Cl.** **162/343,** 162/303, 162/345
[51] **Int. Cl.** **D21f 1/02**
[58] **Field of Search** 162/336, 338, 343, 203, 162/303, 345

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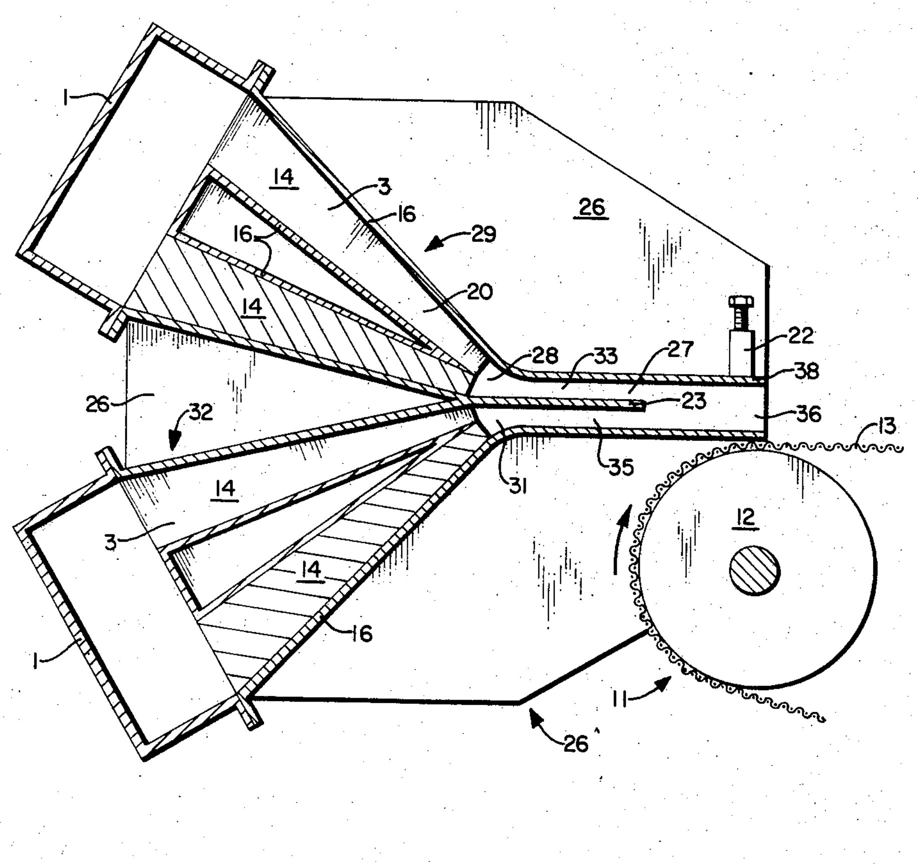
[57] **ABSTRACT**

This disclosure relates to flowboxes including headboxes and other apparatus for delivering solid-containing suspensions to forming units of papermaking or similar machines. The flowbox receives the suspension from a supply conduit and delivers it to the forming unit as a jet having the desired configuration, required speed and adequate distribution of solids by employing a controlled flow pattern through the flowbox. Preferably two banks of elongated channels having varying cross sections are positioned in the flowbox to provide a plurality of streams discharging from each bank which intercept at an acute angle and merge together within a discharge passageway to form a single jet which is discharged to the forming unit.

11 Claims, 7 Drawing Figures



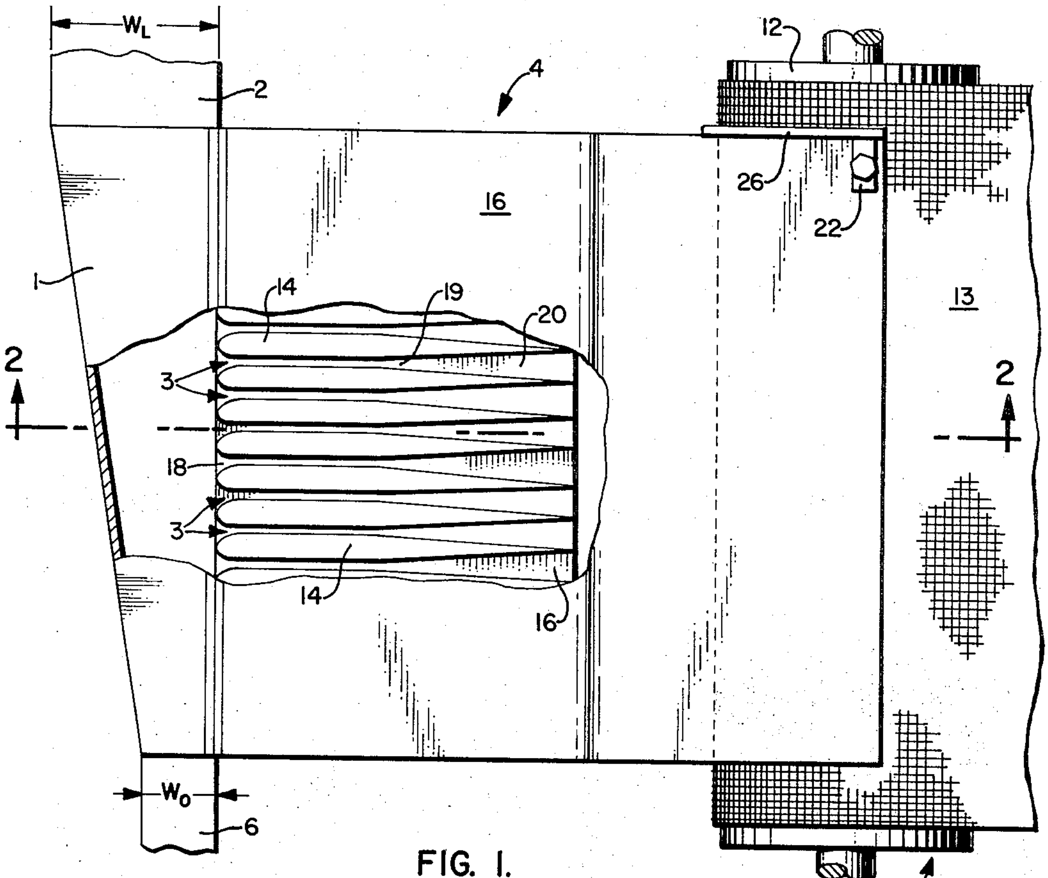


FIG. 1.

