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Back et al.

[11] **3,853,695**

[45] **Dec. 10, 1974**

[54] **ENTRAINING A LIQUID INTO A FIBER SLURRY TO ACCELERATE IT PRIOR TO DISCHARGE FROM A FLOW PATH ONTO A FORMING WIRE**

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[21] Appl. No.: **437,112**

Related U.S. Application Data

[63] Continuation of Ser. No. 297,094, Oct. 12, 1972, abandoned.

[52] **U.S. Cl.** **162/216,** 162/104, 162/129, 162/336, 162/338, 162/343, 162/344, 162/347, 239/418

[51] **Int. Cl.** **D21f 1/02,** D21f 1/06

[58] **Field of Search** 162/216, 104, 129, 336, 162/338, 343, 344, 347; 239/418

[56] **References Cited**

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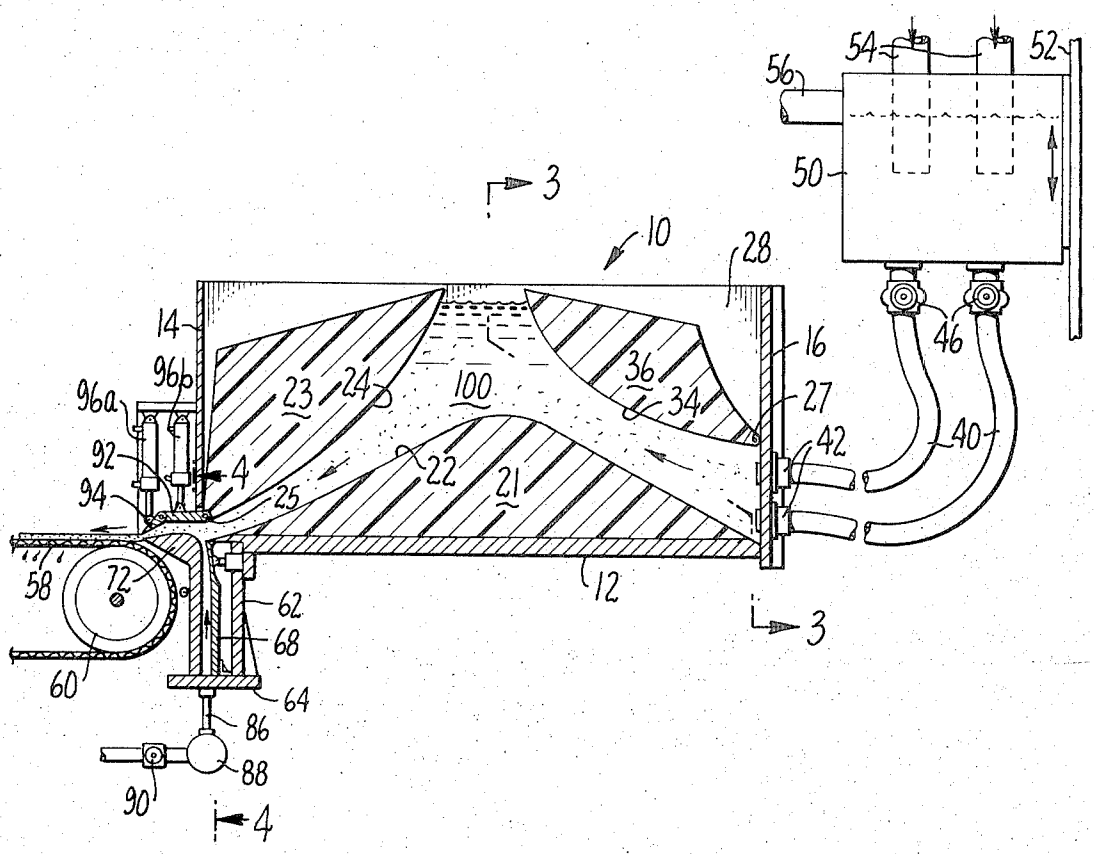
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Assistant Examiner—Richard H. Tushin
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[57] **ABSTRACT**

A slurry mixture of fibrous material and fluid is introduced into a predetermined flow path which leads to an exit aperture. A restricted opening preferably in the form of a slit is provided which communicates with the flow path at a predetermined location upstream from said exit aperture. An entraining fluid, such as clear or white water, is introduced through the slit and into the flow path whereupon the entraining fluid, due to a "Coanda effect," attaches itself to a convexly-curved flow attachment surface positioned adjacent to said slit whereby said entraining fluid flows along said flow path in a direction toward said exit aperture at a velocity substantially greater than the flow velocity of the slurry upstream from the slit. The entraining fluid accelerates the slurry and causes same to exit from the exit aperture at a high rate of speed to the forming surface of a web-forming machine positioned adjacent to the exit aperture.

24 Claims, 10 Drawing Figures



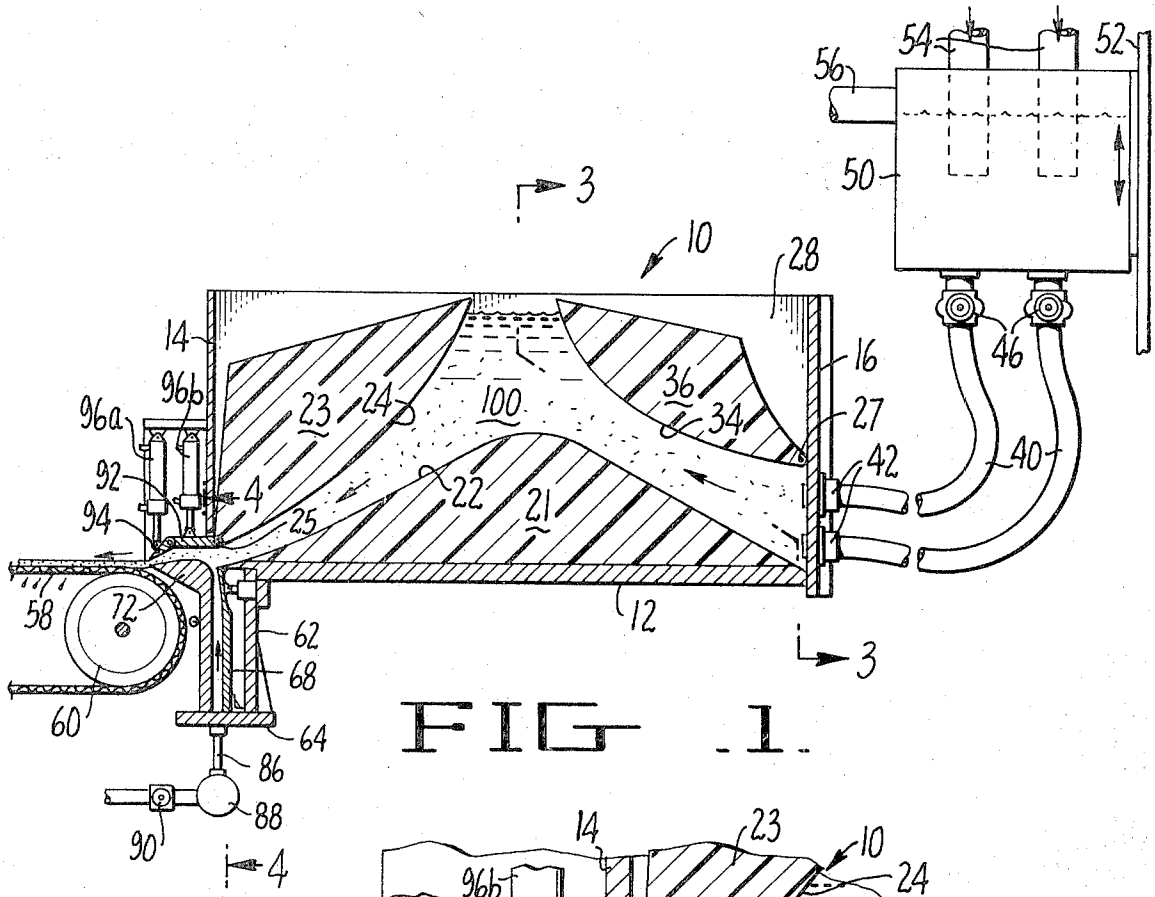

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FIG. 1.

