METHOD AND APPARATUS FOR SUPPLYING STOCK TO PAPERMAKING MACHINE

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The present invention relates to the art of making paper, and particularly, to an improved process of and apparatus for forming continuous webs of paper.

It has previously been proposed to form paper on apparatus known as a cellular suction forming roll, either with or without a traveling forming wire trained over the roll. Apparatus of the general character, with a traveling forming wire, is illustrated and described in the patent to Ostertag and Boylan 2,418,600 wherein the roll is shown as comprising, in essence, a rotating cylindrical shell having a plurality of closely spaced holes or cells therethrough, a plurality of circumferentially spaced longitudinally extending spacer strips radiating from the surface of the shell, a formative sleeve wound tightly about and supported by the spacer strips, and a traveling Fourdrinier forming wire reaved over the formative sleeve, whereby the roll comprises a breast roll for the wire.

At the side of the roll wrapped by the wire there is mounted a stock nozzle for feeding a liquid stock suspension or furnish onto the Fourdrinier wire as it is supported by the roll, the nozzle including a portion overlying the roll and the Fourdrinier wire and defining therewith a web-forming area. Mounted within the interior of the roll are means defining suction boxes throughout and beyond said forming area, which serve to de-water the stock or furnish and pull the water into the holes or cells in the roll shell, thereby to cause a layer of fibers to be deposited on the Fourdrinier wire as the same travels through said forming area.

At the forming portion of the suction box a short distance circumferentially from the nozzle, the wire leaves the roll bearing thereon a continuous layer of fibers, i.e., a web of paper. The suction boxes terminate substantially at or slightly past this location, whereby the water held in the holes in the roll shell is released and thrown centrifugally from the roll into the space between the two reaches of the Fourdrinier wire. The web of paper is subsequently coughed off the upper reach of the wire and dried, calendered, etc., in a generally conventional manner. The processing of the web subsequent to its formation is not part of the present invention and no further reference shall be made herein to such subsequent processing steps, this invention being concerned only with formation of the web.

The forming apparatus above described has for a number of years been in successful commercial use for the formation of tissue, but efforts to utilize the same for production of book paper have not heretofore proven successful.

The object of the present invention is to provide an improved process of and improved apparatus for forming paper on suction forming roll apparatus to facilitate the formation of high quality book paper, and also to facilitate the consistent high quality formation of tissue, towelling and other papers of uniform characteristics.

More specifically, it is an object of this invention to provide an improved process of supplying a stock suspension or furnish (a suction forming roll) characterized by the steps of physically confining the stock against the forming wire under positive pressure throughout the full area of confinement, and progressively decreasing the pressure from the inlet end to the outlet end of said area.

Additional objects pertaining to the process of the present invention are to decrease the pressure on the stock without inflection points, i.e., without abrupt change; to decrease the pressure to practically zero at the outlet end of the area of confinement; to de-water the stock at a rate, the logarithm of which is an inverse function of time; and to maintain an average velocity gradient through the stock varying at an increasing rate from the inlet end to the outlet end of the area of confinement, starting at a gradient of not less than 5,000 inches per minute per inch of thickness of the stock suspension. The velocity gradient is measured radially between the forming surface of the roll and the inner surface of the nozzle connecting portion.

By attainment of these steps, books papers of excellent quality are formed on a suction forming roll.

Another object of the invention is to provide improved apparatus for forming paper on a suction forming roll characterized by a stock nozzle juxtaposed to the forming roll and having a predetermined dimension at its throat, i.e., its point of inlet connection with the roll, an outlet tip spaced circumferentially from said throat and spaced from the forming wire by a dimension less than that of said throat, and a connecting port progressively converging toward the forming wire from said throat to said outlet tip according generally to a logarithmic function, whereby to facilitate performance of the above described process.

A further object of the invention is to provide an improved stock nozzle as aforesaid wherein said connecting portion converges toward the forming wire in general accord with the formula Log D equals K A plus Log C, where D is the clearance of the connecting portion from the forming wire at any point along the nozzle, A is the linear distance of said point from the throat, C is the throat dimension, and K is a constant equal to the logarithm of the outlet dimension minus the logarithm of the throat dimension divided by the length of the connecting portion.