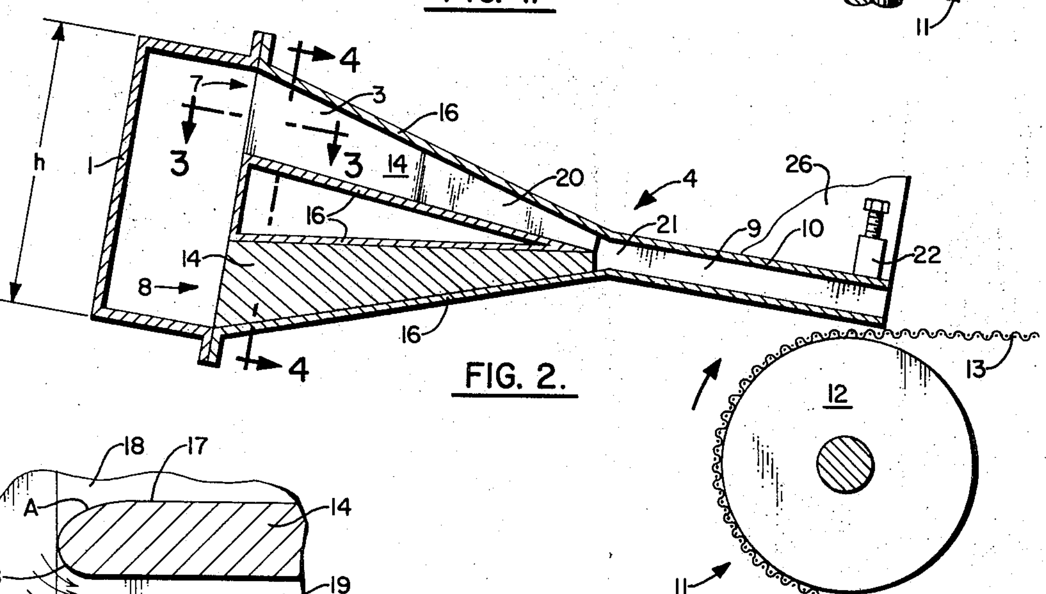


FIG. 2.

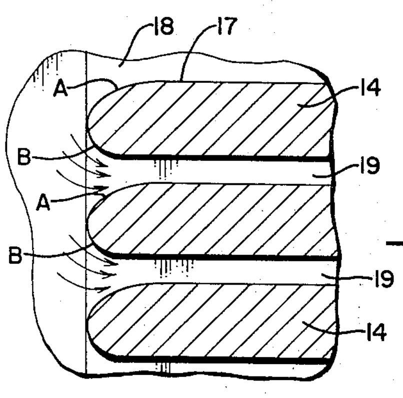


FIG. 3.

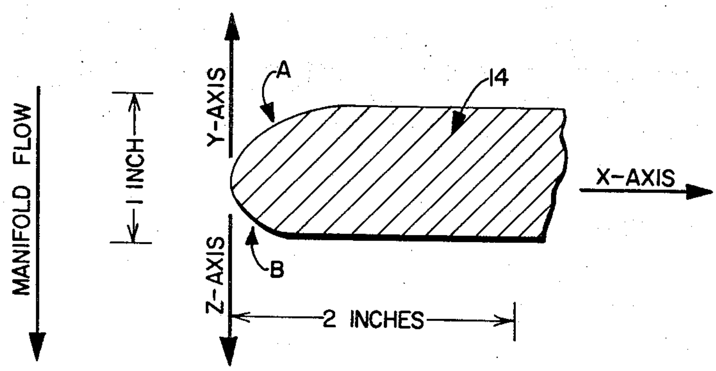


FIG. 3A.

CURVE SURFACE B IS DEFINED BY THE EQUATION:

$$Z = B\left(\frac{\tan^{-1} X}{23.0}\right) + (1.0 - B)\left[3.52 \log (X+1)\right]$$

WHERE: $0.00 \leq X \leq 10.00$ AND $0.00 \leq B \leq 1.00$

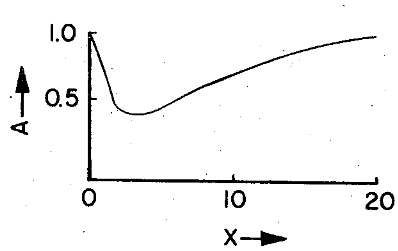
B PREFERRED = 0.50

CURVED SURFACE A IS DEFINED BY THE EQUATION:

$$Y = A\left(\frac{\tan^{-1} X}{13.7}\right) + (1.0 - A)\left[4.79 \log (X+1)\right]$$

WHERE: $0.00 \leq X \leq 20.0$ AND $0.00 \leq A \leq 1.00$

BUT, PREFERRED A RELATED TO X IS SHOWN BELOW



(UNITS FOR X,Y, AND Z ARE IN TENTHS OF INCHES)