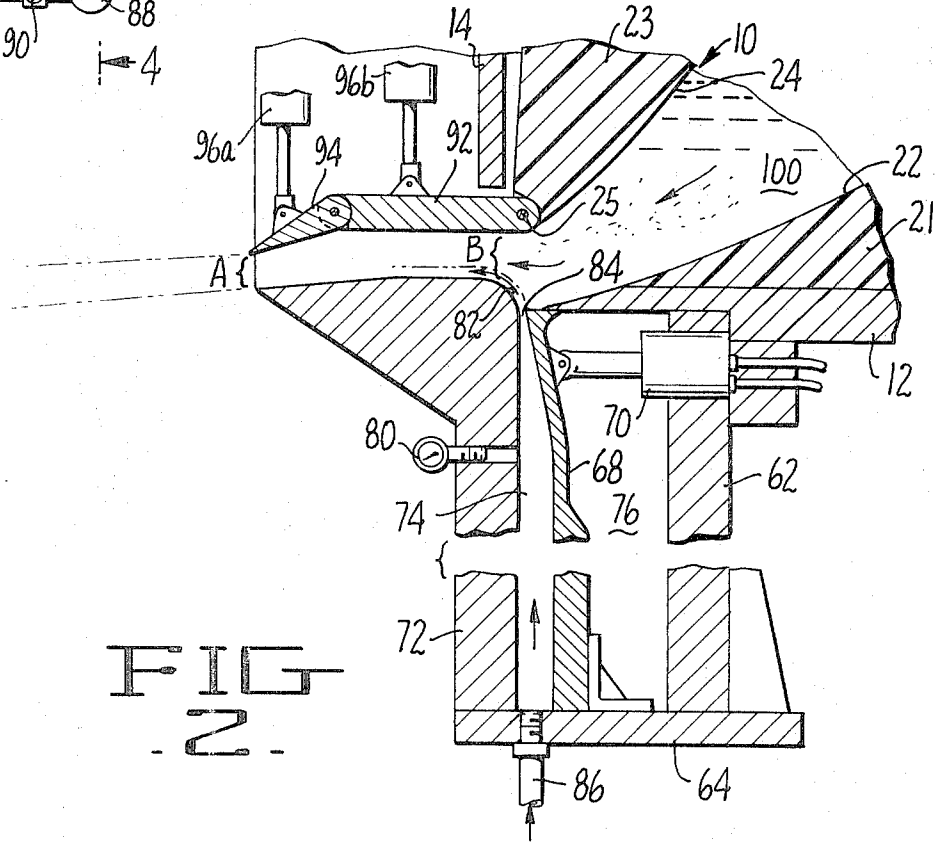

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FIG. 2.

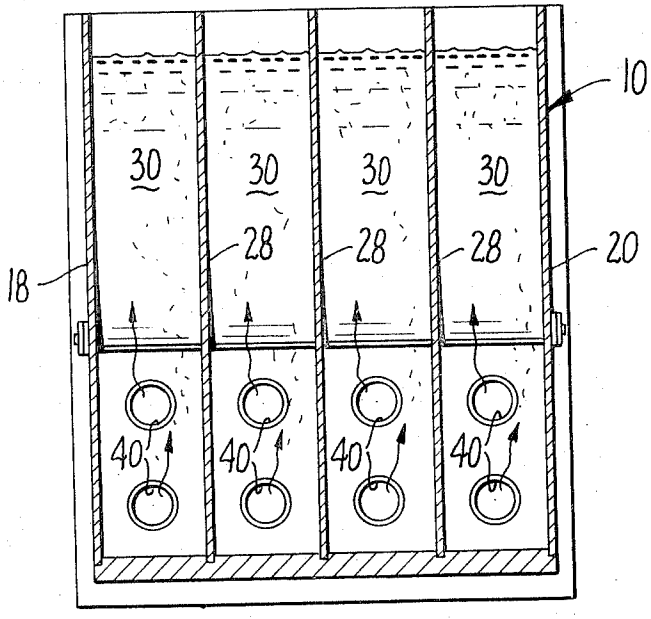

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FIG. 3.

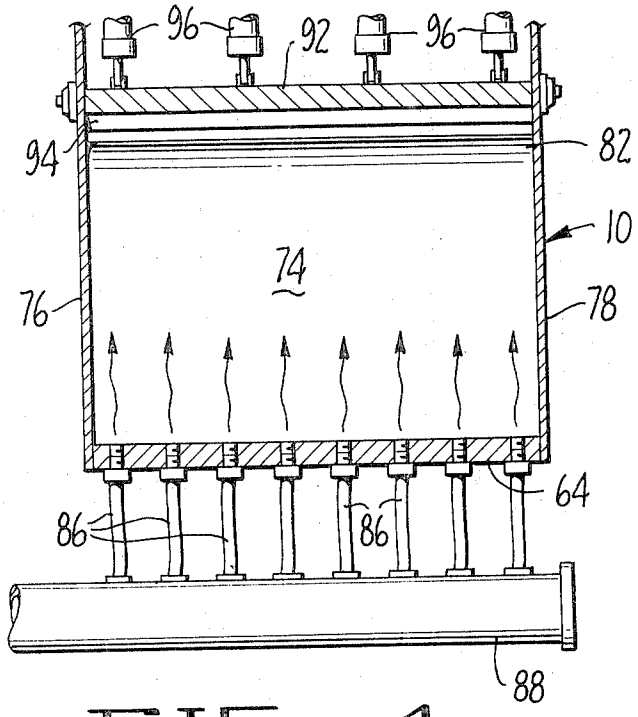

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FIG. 4.

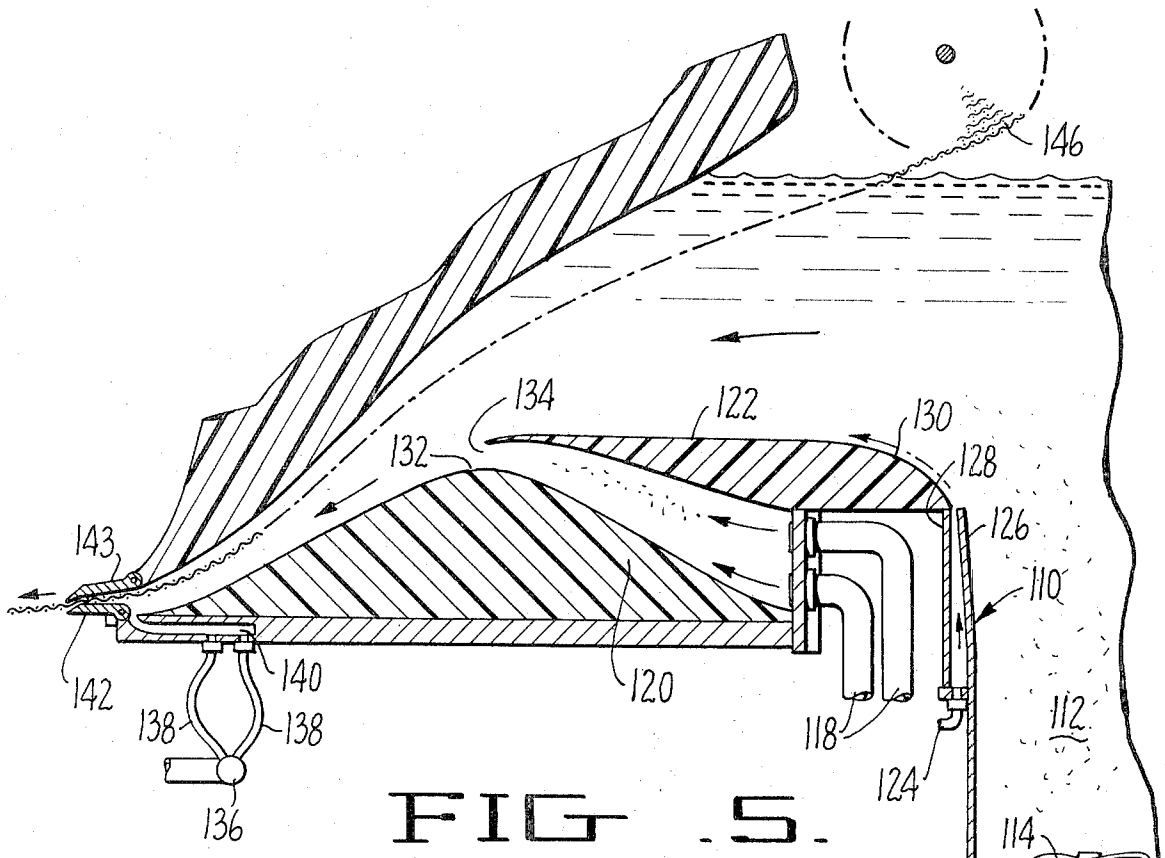

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FIG. 5.