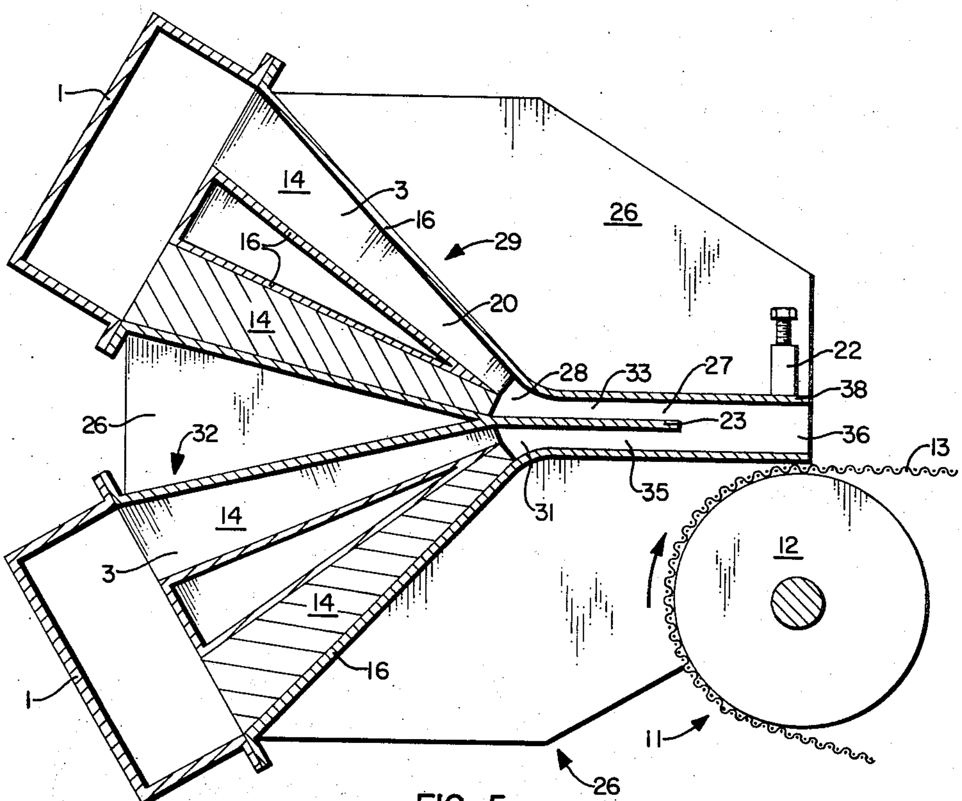


FIG. 5.

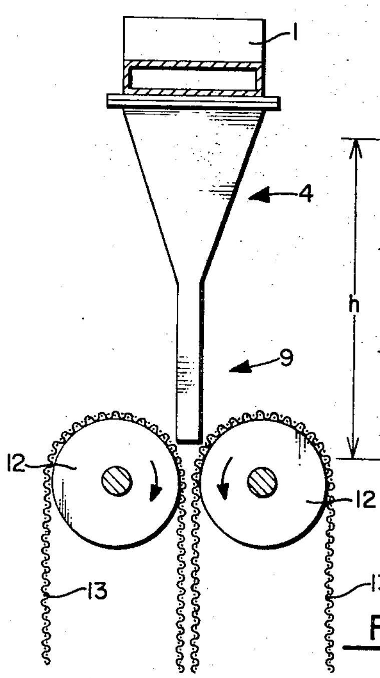


FIG. 6.

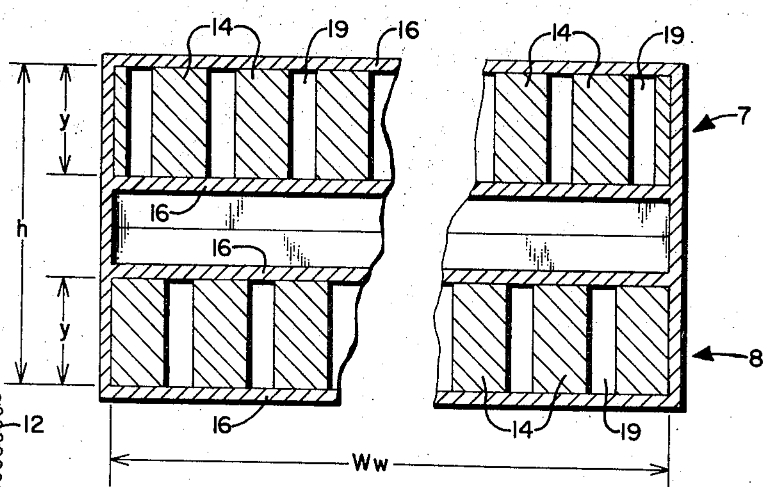


FIG. 4.

APPARATUS FOR DELIVERING A FLUID SUSPENSION TO A FORMING UNIT

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of prior application Ser. No. 852,214, filed Aug. 22, 1969, now abandoned.

BACKGROUND OF THE INVENTION

In the manufacture of paper and other web materials liquid suspensions including fibers or other solid materials are required to be delivered to the mat or web forming unit in a jet of selected configuration, at a desired speed and with the solids properly distributed therein. It is important that the suspension be deposited on the wire of the forming unit in properly dispersed condition to obtain a uniformly formed web with good formation, i.e., provide a uniform distribution of fibers, filler particles and other additives throughout the sheet. The principal difficulty in achieving this is the natural tendency of the fibers to flocculate or agglomerate while suspended in water at the concentrations normally used for papermaking.

These concentrations usually range from less than 1 percent to about 5 percent solids. Therefore even though there is uniform flow by volume to the forming unit, there may still be unacceptable variations in the weight and thickness of the mat due to this agglomeration of fibers during their travel through the headbox or flowbox. Some form of agitation or turbulence must be employed in the distribution system to overcome this. However, the agglomeration of fibers is highly dependent upon the shear rate and may be promoted by eddies and vortices caused by anomolous shear fields in the suspension as it is delivered to the forming unit. Therefore, the turbulence or shear used in the distribution system must be carefully applied.

The distribution system must deliver a flow to the forming section which is:

a. Uniform across the entire width of the paper machine.

b. Uniform in the machine direction, i.e., constant with time.

c. Free of fiber flocs or agglomerates.

These requirements are common to all types of papermaking equipment including Fourdrinier, certain cylinder and twin wire machines. These requirements are compounded as greater productivity and quality requirements are realized or encountered such as:

a. Increasing roll size (to reduce handling requirements and to increase pressroom efficiency) requires more uniform paper to obtain good roll condition.

b. Increasing printing press speed which can tolerate fewer variations in sheet strength.

c. Increasing print quality requirements which place greater demands on paper surface uniformity.

d. Increasing paper bulk so that lighter weight sheets can be used to offset postal and shipping costs precludes the use of calendering to reduce surface non-uniformities.

The distribution systems, e.g., headboxes or flowboxes designed and used to date represent a compromise between uniform flow and deflocculation of the fibers. They employ various forms and combinations of perforated rolls, plates, baffles, rods, etc., to introduce

turbulence in the flow to minimize floc generation and disrupt existing fiber flocs. Unfortunately, these devices also disrupt the desired uniformity of flow resulting in swirls or eddy currents which result in non-uniform flow across the machine direction resulting in variations in the weight distribution of the fibers. Also, these flow interruptions produce discontinuities, stagnation points, air pockets, etc., in the box permitting accumulations of fibers, slime deposits, etc., requiring frequent cleaning.

In some cases the first part of the Fourdrinier forming section is used to deflocculate the fibers in the flow coming from the headboxes. However, the use of twin wire formers require that the flow be frozen essentially in the same form as it emanates from the headbox precluding the use of the forming section for deflocculation.

Recently headboxes have been introduced which confine the flow in localized bands across the width of the machine to minimize gross lateral instabilities such as the use of bunched tubes, and other flow dividers such as a plurality of plates, rods, filaments, etc., in the flow direction. However, these fail to satisfactorily reach the desired objectives.

OBJECTS OF THE INVENTION

Some of the objects of our invention are to:

a. Provide a headbox which will produce a homogeneous, stable flow of stock (water, fiber, filler particles, and other additives) to the papermaking forming section without the presence of fiber flocs.

b. Provide a headbox that operates without gross turbulence, has good jet stability in the machine direction and has inherently good cross machine distribution.

c. Provide a headbox that permits operational control and flexibility when desired, but requires a minimum of operator adjustments.

d. Provide a headbox with no internal moving parts requiring maintenance.

e. Provide a headbox with no internal air pockets or stagnation points, which result in the buildup of slime deposits requiring internal showers.

f. Provide a headbox with stream-lined flow that prevents fiber hang-ups and slime deposits and is self-cleaning.

g. Provide a headbox that has inherently good formation in the stock flow emanating from the box so that the forming section does not have to be used to deflocculate fiber networks.

h. Provide a headbox that can be used with Fourdrinier, certain cylinder and twin wire machines.

i. Provide a headbox that is small, compact and lightweight for ease of installation.

j. Provide a headbox that is simple in design and construction and that is easy to fabricate (machine, mold parts, and assemble) and is low in cost.

k. Provide a headbox which by virtue of its size, configuration and jet flow characteristics can be used in multiples of two or more to provide a layered sheet of paper with different fibers in the various layers.

SUMMARY OF THE INVENTION

The flowbox of the present invention provides a flow pattern which develops proper shearing forces to create and maintain desired solids distribution in the stock. The present flow-box uses one or more banks, preferably two, of elongated flow channels to control the shearing forces in the flowing stock and employs a novel configuration for the entrances to these channels to prevent fiber buildup.

Broadly, the present invention comprises an apparatus for delivering a solid-containing suspension to a forming unit which includes a supply header for supplying stock at a substantially constant pressure, one or more banks of elongated channels conducting stock from the header and a discharge passageway connected to the banks of elongated channels and having an inlet portion for receiving the plurality of exiting streams of stock and forming therefrom a jet of stock and having an outlet portion for discharging the jet to a forming unit.

It is also a feature of the invention that the plurality of streams flowing in the channels intercept and merge in the inlet section of discharge passage of the flowbox without the creation of agglomerate-forming turbulence or vortices.

The headbox or flowbox of the present invention utilizes the principles of hydrodynamics and stream-line flow to deliver a stable jet of stock of uniform velocity to the forming section. Controlled laminar shear is used to break up and prevent fiber flocculation. This laminar shear is obtained by continually accelerating the stock from the manifold or inlet aperture to the slice or exit aperture. The stock is accelerated by forcing it through a plenum which uniformly decreases in cross-sectional area perpendicular to the flow direction. The width of the plenum is essentially equal to the width of the forming section of the paper machine. The decrease in cross-sectional area is obtained by decreasing the height of the plenum. Gross lateral instabilities are avoided by confining the flow in a series of narrow channels across the plenum by the use of flow dividers, the channels being essentially parallel to the flow direction. We shall refer to this subdivided plenum as a bank of channels.

The stock enters the headbox inlet or aperture from a manifold, preferentially one of advanced tapered rectangular design of decreasing cross-sectional area, so that uniform pressure is provided along the entire width of the inlet aperture of the headbox. It is customary to use an oversized manifold so that the flow of stock through the manifold is greater than that through the headbox with the excess stock being drawn off from the end of the manifold and recycled.