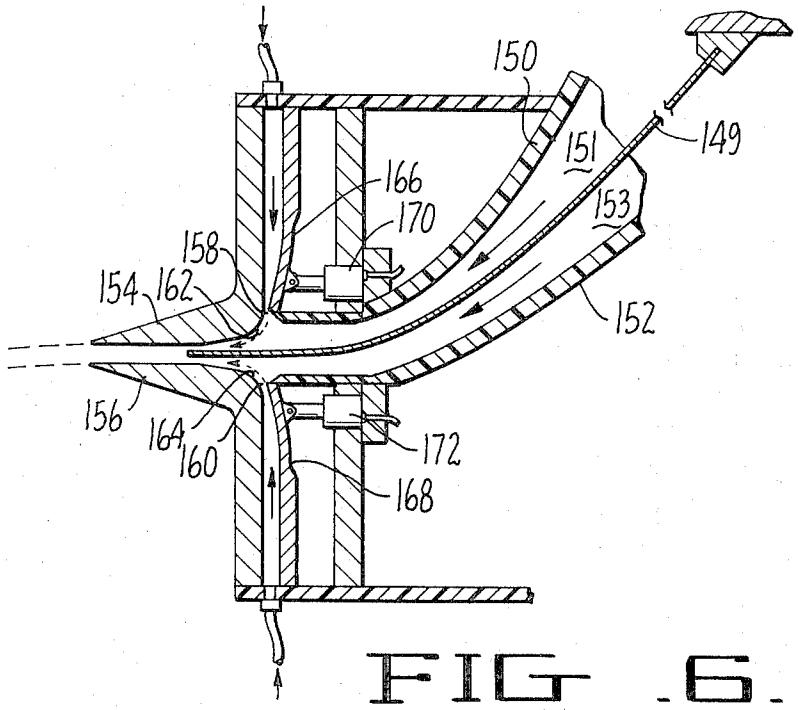

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FIG. 6.

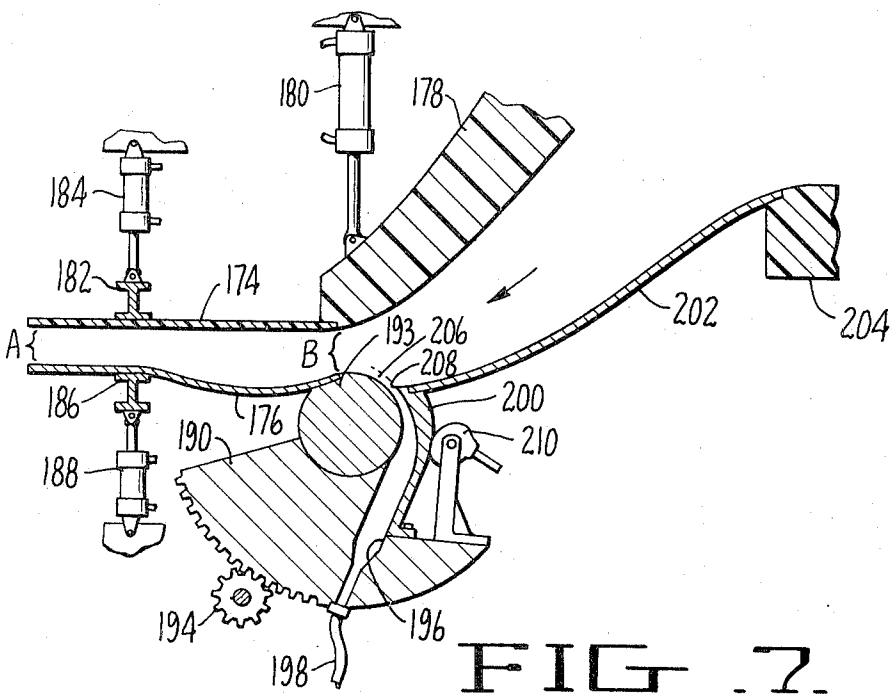


FIG. 7.

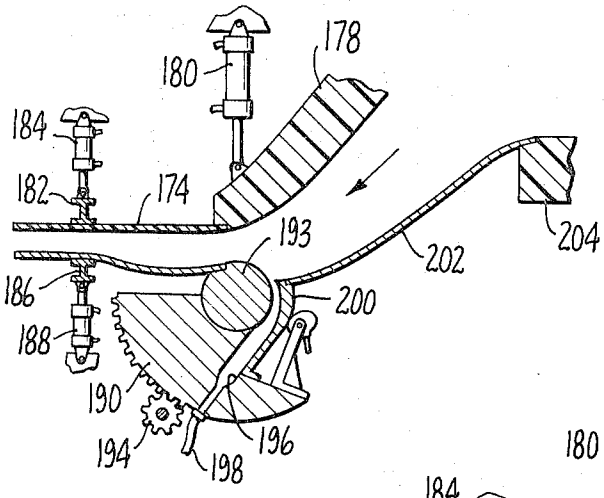


FIG. 8.

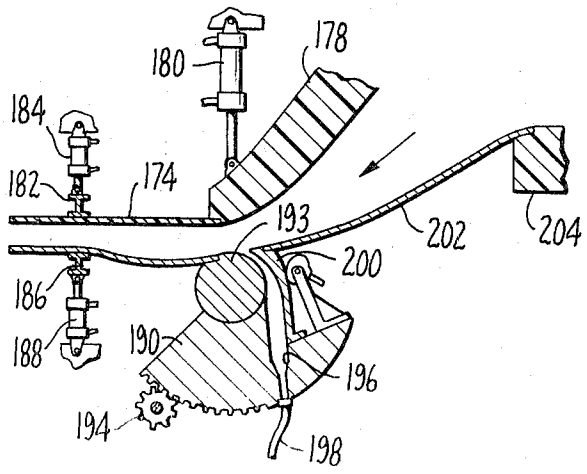


FIG. 9.

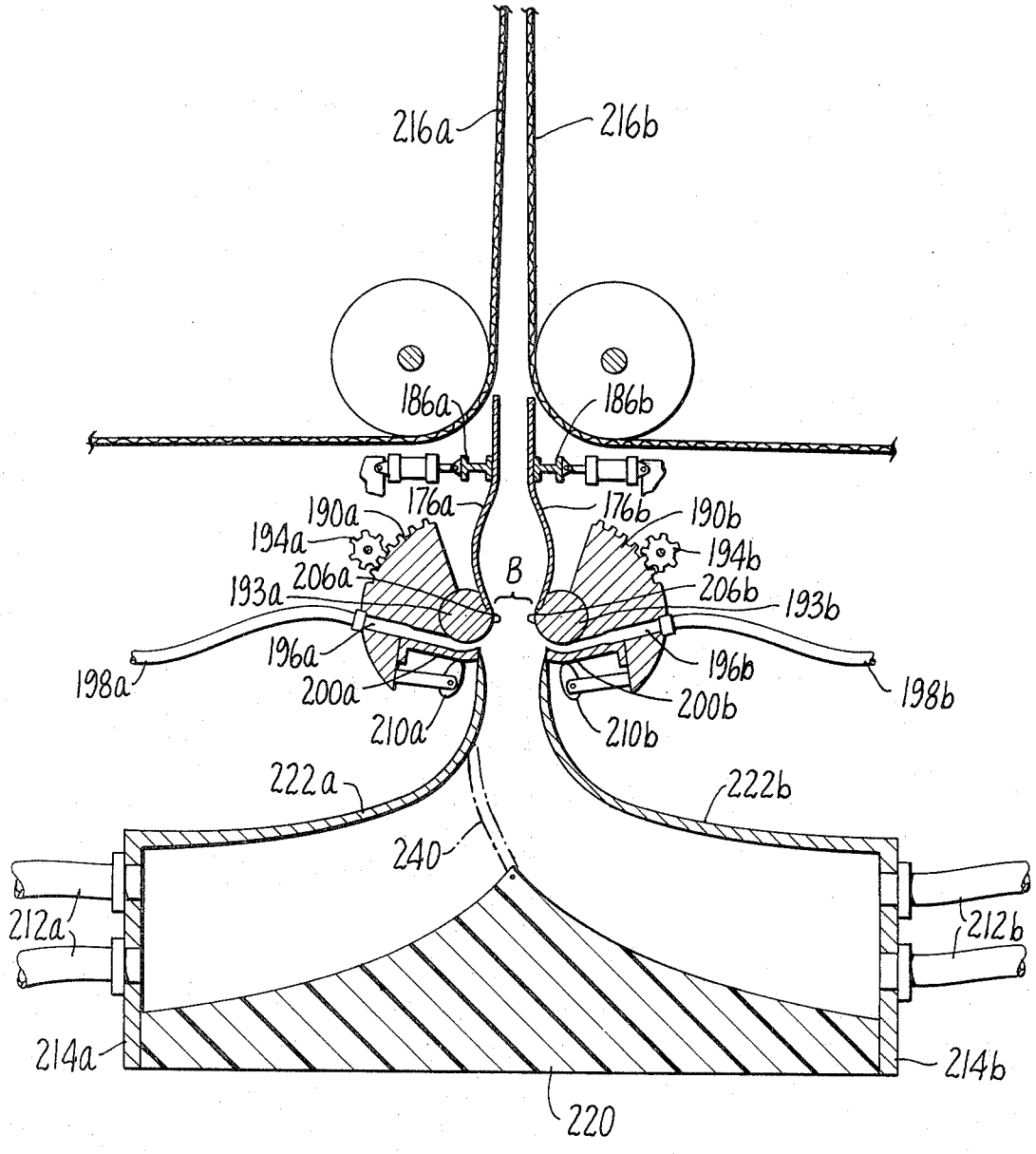

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FIG. 10.