The stock flows through the manifold across the machine, i.e., in a direction essentially perpendicular to the flow of stock through the headbox. Thus, the flow of stock must turn approximately 90° from the direction of flow in the manifold to the direction of flow in the plenum of the headbox. It is difficult to make this approximately ninety degree transition in flow direction smoothly with uniform flow of fiber suspension across the entire width of the paper machine. The prior art use of rectangular shaped flow dividers in the plenum to obtain uniform flow rate across the width of the machine results in unwanted turbulence and eddy currents as the direction of stock flow is being changed by about 90° at the entrance ports. These dividers also provide stagnation points and sharp corners permitting fibers to hang-up. We have unexpectedly found that the desired streamlined flow characteristics can be obtained by using flow dividers or vanes having a cross-section similar to the cross-section of an airplane wing. The vanes of the present invention, after an initial length of constant width immediately following the asymetrically curved nose section, gradually taper down to a feather edge as the parallel flows of stock are merged at the exit of the plenum. Thus, the open area of the individual channels decrease in height and increase in width simultaneously, with the decrease in height being slightly greater than the increase in width so that the desired decrease in cross-sectional area is obtained perpendicular to the flow direction to achieve the desired continual acceleration and laminar shear necessary to break up and prevent fiber flocs.

The rounded blunt ends of the vanes or channel dividers of the present invention are presented to the incoming stock thereby preventing fiber buildup (long cotton linters have been run through a box of this type without any fiber hang-ups and with gas and dispersion).

Stock flows through the tapered manifold, smoothly turns an essentially 90° corner assisted by the hydrodynamics of the vane configuration and is accelerated by virtue of decreasing cross-sectional area through the channeled plenum where it is spread out and then is uniformly deposited onto the sheet forming section with the desired random fiber orientation without the presence of undesired fiber floc.

The preferred form of our invention uses two banks of channels superimposed one over the other and oriented so that the stock flows from the two banks merge at an acute angle (for example, 11°) into a common plenum of decreasing and adjustable cross-sectional area referred to as a discharge passageway from which it is extruded into the forming section. The flow of stock from the two banks of channels merge in the discharge passageway without turbulence or altering the flow uniformity of each bank. The banks are laterally offset approximately one-half the width of the individual channels so that the vane tips of one bank are located at the center of the channels of the other bank and vice versa to smooth out any slight discontinuity in flow at the feathered vane tips as the stock from the separate small channels merge. More than two banks of channels may be employed in practicing the present invention, if desired.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, FIG. 1 is a plan view, partially cutaway, of the flowbox apparatus of the present invention positioned to discharge onto a horizontal mat forming wire; FIG. 2 is a sectional view taken along line 2—2 of FIG. 1; FIG. 3 is an enlarged sectional view taken along line 3—3 of FIG. 2; FIG. 3A is a further enlarged view of one of the vanes in FIG. 3 showing the basis for the mathematic definition of the curve shapes; FIG. 4 is a broken sectional view taken along line 4—4 of FIG. 2; FIG. 5 is another embodiment of the apparatus of the present invention in which two pairs of banks of channels are used; and FIG. 6 is a side elevational view of the apparatus of the present invention with the apparatus located to discharge stock between vertically-positioned twin forming wires.

Referring now to FIGS. 1 and 2, the headbox, designated generally by the numeral 4, is positioned to deliver paper stock to the forming section, designated generally by the numeral 11. The headbox is fed by a tapered manifold 1. The headbox includes two banks of channels 7 and 8 with rounded divider vanes or flow separators 14 which divide the flow into a series or bank of channels 3. As seen in FIG. 2 the upper and lower banks of channels or plenums 7 and 8 open into the manifold 1 at their forward ends and open into the inlet portion 21 of the discharge passageway 9 whereby the stock is fed onto the forming wire 13 carried by roll 12.

Fibrous paper stock is pumped into tapered stock manifold 1 through stock inlet conduit 2 and the excess stock which does not flow into the channels 3 of the flowbox 4 continues on out through stock outlet conduit 6 where it is recirculated back into inlet conduit 2. Stock manifold 1 is tapered for the purpose of achieving a relatively constant pressure throughout the length of the manifold, substantial amounts of the entering stock being continuously drawn from the manifold as the stock flows toward outlet conduit 6. Since the volume of stock reaching the smaller end of the manifold is considerably less than the entering volume, the cross section of manifold is required to be tapered or reduced to achieve the desired constant pressure which assists in the desired uniformity of stock flow into the flowbox channels 3.

Channels 3 are arranged in upper and lower banks 7 and 8, respectively, which channels are positioned across the width of the box with their inlets spaced apart by the thickness of the vanes 14 and their outlets merging to permit the streams of stock flowing in each bank of channels to flow against one another and merge while the upper and lower streams intersect at an acute angle and merge to form a single stream or jet of paper stock. The jet is then carried in flowbox discharge passage 9 to the forming wire 13 of the forming unit 11. Passageway 9 has a width substantially equal to the width of the mat to be formed. If it is desired to make the passageway 9 slightly converging toward its open end, upper wall 10 can be moved downward using adjusting means such as the screw jack 22.

Channels 3 of banks 7 and 8 are defined by the sides of flow separators 14 and the channel bank walls 16—16. Flow separators 14 have curved entrance-forming sections 17 (FIG. 3) to assist the stock in changing direction and entering channels 3 without significant turbulence or fiber buildup on the forward ends of the separators 14. Entrance-forming sections 17 include vertically-disposed convex surfaces A generally facing the direction from which the stock flows and surfaces B generally facing away from the stock flow. Surface A which is larger than surface B is shaped and positioned to provide the desired stock flow characteristic into the channel immediately ahead of it.