ENTRAINING A LIQUID INTO A FIBER SLURRY TO ACCELERATE IT PRIOR TO DISCHARGE FROM A FLOW PATH ONTO A FORMING WIRE

This is a continuation of application Ser. No. 297,094 filed Oct. 12, 1972, now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates to an apparatus and method for delivering a fiber slurry to the forming surface of a web-forming machine, such as the wire of a Fourdrinier-type papermaking machine.

In a typical web-forming machine, such as a papermaking machine, the fiber slurry, which is disposed in a headbox, is ejected from the exit slit of the headbox onto a Fourdrinier wire or other suitable web-forming device by having energy transmitted directly to the fiber suspension or slurry itself. This is conventionally accomplished in existing equipment by feeding the entire stream of fibrous slurry through a pump which exerts sufficient energy to expel the fibrous slurry at the desired velocity through the discharge orifice of the headbox. Alternatively, the "head" of the slurry itself is utilized to force the slurry out of the headbox discharge orifice. Such an approach obviously requires a headbox of great depth to maintain the exit speed of the slurry at a sufficiently high velocity to provide for proper delivery of the slurry as it exits from the headbox discharge orifice. Sometimes, the energy used to accelerate the fiber slurry is at least partially derived from a pressurized air cap above the slurry in the headbox.

One major problem inherent in these typical existing headboxes is the nonuniform distribution of the energy applied to the system across the span of the discharge jet. Nonuniform distribution of energy is manifested in several ways such as cross-machine velocity gradients, locally high or low velocities, transient disturbances, wakes, cross-flows and nonuniform turbulence scale. In turn, these phenomena appear in the finished, dried, fibrous web as undesirable thick spots, thin areas, patterns or blemishes.

In addition to the nonuniform distribution of energy, the typical headbox also creates a situation of nonuniform distribution of fibers. Fibers in suspension tend to form flocs, clods, or agglomerations which, if not broken up in some manner, will likewise cause the finished, fibrous web to have undesirable local irregularities. In the case of existing web-forming machines, it has been necessary to employ rectifier rolls, baffles, tubes, converging plates or other physical means of controling or acting upon the mass and energy distributions of the entire fibrous slurry in attempts to obtain uniform distribution of energy and fibers.

According to the present invention, many of these typical flow problems are overcome so that the fiber suspension may be accelerated to the desired uniform velocity and dispersion of fibers immediately prior to discharge to the forming wire or other forming surface of a web-forming machine. This is accomplished by utilizing a phenomenon known as the "Coanda effect" to indirectly accelerate the slurry. The Coanda effect has been known for many years, as exemplified by U.S. Pat. No. 2,052,869, issued to Henri Coanda. Briefly, this phenomenon can be described as the tendency of a fluid, which emerges from a slit under pressure, to attach itself or cling to and follow a surface in the form of an extended lip of the slit, which recedes from the flow axis of the fluid as it emerges from the slit. This creates a zone of reduced pressure in the area of the slit so that any entrainable material which is in the zone will become entrained and flow with the fluid which has attached itself to the extended lip.

SUMMARY

According to the present invention, the Coanda effect has been utilized as a direct means for introducing a high percentage of all energy required to accelerate slurry fibers through a discharge orifice to a foaming surface. Specifically, energy is introduced into the slurry stream by forcing a fluid under pressure through a narrow slit communicating with the slurry flow path and causing said fluid to attach itself to a convexly-curved fluid flow attachment surface adjacent to said slit whereby the entraining fluid, by virtue of the Coanda effect, rapidly proceeds toward an exit aperture for the slurry. Rapid flow of the entraining fluid after expulsion from the slit, induces flow of the slurry, causing same to be entrained and accelerated, and the combined flows then mix and proceed toward the exit aperture. In other words, in contrast to conventional headbox arrangements wherein the slurry stream is "pushed" through the exit aperture, in apparatus constructed in accordance with the present invention the slurry stream is "pulled" through the exit aperture. Consequently, handling of long, fibrous materials is facilitated, without tangling and matting problems customarily associated with such materials. During the interval from the slit to the exit aperture, the high, initial velocity and concentration gradients between the two streams tend to level out resulting in a relatively uniform vertical slurry concentration and energy distributions at the point of discharge.

In practice, clear or white water under pressure may be utilized in the system of this invention as the entraining fluid. Because the entraining fluid is a clear liquid, its energy content may be easily controled and modulated, and many of the problems that usually attend attempts to modulate and control velocity (or energy), such as nonuniformities in pulp slurry, are eliminated. Simple, inexpensive screens, and/or small diameter tubes whch are commonly used to smooth and control velocity and turbulence in clear fluids, may freely be used to achieve dessired desired characteristics of entraining fluid expelled through the slit. In this way, the problems of shedding, plugging, etc., which are encountered when control of the entire process slurry stream is attempted, may be avoided.

Furthermore, the necessity of utilizing rectifier rolls is eliminated due to the shear conditions imposed on the incoming, entrained fiber slurry. The velocity ratio between the entraining fluid and the entrained fiber slurry stream is in the order of at least ten in the region of initial mutual contact therebetween. The resultant high shear with combined dilution breaks the flocs and creates a condition of uniform fiber dispersion as the entraining fluid and slurry mixture exit together onto a web-forming surface.

The method and apparatus according to the present invention additionally provide numerous advantages over conventional headbox constructions including simplicity and relatively inexpensive construction, an ability to handle a wide variety of fibers, including synthetic fibers, as well as ease of control and maintenance. Furthermore, this apparatus eliminates the ne-

cessity for any pressure cap and/or direct pumping of the slurry. It also permits the use of a low profile construction, and offers the ability to control basis weight of the web with minimum time delay. The invention has as its further aspect the provision of an improved method and apparatus for delivering a fibrous slurry to a forming machine which is readily adapted to a wide variety of slurry types and consistencies.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention are illustrated in the accompanying drawings in which:

FIG. 1 is a generally diagrammatic side view and partial section of apparatus constructed in accordance with the principles of the present invention;

FIG. 2 is an enlarged cross-sectional view illustrating certain operational details of the apparatus of FIG. 1.

FIG. 3 is a view taken along line 3—3 of FIG. 1;

FIG. 4 is a view taken along line 4—4 of FIG. 1;

FIG. 5 is a vertical cross-sectional schematic view of a fragmentary portion of an alternative embodiment of a machine constructed in accordance with the teachings of the present invention;

FIG. 6 is an enlarged, vertical, cross-sectional schematic view of a fragmentary portion of still another type of machine incorporating the present invention;

FIGS. 7, 8 and 9 are side elevational, sectional views showing selected components of still another alternative embodiment of a machine constructed in accordance with the present invention, said components being illustrated in three separate, selected, operational positions; and

FIG. 10 is a vertical, cross-sectional schematic view of still another form of apparatus constructed in accordance with the teachings of the present invention, this form of apparatus being illustrated in combination with a generally vertically disposed web former.

GENERAL DESCRIPTION

Reffering now to FIGS. 1, 3 and 4, the apparatus constructed in accordance with the teachings of the present invention is indicated generally by means of reference numeral 10. Apparatus 10 includes a bottom wall 12, end walls 14 and 16, and side walls 18 and 20. The walls may be constructed of any suitable material such as reinforced plastic or stainless steel and are secured together in any desired manner to provide a generally box-like configuration. Disposed within the walls are three segmented separate baffles 21, 23 and 36. Lower baffle 21 has a top contour defined by the surface 22. Baffle 23 has a flow surface 24 and is pinned and capable of rotation about its mounting pin 25 to permit minor adjustments of the flow channel defined between surfaces 22 and 24. Baffle 36, having a flow surface 34, operates similarly to 23, and can be selectively moved about its mounting pin 27 to adjust the clearance between surfaces 34 and 22. Pins 25 and 27 extend between side walls 18 and 20 and are mounted thereon in any suitable manner. Baffles 21, 23 and 36 may be constructed of any suitable material such as plastic. With particular reference to FIG. 3, a plurality of divider panels 28 extend lengthwise between the confines of side walls 18 and 20, thereby dividing the apparatus 10 into a plurality of substantially equi-dimensioned chambers 30. Sandwiched between adjacent divider panels 28 and between the endmost panels and side walls are separate segments or slices of baffles 21, 23 and 36, the respective contoured surfaces 22, 24 and 34 of which form in each chamber 30 a flow passage 100 (FIG. 1). The segments of baffles 21, 23 and 36 are of a size to fit snugly against panels 28, thereby permitting easy adjustment of these baffles to vary the configuration of the flow passage. If desired, the baffles may be mounted for total removal from the rest of the apparatus.

A plurality of flexible slurry-supply conduits 40 communicate with the interior of each chamber 30 through apertures formed in end wall 16. The slurry-supply conduits 40 are attached to the end wall 16 by suitable coupling elements 42. The other ends of slurry-supply conduits 40 are connected through valves 46 to the interior of head control box or reservoir 50. Reservoir 50 may be selectively moved up or down through a suitable mechanism (not shown) with respect to its supporting wall 52. Reservoir 50 is adapted to supply fiber slurry to apparatus 10 in a manner that will be described in greater detail below. A plurality of supply tubes 54 lead to the interior of reservoir 50 as shown. The other ends of the supply tubes are connected to a main fiber slurry stock reservoir (not shown) whereby reservoir 50 is continuously supplied from the main stock reservoir. One or more overflow lines 56 may be provided which are adapted to maintain a constant head in reservoir 50 and allow the overflow to return to the main stock reservoir. The rate of discharge from head control box or reservoir 50 may be controled by adjustment of valves 46 and/or by raising or lowering same with respect to its supporting wall 52.

Referring now to FIGS. 1, 2 and 4, apparatus 10 includes at the forward or downstream end thereof (the left-hand side of the apparatus as viewed in FIGS. 1 and 2) a mechanism utilizing the Coanda effect which induces flow in the fiber slurry introduced in apparatus 10 and causes same to exit onto a web-forming surface such as a Fourdrinier wire 58 which is conventionally journaled on a breast roll 60 to receive the fiber slurry exiting from apparatus 10 in a manner to be described.

Depending from the downstream end of bottom wall 12 in the manner illustrated is a vertical support member 62. Integrally attached to the vertical support member 62 at the lower end thereof is a horizontally disposed support frame 64. Fixedly attached to support frame 64 and extending upwardly therefrom is a first slit-defining member 68 which is of cantilever construction having its upper end disposed in close proximity to bottom wall 12 but relatively movable with respect thereto. A hydraulic or electrically operable ram device 70, or other suitable mechanism, is employed to move the upper end of first slit-defining member 68 to the desired predetermined location. A number of such rams are distributed span-wise along member 68 so that the local span-wise position of member 68 may be precisely controled.

Also affixed to support frame 64 and extending upwardly therefrom is a second slit-defining member 72 which is spaced from slit-deforming member 68 so that an entraining fluid flow path 74 is defined by the first and second slit-defining members 68 and 72 and side plates 76 and 78 (FIG. 4) which extend upwardly from support frame 64 and are attached to side walls 18 and 20 in any desired fluid-tight manner. A pressure gauge 80 is preferably attached to second slit-defining mem-

ber 72 so that the pressure of the fluid flowing through entraining fluid flow path 74 may be monitored. The upper end of second slit-defining member 72 has formed thereon a convexly-curved fluid-flow attachment surface or foil 82. Fluid-flow attachment surface 82 leads from a slit 84 formed between the upper end of first slit-defining member 68 and the second slit-defining member 72. The curved fluid-flow attachment surface 82 is in the form of an extended lip which recedes from the flow axis of fluid as it emerges from the slit to provide a flow attachment surface for the fluid so that it operates in accordance with the aforementioned Coanda effect.

Leading to the entraining fluid-flow path 74 through apertures provided in support frame 64 are a plurality of entraining fluid conduits 86. The other ends of the conduits are connected to a manifold 88. The interior of manifold 88 is connected to a suitable source of pressurized entraining fluid through valve 90. The manifold and plurality of conduits operate to introduce entraining fluid into entraining fluid-flow path 74 in a uniform manner across the width of the fluid-flow path.

Cooperating with second slit-defining member 72 to form an exit aperture from the interior of apparatus 10 is an articulated upper lip comprised of a first lip element 92 pivotally attached to pin 25 so that it overhangs slit 84 and a second lip element 94 pivotally attached to lip element 92 at the outermost extent thereof. Lip elements 92 and 94 are adapted for relative rotation with respect to wall 14 and with respect to each other by means of prime movers, which, in the present embodiment, are in the form of hydraulic rams 96*a* and 96*b*.

The operation of the aforedescribed embodiment of the present invention is as follows: For purposes of illustration, the apparatus and method according to the present invention will be described as being utilized in the papermaking art, with the fiber slurry being a conventional pulp slurry and the entraining fluid being water. It will be appreciated, however, that the apparatus and method may be utilized to advantage with a wide variety of slurry and entraining fluid materials.

Valve 90, controling the entraining fluid, which, in this case, is clear or white water, is opened allowing the water to enter into manifold 88. The water moves along entraining fluidflow path 74 and thence through the slit 84 at which point it attaches itself to curved fluid-flow attachment surface 82 by virtue of the Coanda effect and flows in the direction of the arrow toward the exit aperture of apparatus 10 formed between the fluid-flow attachment surface 82 and elements 92 and 94.

At the same time, the desired pulp slurry head is established in reservoir or head control box 50, and valves 46 are opened to introduce the slurry into the chambers 30 of apparatus 10 through slurry-supply conduits 40. The rapid flow of the water on the fluid-flow attachment surface or foil 82 creats a low pressure zone which, in turn, induces flow of the fiber slurry within the flow path 100 of each chamber. The fiber slurry is, in effect, "pulled" toward the exit aperture by the water.

The combined flows progress from the region of the slit to the exit aperture and then on to the forming surface of the web former, which in this case is Fourdrinier wire 58. Thorough mixing of the water and pulp slurry occurs in the region between slit 84 and the exit aperture. Adjustment of lip elements 92 and 94 with respect to one another and relative to the curved fluidflow attachment surface 82 controls such characteristics as entrainment ratios, angle of the discharged jet, turbulence and jet stability.

Curved surfaces 22, 24 and 34 and the divider panels 28 serve to smooth out the flow of the slurry as it progresses through apparatus 10. In addition, such elements discourage coagulation, eliminate back flow, eddies and vortices, which will cause air entrainment. Also, flow path 100 is designed to develop a uniform flow velocity for the slurry as it approaches the vicinity of slit 84.

The velocity ratio of the entraining fluid to the entrained slurry is one way to define the conditions for proper operation of the present apparatus. For efficient operation of the apparatus, the velocity ratio between the entraining fluid and the slurry immediately upstream from the slit 84 should preferably be at least equal to the value of ten and, typically, may have a value of twenty or more. The high velocity differentials existing between these two streams result in another important advantage for this system. The extreme shears generated will disperse the fiber flocs or agglomerates, and the simultaneous dilution by the entraining fluid will prevent flocs from reforming. Dispersion is thus effected fluid-dynamically eliminating the need of troublesome mechanical devices such as the rectifier roll.

Another way of defining the operating conditions for this method and apparatus is to note the ratio of the kinetic energy level of the entraining fluid to that of the entrained slurry stream immediately upstream from the slit. Kinetic energy content at the given point of interest is defined as mass flow rate times velocity squared divided by two times g_c (the conversion factor) $mv^2/2g_c$. Units derived from this expression are foot-pounds/seconds. The ratios for efficient operation of the apparatus and method according to this invention are preferably greater than 50 and may run as high as 400, or more.

Operation of the structure thus far described can best be understood by referring to FIGS. 1 and 2 in connection with the following description. A device, as illustrated in FIGS. 1 and 2, was constructed having a width of twelve inches. Apparatus 10 was left open to the air and a stock head of only eleven inches, i.e., approximately 0.4 psi, was maintained. The slurry utilized was a pulp slurry and the entraining fluid was clear or white water. During operation of this unit, the width of slit 84 was selectively varied between 0.01 inch and 0.07 inch. With the velocity ratio between the entraining fluid and the slurry immediately upstream from the slit (approximately one inch from the slit in the illustrative device) being maintained at a value of 10 or more, approximately 90 percent or more of the energy needed to accelerate the fiber slurry was supplied by the entraining fluid. Since the entraining fluid itself contained no fibers, it was able to pass through small valves, small diameter tubes and orifices without plugging or shedding, problems which typically attend flow of a fiber slurry through such apparatus. In this way, the energy required to drive the system was thoroughly controled before it performed the ultimate task of accelerating the fiber slurry. The high velocity differentials existing between these two streams resulted in extreme shears which dispersed the fiber flocs or agglomerates.