The cross-sectional configuration of each channel 3 is rectangular throughout its length and has different proportions and area at various positions along its length. The channels may have a cross-sectional configuration other than rectangular but a rectangular shape is preferred because the streams merge with less interference. The blending of a plurality of round cross-sectional streams, for example, would leave open spaces between them into which the stock would immediately flow causing interference in the desired flow pattern. Starting at the entrance to the channel and moving in the direction of stock flow, it is seen that the cross-sectional area steadily decreases in the entrance section 18 which section is partially defined by surface A of one separator and surface B of an adjacent separator. After passing surfaces A and B, the channel continues to converge but at a less rapid rate. The convergence of this intermediate section 19 is accomplished by the sloping of walls 16—16 leaving the parallel channel side walls to provide a stabilizing effect on the stock which travels straight a short distance after having changed direction as it entered the channel. The stream continues to accelerate as the channel converges and the shearing action of the fluid moving in an elongated channel holds the fibers in proper suspension. The length of section 19 may vary, but a length of about ten times its width is preferred.

Following intermediate section 19 the stock moves into the diverging-converging section 20 where the vertical walls of the vanes 14-14 diverge while the upper and lower walls 16—16 continue to converge. In this section, the rectangular cross-sectional configuration of the stream is changed by reducing its height and increasing the width; however, as the proportions of the cross section are changed, the area is steadily reduced in size for the purpose of continuing to accelerate the stream as it moves toward the inlet portion 21 of the discharge passageway 9. The diverging angle of the vertical walls of the vanes in section 20 should be less than about 15° to avoid separation of the fluid from the wall. An angle of about 8° is preferred.

The plurality of channel streams of paper stock in each bank 7 and 8 merge as they reach the end of the channels by the sides of each stream engaging the sides of the adjacent streams. The upper and lower bank of streams then immediately merge with one another to form the composite integral jet of stock which flows the length of the discharge passageway 9 where further shearing action will occur to assist in maintaining proper solids distribution in the flowing stock. The merging of the upper and lower streams is assisted by the staggering of the individual streams in that a stream from upper bank 7 is not directly above a stream from lower bank 8 (see FIGS. 2 and 4). The jet is then discharged from the passageway onto moving forming wire 13. The angle of discharge may be varied by changing the attitude of the flowbox by conventional means (not shown).

Referring now to FIG. 5, two headboxes, designated generally by numerals 29 and 32, are combined to form a layered sheet. The numbers corresponding to those used in the earlier figures are used where appropriate. Two pairs of channel banks are combined and connected to dual passageway 27 to form a flow-box which is in turn mounted on frame 26. Dual passageway 27 has an upper entrance portion 28 for receiving converging streams of stock of one type from the upper headbox 29 and lower entrance portion 31 for receiving converging streams of stock of a second type from the lower headbox 32. A divider strip 23 is employed to keep the flows of stock, which may be different, from the two headboxes separated until the flows are parallel and stabilized.

Streams converging in portions 28 and 31 flow through upper and lower passageway flow sections 33 and 35, respectively, before entering the discharge section 36 of passageway 27. The entrance portions 28 and 31 and flow sections 33 and 35 are separated by baffle 23. Sections 33 and 35 are of sufficient length and uniformity of cross section to cause the flow of stock in these sections to stabilize sufficiently so that as the flow from the sections 33 and 35 enters discharge section 36, the two streams of stock substantially maintain their integrity, one flowing as a layer on top of the other through the remainder of passage 27 and onto the wire 13. Discharge section 36 may be made a converging passage by deflecting downward its upper wall 38 using screw jack 22.

Multilayer paper may be produced using the flowbox apparatus shown in FIG. 5; for example, upper banks 29 may supply short fiber stock and the lower banks 32 supply a long fiber stock to provide a web comprising one-half long fiber stock and one-half short fiber stock. It is also contemplated that three or more different stocks may be supplied to a discharge passageway having an entrance and a flow section for each stock to produce three or more layers of the differing stock in the paper web. The stability of the stream just prior to its discharge onto the wire, whether the stream is multilayered or single layered, is attributable in part to the flow pattern of numerous streams in the banks of channels 3, the non-turbulent merger of the streams in portions 28 and 31, and the stabilized flow in passageway sections 33 and 35.

Referring to FIG. 6, the headbox apparatus 4 of FIGS. 1–3 is shown discharging stock downwardly between two wires 13 and 13*a*. The apparatus of the invention, including the embodiment of FIG. 5, is useful in supplying stock at any angle to the forming wire, such as horizontally or vertically, as illustrated, or at any other desired angle.

In order to more completely describe the preferred embodiment of our invention, we refer again to the drawings, FIGS. 1, 2, 3, 3A and 4. The overall size and relative geometry of the components are dictated by the intended end-use application as shown in the following mathematical derivations. The following definitions are used:

Wi = width of manifold inlet (ft.), see FIG. 1
Wo = width of manifold overflow (ft.), see FIG. 1
h = height of manifold (ft.), see FIG. 2
Vm = stock velocity in manifold (fpm)
Vw = velocity of stock delivered from headbox to the forming section (fpm)
Ww = width of stock flow delivered to forming section (ft.)
B = basis weight of dry web formed lbs./ream or lbs./3300 ft.^{2}
R = retention, e.g., that portion of the solids content of the stock that is retained in the formed web
C = consistency of the stock slurry, e.g., the solids portion of the stock
d = density of stock slurry (lbs./ft.^{3})
Z = overflow = ratio of stock volume rate of flow through manifold outlet divided by stock volume rate of flow at inlet
a_h = acceleration of stock through headbox defined as:

$$a_h = Vw/Vm$$

a_d = acceleration of stock in discharge passageway (No. 9)
a_b = acceleration of stock in bank of channels (Nos. 7 and 8)
a_m = acceleration of stock in merge area of banks of channels (No. 21)
A_h = entrance area of headbox
A_m = entrance area of manifold
F = flow rate of stock through headbox (ft.^{3}/min.)