In general, it has been found that discharge velocity of the material from the apparatus desscribed varies in accordaznce with changes made in the width of the slit and the pressure of the entraining fluid, the higher the pressure and/or the wider the slit, the higher the discharge velocity. Likewise, the exit aperture or slice dimension "A" and the throat dimension "B", shown in FIG. 2, are important variables for regulating the discharge velocity of the jet. In general, minimizing throat and slice will yield higher discharge velocites.

An important interrelationshp having a bearing on proper operation of apparatus constructed in accordance with the teachings of the present invention exists between "R", the radius of curvature of the fluid-flow attachment surface at the location of the slit 84, and the width (hereinafter "S") of the slit. Experimental data suggests that the apparatus will operate efficiently when the ratio of R to S, i.e., R/S, lies in the range of from 2.5 to 150.

The entrainment ratio, which is defined as the mass or volumetric ratio of the slurry stock to the entraining fluid flow, depends upon the width of the slit and, also, upon the width of the exit aperture. Furthermore, the ratio between exit aperture or slice dimension A and the throat dimension B has a critical effect on entrainment ratios. In general, the slice-to-throat ratio increases, the entrainment ratio also increases; however, when slice-to-throat ratio exceeds unity, the resulting divergence of the jet may limit the practical value of slice-to-throat ratios greater than one. Entrainment ratio also depends on pressure of the entraining fluid to a lesser degree, with the entrainment ratio increasing gradually as the pressure decreases.

It is felt that the ability to handle a wide range of pulp consistencies, especially those of a high consistency, is one of the important advantage of the present invention as compared to the prior art. Experimentation has shown that apparatus constructed in accordance with the teachings of the present invention is capable of handling pulp slurries in the high consistency range of from 1 to 4 percent or above, as well as those slurries in the low consistency pulp range of between 0.2 and 1.0 percent. Virtually any slurry which can be delivered to the apparatus 10 may successfully be delivered from its exit aperture at high speeds. It should be understood that the dilution of the entrained fiber slurry by the entraining stream is one of the necessary aspects of operation for the apparatus. For example, if the entrained slurry is supplied at 4 percent consistency and the entrained slurry flows in a rate twice that of the entraining fluid (i.e. entrainment ratio equals 2), then the discharge consistency will have been diluted to 2.67 percent. Corresponding dilution of the incoming fiber will occur according to the entrainment ratio resulting from specific operating conditions.

Referring now to FIG. 5, an alternative embodiment of the present invention is illustrated. The apparatus shown actually incorporates a variety of optional features which may be employed in a system utilizing the induced forming technique of the present invention. These features may be utilized alone or in combination depending upon the materials being utilized in the formation of the web and/or results desired. For example, the baffle members and divider panels of the type described above with respect to the first embodiment of this invention may possibly be dispensed with and the shapes of the slurry-flow-path defining means may be varied, as, for example, in the manner illustrated in FIG. 5. In that figure, the Coanda effect is actually utilized in a plurality of locations in the illustrated apparatus. In this embodiment, two or more fiber slurries may be mixed just prior to their ejection on to an appropriate web-forming surface. In unitary chamber 110 of the illustrated alternative embodiment, for example, may be disposed a synthetic fiber slurry 112 which is kept continually mixed by means of a mixed impeller 114 driven by a suitable prime mover such as electric motor 116. Flowing through conduits 118 into a flow path defined by curved baffle members 120 and 122 is a second type of slurry, for example, a conventional wood pulp slurry. Alternatively, one of conduits 118 may be a source of a chemical or, for that matter, plain water. Simultaneously, any desired fluid such as water may be introduced through conduit 124 into a flow path defined by bent wall 126 of chamber 110 and a plate 128 extending downwardly from a convexly-curved fluid-flow attachment surface 130 formed on baffle member 122. Since a slit is formed between the uppermost extent of bent wall 126 and the plate 128 at the location where the plate joins baffle 122, the Coanda effect will operate to direct flow of the fluid passing through conduit 124 about convexly-curved fluid-flow attachment surface 130. This fluid flow will serve to entrain and induce flow of synthetic fiber slurry 112 as shown by the arrows.

A convexly-curved fluid-flow attachment surface 132 is also formed on baffle member 120 in the vicinity of a slit 134 formed by the outermost extremity of baffle member 122 and baffle member 120. This arrangement again utilizes the Coanda effect to induce additional flow of synthetic fiber slurry 112 and cause same to mix with the material exiting from conduits 118.

The final application of the Coanda effect in the FIG. 5 embodiment is at the downstream end of the apparatus wherein a fluid such as water is injected through manifold 136 and conduits 138 into passageway 140. The fluid exits from the passageway through a slit in the vicinity of a convexly curved surface formed on a lower rotatable jaw member 142 which defines, along with upper jaw member 143, the exit aperture from the apparatus. The material, such as water, which flows through passageway 140 attaches itself to the curved surface of the lower jaw member and thus entrains and mixes with the material flowing into engagement therewith, the purpose of the final slit being to accelerate the incoming mixture to the final desired velocity.

The arrangement illustrated in FIG. 5 has great versatility in that it can be used to form a wide variety of webs through the admixture of various types of slurries and fluids. For example, soluble chemicals, such as wet strength aids, drainage aids or flocking agents, which may hamper operation of upstream screens or media. equipment, might successfully be introduced in one of the entraining mecia. Chemical reactants — one introduced on the fibers (such as polyvinyl alcohol) and the other introduced as a soluble salt in the entraining stream (such as borax) — might be utilized in the manufacture of paper products. Similarly, dispersions of foamed fibers for functional webs can be introduced to the system and accelerated to high speeds. If desired, a reinforcing scrim of nylon or other suitable material may be fed into the system, as shown schematically and identified by means of reference numeral 146. Because

the system utilizes induced flow and a high velocity flow rate is developed at the exit aperture of the mechanism, the scrim may be placed on a freely rotating roll and will be self-fed therefrom by virtue of its entrainment in the flow path stream. The slurry fibers will adhere to the scrim upon its exit from the apparatus and reinforcement means is thus provided for the finished web.

Referring now to FIG. 6, still another alternative embodiment of apparatus constructed according to the teachings of the present invention is illustrated. A flow path for the slurry being delivered from a suitable reservoir is defined by curved walls **150** and **152**. The walls converge and gradually flatten out with the terminal portions thereof cooperating with jaw members **154** and **156**, respectively, to provide narrow slits **158** and **160**, as shown. Jaw members **154** and **156** are provided with convexly-curved fluid-flow attachment surfaces **162** and **164** leading in a downstream direction from slits **158** and **160**, respectively. The size of slits **158** and **160** may be varied by the operator through the manipulation of cantilever members **166** and **168** as by means of hydraulic ram members **170** and **172**. Fluid flow paths are defined by the jaw members and the cantilever members so that a desired fluid may be introduced through the slits into the slurry flow path, as indicated by the arrows, so that the slurry is entrained at both the top and bottom thereof prior to its exit from the aperture formed by the jaw members. In other words, entraining fluids are introduced at two locations in the system and the Coanda effect is utilized at both locations. Introduction of entraining fluid at both locations enhances the jet discharge velocity through the exit aperture as compared to the single slit apparatus of FIGS. 1–4. The same type of entraining fluid may be used at both locations or, alternatively, two different types of entraining fluids may be utilized. For example, either the top or bottom arrangement may be used for the introduction of a desired active, dissolved chemical, while the other may be a source of clear water. The apparatus shown in FIG. 6 may be used, if desired, to form a multilayered web. To produce a two-layered web, two slurries **151** and **153** are introduced thereinto from two separate sources of slurry (not shown). A thin, flexible plastic or metal strip **149**, anchored at a location upstream of entry points for slurries **151** and **153**, and fixedly secured to the side walls of the unit, maintains separation between the two entrained slurry streams **151** and **153**, as they flow simultaneously toward the exit aperture. One potential application for such an arrangement may, for example, be in the manufacture of linerboard having a good print surface on its exterior and an inexpensive fibrous body. This construction could be made by introducing board stock as slurry **153** and the print-grade fiber as slurry **151**. Other potential applications will become readily apparent to those skilled in the art of sheet-and web-forming. If desired, the separation strip may be adjustably mounted in any suitable manner relative to the side walls of the unit so that the relative thicknesses of the slurry layers may be selectively varied.

Still another alternative embodiment of apparatus constructed in accordance with the teachings of the present invention is shown in FIGS. **7, 8** and **9** of the drawing. This embodiment incorporates features which render it particularly effective for use with a wide variety of slurry materials and other changing operating conditions.

Large scale turbulence is an undesirable property of the jet discharged from the apparatus as it leads to nonuniformities in the finished wet web product. Through the utilization of the form of apparatus shown in FIGS. **7, 8** and **9**, reduction in the scale of turbulence and consequent minimization of local irregular flow patterns in the discharge stream may readily be effected. It has been found that the location of the slit through which the entraining fluid exits into the main flow path of the apparatus relative to its associated flow attachment surface has a marked influence on the formation and location of eddies, back flow systems and vortices in the area of mixing of the entraining fluid and the entrained slurry. This area is located between the slit and the exit aperture. The eddies and vortices which form in this mixing zone, in turn, control discharge jet stability and turbulence level. With the form of apparatus shown in FIGS. **7, 8** and **9**, the location of the slit relative to the flow attachment or foil surface may be adjusted in accordance with changed materials or conditions encountered, such as changes in entraining fluid or slurry consistency or pressure, changes in the dimension of the exit aperture, throat opening and slit width, contour and length of lips, etc. Additional influence on turbulence and efficiency of the discharge jet from the apparatus may be effected through the utilization of lips of various lengths, contour and flexibility.

In the form of apparatus shown in FIGS. **7, 8** and **9**, two lips **174** and **176** are employed to define at the extremities thereof an exit aperture or slice A and a throat opening B. Upper lip **174** is connected at the upstream terminal end thereof to a curved baffle **178** which defines the upper limits of the slurry flow path and which may be pivotally attached to the rest of the apparatus at some point upstream (not shown) so that it may be pivoted with respect thereto through the action of a hydraulic ram element **180** to vary the configuration of the flow path as desired. The downstream terminal end of the upper lip **174** is in engagement with a span-wise beam element **182**. The outer or downstream terminal end of lower lip **176** also cooperates with a similar beam element **186**. The clearance between lips **174** and **176** (which in turn influences discharge jet turbulence and stability) can be adjusted overall and/or locally by appropriate motion of rams **184** and **188**, a number of which are disposed lengthwise in operative association with their respective beam elements **182** and **186**. It is also by virtue of adjustment of rams **184** and **188** and attached beam elements **182** and **186**, that the thickness and velocity of the discharge jet may also be controled in a manner described previously. The lips may be affixed to their respective beam elements or simply maintained in engagement therewith by the pressure exerted by the slurry as it exits therebetween.

The upstream terminal end of lower lip **176** is attached to a member **193** which is fixedly positioned, and in essence this lower lip becomes an extension of convexly-curved fluid-flow attachment or foil surface **206** formed on member **193**. Mounted in any suitable manner for rotatable movement relative to member **193**, is a rotatable member **190** which may be selectively positioned relative to member **193** through the action of a cooperating geared driving pinion **194**

which, in turn, is driven by a suitable prime mover (not shown).

Rotatable member **190** has formed therein a fluid flow path **196** for entraining fluid which is introduced therein through conduit **198.** The upper right-hand side of the flow path **196** is, as may be clearly seen with reference to the figures, defined by a cantilever member **200** which is fixedly attached at the lower end thereof to rotatable member **190.** Attached to the upper terminal end of cantilever member **200** is a flexible, fluid-flow-path defining plate **202** which has the other end thereof rigidly secured to a fixed fluid-flow-path defining member **204.** The cantilever member **200** cooperates with the curved fluid-flow attachment surface **206** formed on fixed member **193** to form a narrow slit **208** through which the entraining fluid exits. A cam member **210** is mounted on a bracket affixed to rotatable member **190** to selectively vary the size of the slit **208,** as desired, by its interaction with cantilever **200.**

Through the rotation of members **190** and **200** relative to member **193** by pinion **194,** the location of the slit **208** relative lto flow attachment surface **206** may be selectively varied to control turbulence and efficiency of the apparatus for a wide range of conditions, including changes in the entrained slurry consistency, speed of discharge jet, slice opening, basis weight of desired product. For optimum operation of the induced flow system according to this invention, a balance is established among entrainment efficiency, discharge velocity and turbulence of the discharge jet. To compensate for changes in the width of slit **208,** the height of the exit aperture A, throat opening B, and pressure of the entraining fluid, angular orientation of the slit may be changed by rotating rotatable member **190** as shown in FIGS. **8** and **9,** which illustrate the extreme positions which may be assumed by this member. It should be noted that rotation of member **190** also has the effect of changing the angular disposition of the slit discharge axis relative to the axis of the flow path.

To illustrate the operation of the embodiment of FIGS. **7, 8** and **9** more clearly, it will be assumed that the slurry mixture is a pulp slurry and the entraining fluid is water. After introduction of water under pressure through conduit **198,** the flow is through fluid flow path **196** and then outwardly through slit **208.** The size of the slit may be adjusted by rotation of the cam member **210** against the cantilever member **200.** As has been described with rspect to the other embodiments of this invention, the entraining fluid issuing from the slit accelerates the entrained slurry stream which is introduced into the channel formed by curved plate **178** and flexible plate **202** from whence it progresses through lips **174** and **176** and discharges onto a web-forming surface. Through operation of hydraulic rams **184** and **188,** the operator can set the desired jet or discharge thickness as required by the particular grade of paper. As the clearance between lips **174** and **176** is altered by corresponding motion of beam elements **182** and **186,** ram **180** and hence baffle **178** will necessarily have to be changed as maximum, efficient operation of the headbox is sought.

The lips employed in apparatus constructed in accordance with the present invention may have a wide variety of physical characteristics. For example, either or both of the lips may be rigid or flexible. Also, the lips may be curved or straight, have varying lengths, or be constructed of different, suitable materials. For example, in FIGS. **7, 8** and **9,** lip **174** is illustrated as being straight and constructed of relatively thin, flexible plastic material while lower lip **176** is illustrated as being curved and constructed of stainless steel which is thick enough to prevent deformation of lip **176.** Lip **174,** on the other hand, is flexible enough to deform under the pressures exerted by the slurry flow. It has been found that at least under certain conditions the use of at least one flexible lip results in minimizing turbulence and increasing entrainment efficiency due to the ability of the flexible lip to respond to changes in pressures exerted thereon by the slurry flow. If desired, the lips may be selectively releasably secured to the rest of the apparatus by means of clamps or other releasable attachment means so that different types of lips may be interchanged, as desired by the operator.

Although the apparatus according to the present invention has thus far been illustrated as being utilized to deliver slurry streams in a generally horizontal direction onto a horizontally disposed web-forming surface, the principles of the invention may be employed on apparatus adapted to deliver a slurry in other than a horizontal direction and onto a web-forming surface that is disposed other than horizontally; for example, the present system may be utilized in combination with a generally vertically disposed twin wire paper former, such as the Verti-Former former manufactured by the Black Clawson Company and the Bel Baie former manufactured by Beloit Corporation.

An embodiment of the present invention that may be employed in connection with generally vertically disposed formers is illustrated in FIG. **10.** This apparatus incorporates several features already discussed, such as the dual entraining fluid system and dual fluid attachment surfaces which permit operation at speeds and slice openings greater than those obtainable with the single foil surface arrangement. Also, the apparatus of FIG. **10** incorporates an arrangement whereby the position or discharge angle of the entraining fluid slits may be varied with respect to the direction of slice discharge, thus providing a high degree of adjustability to the system. Furthermore, the system can be fed with two or more separate entrained flow slurries or with a single slurry, as desired.

The entraining flow is supplied under pressure through flexible supply conduits **198***a* and **198***b* and thence into fluid flow paths **196***a* and **196***b* defined by rotatable members **190***a* and **190***b* and their respective attached cantilever members **200***a* and **200***b*. *Rotatable members 190a* and **190***b* are selectively rotatably mounted relative to members **193***a* and **193***b*, respectively, these latter members having a cylindrical configuration with a portion of the circular outer surfaces thereof constituting opposed, convexly-curved fluid-flow attachment surfaces **206***a* and **206***b*, defining along with cantilever members **200***a* and **200***b* a pair of narrow opposed slits. Because of the Coanda effect, the entraining fluid expelled through these respective slits attaches to the fluid-flow attachment surfaces **206***a* and **206***b* formed on members **193***a* and **193***b*.

The slit openings can be adjusted by operating cams **210***a* and **210***b*, while slit location with respect to the fluid-flow attachment surfaces **206***a* and **206***b* can be appropriately adjusted by rotation of pinions **194***a* and **194***b* which, in turn, will rotate members **190***a* and **190***b* and other integrally attached elements in the manner previously disclosed relative to the apparatus

of FIGS. 7, 8 and 9. Dimension B, which is the throat or distance between the foil surfaces 206*a* and 206*b*, is not adjustable in the arrangement here illustrated; however, suitable means for providing such adjustment could be readily devised and utilized where appropriate.