The first step in designing a headbox according to our invention is to establish the normal or average flow rate (F) which is given by the following expression:

$$F = (Vw) \times (Ww) \times (B)/(C) \times (R) \times (d) \times (3300)$$

This flow rate equals the flow rate at the manifold inlet less overflow rate, or:

$$F = (Am) \times (Vm) \times (1 - z) \quad (1)$$

By combining and rearranging terms we obtain the following relationship:

$$A_m = (Vw) \times (Ww) \times (B)/(Vm) \times (C) \times (R) \times (d) \times (3300) \times (1 - Z) \quad (2)$$

For practical purposes, we can treat C, R, d and Z as constants specified by one familar with papermaking practices and skilled in the art and rewrite the above equation (2) as follows:

$$A_m = k \times [(Vw) \times (Ww) \times (B)/(Vm)] = k \times (a_h) \times (Ww) \times (B) \quad (3)$$

It is customary to design tapered rectangular manifolds with a height 1.5 times its inlet width, e.g.:

$$h = 1.5\ Wi \text{ or } h/Wi = 1.5$$

Other height to width ratios are permissible, but the 1.5 ratio is preferred. Since the area of the manifold inlet is equal to the product of its height and width, i.e.:

$$A_m = (h) \times (Wi)$$
$$= 1.5\ (Wi)^2 \text{ or } Wi = \sqrt{Am/1.5}$$
$$= (h)^2/1.5 \text{ or } h = \sqrt{1.5\ A_m}$$

Therefore equation (3) can be rewritten as:

$$Wi = \sqrt{(k) \times (a_h) \times (Ww) \times (B)/1.5} = k' \sqrt{(a_h) \times (Ww) \times (B)} \quad (4)$$

or:

$$h = \sqrt{1.5 \times (k) \times (a_h) \times (Ww) \times (B)} = k'' \sqrt{(a_h) \times (Ww) \times (B)} \quad (5)$$

Practice has shown that the stock flow rates in the manifold should be in the range of 5–10 ft./sec. (Vm = 300–600 fpm). A larger range is permissible, but at lower flow rates, the level of fiber flocculation becomes objectionable and at higher rates, it is more difficult to divert the stock flow essentially 90° from the flow direction in the manifold to the flow direction in the headbox. In practice it is common to control through put of the system by varying flow rate in the manifold over a portion of the 5–10 ft./sec. range although normally it would be centered about the midpoint or 7.5 ft./sec., i.e., Vm = 450 fpm ± 150 fpm.

In our invention, upon leaving the manifold, the stock is continually accelerated through the banks of channels 7 and 8 and through the discharge passageway 9. We have found that the acceleration factor through the banks of channels (a_b) should be 1.25 or larger. Smaller acceleration rates, i.e., approaching zero are permissible due to the converging-diverging nature of the channels, but optimum results are obtained at an acceleration rate of 1.25 or larger. Larger acceleration rates are employed in this section where high web velocities are desired for the forming section. We have found it desirable to have the merge area of the two banks of channels at the inlet portion 21 of the discharge passageway 9 slightly smaller than the combined exit area of the two banks of channels to provide an additional acceleration factor (a_m) of approximately 1.1. A larger or smaller acceleration factor in the region is permissible, but the 1.1 factor is preferred. We have also found that the acceleration factor in the discharge passageway (a_d) should be 1.6 or higher. The upper lip **10** of the discharge passageway **9** is adjustable preferably over a 2:1 range, i.e., $a_d = 1.6 - 3.2$. At so-called normal operating conditions (normal or average web speed and basis weight) the lip would be adjusted for the midpoint of its operating range, i.e., $a_d = 2.4$. The so-called normal acceleration a_h through a box such as described herein would be:

$$a_h = (a_b) \times (a_m) \times (a_d)$$
$$= 1.25 \times 1.1 \times 2.4$$
$$= 3.3$$

An example of the overall operating parameters for such a box is summarized in Table No. I.

Table I

Vm	a_d	V_w	B
300 fpm	1.6	660 fpm	1.33 B_n
	2.4	990	1.00 B_n
	3.2	1320	0.67 B_n
450 fpm	1.6	990	1.33 B_n
	2.4	1480	1.00 B_n
	3.2	1980	0.67 B_n
600 fpm	1.6	1320	1.33 B_n
	2.4	1980	1.00 B_n
	3.2	2640	0.67 B_n

where B_n = normal basis weight

Obviously as noted earlier, headboxes with either higher or lower speed capability can be obtained by designing channel banks with higher or lower acceleration factors (a_b). Obviously a headbox of a given design can be operated outside the range shown in Table I by either adjusting the manifold velocity outside the preferred 5–10 ft./sec. range and/or adjusting the discharge passageway outside the preferred 1.6 – 3.2 acceleration range.

The overall geometry of the headbox of our invention is designed consistent with equations (4) and (5) and other characteristics described below.

The length of the discharge passageway is preferably 14–16 inches. Other lengths are of course permissible.

The flow dividers **14** in the discharge passageway have rounded blunt ends with curve shapes A and B on the upstream and downstream sides respectively. These curves both facilitate the transition of stock flow through the essentially 90° turn from the manifold to headbox and prevent the accumulation of unwanted fiber bundles on the surface of the flow dividers. These curve shapes are defined in FIG. **3A**.