The entrained slurry is supplied from one or more head control boxes similar in design and concept to that shown in FIG. 1, but not illustrated in FIG. 10. Slurry flow from the head control box (or boxes) then proceeds via flexible tubes 212*a* and 212*b* through side walls 214*a* and 214*b* into a passageway defined by lower baffle member 220 and curved upper plates 222*a* and 222*b* which are attached to the side walls. The walls 214*a* and 214*b*, the plates 222*a* and 222*b* and the lower baffle member 220 may be constructed of any suitable material, such as plastic or stainless steel.

Plates 222*a* and 222*b* are curved upwardly, as shown, to provide a centrally disposed orifice in communication with throat opening B. The uppermost portions of the plates 222*a* and 222*b* are in fluid-tight, slideable engagement with cantilever members 200*a* and 200*b*, respectively. Member 220 is shaped to insure that the slurry passageway gradually converges as it approaches the throat opening. Two or more types of slurry material may be introduced into the system merely by placing conduits 212*a* and 212*b* in communication with separate sources of different slurries. Slurry material will then enter the system from both the right and left sides, as viewed in FIG. 10. If, however, the operator wishes to draw slurry from only one side of the unit, a baffle plate, such as baffle plate 240 (illustrated by dashed lines), may be mounted in any suitable manner within the system to cut off flow from one side or other of the system.

By virtue of the Coanda effect previously described, slurry flowing into the passage defined by plates 222*a*, 222*b* and baffle member 220 is drawn into the throat opening and through the passage formed by the slice lips 176*a* and 176*b* which are suitably positioned by prime movers 186*a* and 186*b*. The combined flows then proceed toward the exit aperture where the discharge is intercepted between the converging continuous twin wires 216*a* and 216*b* which, together, comprise the web former section of a generally vertically disposed twin wire former of the type described above. For purposes of simplicity, only this portion of the former is shown since the operation of such devices is well known.

It will be appreciated that apparatus constructed in accordance with the teachings of the present invention may take forms other than those illustrated. For example, the apparatus may be adjustably rotatably mounted to provide for any desired angular orientation relative to a web-forming surface, including in a generally downwardly direction. Also, suitable elements, such as deflector plates, may be disposed in the slurry flow path to additionally modify the flow characteristics of the slurry.

We claim:

1. Apparatus for delivering a fiber slurry to the forming surface of a sheet- or web-forming machine, including:

means defining a flow path for said slurry and leading to an elongate exit aperture;

means defining at least one elongate, narrow slit communicating with said flow path and extending substantially parallel to said exit aperture closely adjacent thereto;

means for introducing an entraining fluid through said slit and into said flow path at a velocity substantially greater than the flow velocity of said slurry immediately upstream from said slit; and

a convex, generally curved fluid-flow attachment surface leading from said slit toward said exit aperture to which the entraining fluid attaches itself due to the Coanda effect and exerts a substantial pulling force on said slurry to entrain and accelerate said slurry toward said exit aperture while mixing with said slurry, and provide a high percentage of all energy required to accelerate said slurry.

2. The apparatus according to claim 1 wherein said slit is disposed substantially perpendicularly to said slurry flow path.

3. The apparatus according to claim 1 including means for selectively varying the location of said slit relative to said flow attachment surface.

4. The apparatus according to claim 1 including means for selectively varying the angular disposition of said slit relative to said slurry flow path.

5. The apparatus according to claim 1 wherein said flow-path defining means includes a pair of spaced-apart lips for directing said entraining fluid and the entrained slurry to said forming surface.

6. The apparatus according to claim 5 wherein said fluid-flow attachment surface is formed on at least one of said lips.

7. The apparatus according to claim 5 additionally including means for adjustably moving said lips relative to one another.

8. The apparatus according to claim 5 wherein at least one of said lips is constructed of a flexible material.

9. The apparatus according to claim 5 wherein one of said lips extends inwardly from said exit aperture a sufficient distance such that a portion thereof is juxtaposed relative to said slit.

10. The apparatus according to claim 1 wherein said entraining fluid introduction means is adapted to introduce said entraining fluid into said flow path at a flow velocity equal to at least ten times the flow velocity of the slurry immediately upstream from said slit.

11. The apparatus according to claim 1 wherein said entraining fluid introduction means is adapted to introduce said entraining fluid into said flow path at a kinetic energy level of at least fifty times the magnitude of the kinetic energy level of the slurry immediately upstream from said slit.

12. The apparatus according to claim 1 additionally including means for adjusting the size of said slit.

13. The apparatus according to claim 1 wherein a plurality of slits communicate with said flow path and said means for introducing said entraining fluid into said flow path includes means for forcing entraining fluid through each slit and a fluid-flow attachment surface leading from each slit, each said fluid-flow attachment surface being positioned to direct the fluid attached thereto in a downstream direction.

14. The apparatus according to claim 13 additionally including separator means disposed in said flow path between at least some of said fluid-flow attachment surfaces.

15. The apparatus according to claim 1 wherein said means defining a flow path for said slurry includes a headbox chamber.

16. The apparatus according to claim 15 wherein baffle means is disposed in said headbox chamber for the purpose of smoothing the flow of said slurry along said flow path.

17. The apparatus according to claim 1 wherein the ratio of the radius of curvature of said surface at the slit location to the width of said slit in the range from 2.5 to 150.

18. A method for delivering a fiber slurry to the forming surface of a sheet- or web-forming machine, comprising the steps of:

introducing a slurry mixture into a predetermined flow path;

injecting a fluid under pressure through an elongated slit disposed substantially perpendicular to said flow path into said flow path at a predetermined location upstream of said forming surface and at a velocity substantially greater than the velocity of the slurry mixture immediately upstream from said location;

attaching the injected fluid due to the Coanda effect to a convex, generally curved fluid-flow attachment surface leading in a downstream direction from said predetermined injection location whereby the injected fluid exerts a substantial pulling force on said slurry and entrains and accelerates the flow of the slurry along said predetermined flow path, and provides a high percentage of all energy required to accelerate said slurry;

mixing the injected fluid and the slurry; and

directing the mixed fluid and entrained slurry onto the forming surface.

19. The method according to claim 18 wherein the step of entraining said slurry is accomplished by creating a zone of reduced pressure in said flow path in the vicinity of said fluid-flow attachment surface.

20. The method according to claim 18 wherein said injected fluid is water.

21. The method according to claim 18 wherein said fluid is injected into said predetermined flow path at a flow velocity equal to at least ten times the flow velocity of the slurry immediately upstream of said predetermined location.

22. The method according to claim 18 wherein said fluid is injected into said predetermined flow path at a kinetic energy level of at least fifty times the magnitude of the kinetic energy level of the slurry immediately upstream from said slit.

23. A method for delivering a slurry to the forming surface of a sheet- or web-forming machine, comprising the steps of:

introducing a slurry mixture into a predetermined flow path leading toward an exit aperture disposed adjacent to said forming surface;

introducing an entraining fluid into said flow path under pressure in the form of a thin, elongated stream; and

directing the flow of said fluid toward said exit aperture by attaching said thin, elongated stream of fluid due to the Coanda effect to a convex, generally curved fluid-flow attachment surface leading from the location of introduction of said slurry toward said exit aperture whereby said slurry is pulled toward said exit aperture by a substantial pulling force exerted by said fluid to provide a high percentage of all energy required to accelerate said slurry.

24. In combination:

means defining a forming surface; and means for delivering a slurry to said forming surface comprising:

a. means defining a predetermined flow path for said slurry leading to an elongate exit aperture through which said slurry is adapted to discharge into engagement with said forming surface;

b. means defining at least one elongate restricted opening communicating with said flow path closely adjacent to said exit aperture and in substantially parallel relationship thereto;

c. a convex, generally curved fluid-flow attachment surface leading from said restricted opening toward said exit aperture; and

d. means for introducing an entraining fluid under pressure into said flow path through said restricted opening whereby said fluid attaches itself to said fluid-flow attachment surface due to the Coanda effect to exert a substantial pulling force on said slurry and direct said slurry toward said exit aperture and provide a high percentage of all energy required to accelerate said slurry.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,853,695 Dated December 10, 1974

Inventor(s) Sangho E. Back et al.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

On the Title Page, the following should be added:

-- [73] Assignee: Crown Zellerbach Corporation, San Francisco, Calif. --

Signed and sealed this 15th day of July 1975.

(SEAL)
Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks

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