The vane dividers as seen in FIG. **1** have the previously described rounded blunt ends, followed by a straight section with parallel vertical walls, then the vanes taper down to a feather edge. The thickness of the vanes in the straight section is preferably 1 inch. Wider or narrower vanes can be used. However, extremely narrow vanes present problems with fiber hang-up at the entrance ports and minimizes the opportunity to utilize the benefits derived from simultaneous converging-diverging flow in the channel banks. Wider banks have the disadvantage of allowing greater cross machine direction or lateral flow instabilities for which the flow dividers are used to overcome. The length of the straight section of the vanes is preferably 3–6 inches. The total included angle of the taper of the vanes must be less than 15° and is preferably about 8°. The angle can be decreased and consequently the overall length of the vanes can be increased in order to fit other geometric requirements of the headbox.

The separation of the vanes or slot width **19** is preferably in the range of ⅜ to ⅝ inches. Narrower widths provide excessive shear with resultant undesirable fiber orientation and greater widths do not provide enough turbulence.

The height of the entrance channels **7** and **8** is predetermined by the flow rates desired through the box, the width of the flow channels **19** and the number of channels per bank. The total channel entrance area of the two banks (A_h) (excluding the effects of the rounded blunt vane ends) is equal to the entrance area of the manifold inlet less the overflow area of the manifold outlet.

Therefore:

$$A_h = A_m (1 - Z)$$

substituting in equation (3)

$$A_h = (k) \times (a) \times (Ww) \times (B) \times (1 - Z)$$
$$A_h = (k''') \times (a) \times (Ww) \times (B) \quad (6)$$

If we let:

Y = channel entrance height

t = channel bank entrance width correction factor which with 1 inch vanes ranges from 0.273 to 0.385 for channel slot widths of ⅜ to ⅝ inches respectively.

Therefore:

$$A_h = 2 \times (Y) \times (t) \times (Ww)$$

substituting in equation (6) and rearranging yields:

$Y = (k''') \times (a) \times (B)/(2) \times (t) = (k'''') \times (a) \times (B)/(t)$

where:

$$0.273 \geq t \leq 0.385$$

The angle of convergence of the tops and bottoms of the plenums **16** is set by design to achieve the desired acceleration factor in the banks (a_b) necessary to attain the desired normal web velocity Vw.

The two banks of channels **7**, **8** merge at an acute angle preferably 15°, but can range from 5° to 45°.

We claim:

1. In a headbox apparatus for delivering a layer of stock to a forming unit, the combination comprising:

a. means forming a flow divider section;

b. means in said flow divider section dividing said flow divider section into a plurality of banks of flow channels having progressively decreasing cross-sectional areas, said means including a plurality of laterally spaced apart immovable divider vanes within each of said banks of channels, said vanes having generally rectangular crosssections;

c. means forming a discharge passageway connected at its inlet end to the discharge end of said flow divider section; and

d. means forming a supply header connected to the inlet end of said flow divider section for supplying stock thereto, the major axis of said supply header being substantially perpendicular to the direction of flow in said channels;

said divider vanes having curved entrance-forming sections to assist the stock in changing direction as it enters said flow channels from said supply header, said banks of channels positioned at acute angles to each other such that they converge towards one another at the discharge end of said flow divider section.

2. The apparatus of claim **1** in which there are only two banks of flow channels.

3. The apparatus of claim **1** wherein the height of said flow channels progressively decreases from the entrance end of said flow divider section to the discharge end of said flow divider section.

4. The apparatus of claim **1** wherein each of said divider vanes in horizontal cross-section is convexly-rounded over its forward portion, substantially rectangular along its intermediate portion and inwardly tapered over its terminal portion.

5. The apparatus of claim **2** wherein said flow channels in one of said banks of channel are offset from said flow channels in the other bank of channel.

6. The apparatus of claim **2** wherein the height of said flow channels in both said banks of channels progressively decreases from the entrance end of said flow divider section to the discharge end of said flow divider section.

7. The apparatus of claim **2** wherein the height of said flow channels in both said banks of channels progressively decreases from the entrance end of said flow divider section to the discharge end of said flow divider section and wherein said flow channels in one of said banks of channels are offset from said flow channels in the other bank of channels.

8. An apparatus for delivering a solid containing suspension to a forming unit comprising

a. an elongated supply header with one end having a cross-sectional area of selected size which end has an inlet opening therein, a plurality of outlets along side portions of the header and an end opposite the first-mentioned end having a cross-sectional area smaller than the first end, the header having its side portions generally tapered along the length of the header such that the cross-sectional area of the header becomes generally smaller as the distance from the inlet is increased and the outlets in the side portions of the header being arranged in at least one pair of banks;

b. at least one pair of banks of elongated channels connected to and communicating with the banks of outlets in the header sides, the banks of channels in each pair of banks of channels,

i. having means defining a row of channels with curved entrance sections for assisting the suspension in changing its direction of flow as it leaves the header to a direction of flow down the channels without creating substantial turbulence and deposition of solids on the entrance sections;

ii. having said row of channels with outwardly tapered outlet portions so that the outlet portion of each channel is not separated from the outlet portion of adjacent channels;

iii. being spaced apart at the channel inlet ends and being positioned at an acute angle so that the banks of channels converge towards one another and are not spaced apart at the outlet ends and therefore each channel outlet is not separated from the adjacent channel outlet;

c. a discharge passageway positioned with its inlet coterminous with the outlets of said elongated channels for receiving the plurality of streams of suspension from said channels which passageway has a non-expanding generally constant cross-sectional area to maintain a stable flow pattern prior to discharge of the suspension to the forming unit.

9. The apparatus of claim **8** in which the elongated channels have cross sections which are steadily reduced in area throughout a portion of their length, moving in the direction of flow of the suspension.

10. The apparatus of claim **8** in which the elongated channels have rectangular cross sections in which the width increases and the height decreases moving in the direction of flow of the suspension.

11. The apparatus of claim **8** in which there is but one pair of banks of channels.

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