A still further object of the invention is the provision of an improved stock nozzle as aforesaid wherein the length of said connecting portion may vary within the range of from about 4 inches up to about 30 inches to facilitate formation of a variety of paper products (tissue, towelling, book paper, etc.) from a variety of furnish on suction forming roll apparatus.

Yet another object of the invention is to provide a stock nozzle as aforesaid cooperable with a suction forming roll directly carrying a forming wire sleeve, whereby to form the paper directly on the periphery of the roll over a short arc thereof and without necessity for a traveling Fourdrinier wire.

It is also an object of the invention to provide means for varying the speed of either or both of (a) the stock suspension and (b) the forming roll within a range of about plus or minus 25% of equal speeds thereby to facilitate attainment of the objectives of the above defined process.

The foregoing and other objects and advantages of the invention will become apparent in the following detailed description.

Now, in order to acquaint those skilled in the art with the manner of making and using my improved apparatus, and practicing my improved process, I shall describe, in connection with the accompanying drawings, a preferred embodiment of the apparatus and the preferred manners of making and using the same.

In the drawings:

FIGURE 1 is a side elevation of paper forming apparatus provided according to the present invention;
FIGURE 2 is a vertical section, on an enlarged scale, of the forming roll, stock nozzle and couch or pick-up roll of said apparatus; FIGURE 3 is a side elevation of the nozzle side seals of said apparatus; FIGURE 4 is a vertical cross-section, on an enlarged scale, taken substantially on line 4—4 of FIGURE 3; FIGURE 5 is a schematic representation of the roll and nozzle depicting the critical dimensions thereof; FIGURE 6 is a graph representing the nozzle dimensions of a 17 inch long nozzle and an ideal pressure plot for stock flowing therebetween; and FIGURE 7 is a similar graph for an 11 inch long nozzle.

With reference to FIGURE 1, it is to be noted that the same does not disclose a complete paper machine, but only the forming section thereof and the portions contiguous to the former. The former is characterized by the forming roll, indicated generally at 10, which is only a few feet in diameter, e.g., about three to five feet, yet takes the place of the extremely long Fourdriner section heretofore required in book paper machines.

The roll 10 is supported at each end on a stanchion 12, and the two stanchions are supported on and form part of a rigid skeletal frame 14 of generally box shape. To one side of the forming roll the frame supports another very similar stanchion 16, whose upper ends are provided with bearings 18 forming a pivotal support for a suspension supply frame or nozzle mount 20.

As illustrated, the frame or mount 20 preferably comprises a skeletal steel frame, narrower than the frame 14, provided adjacent its lower side and intermediate its ends with a group of closely extending trunnions 22 journaled in the bearings 18, whereby the mount is tiltable about the axis of the bearings toward and away from the cylindrical surface of the roll 10. To effect such tilting movement, jacks 24 are disposed between the lower rearward end of the mount 20 and rearward extensions of the stanchions or posts 16.

The mount 20 provides a support for stock suspension supply pipes 26 and transition pieces 28, and a stock nozzle 30. The pipes 26 and transition pieces 28 are preferably rigidly secured to the mount 20, and the pipes 26 include suitable expansion joints or the like (not shown) to accommodate pivotal adjustment of the mount 20 about the axis of bearings 18. The transition pieces 28 serve to change the pattern of stock suspension flow from the plurality of cylindrical pipes 26 into a wide thin slice of uniform dimensions and density across substantially the axial length of the roll 10 and to supply the suspension in this pattern to the nozzle 30.

The nozzle 30 comprises a fixed inlet section 32 secured to and forming an extension of the transition pieces 28 to receive therefrom and complete the formation of a continuous thin flat slice of stock suspension. The inlet section 32 tapers inwardly to maintain the stock under pressure and to complete the transition in flow and feeds the stock to the throat portion 34 of the nozzle. The throat portion 34 is comprised of a fixed lower plate or bottom lip 36 and a pivotally adjustable upper plate or top lip 38, the two defining therebetween (herein being curved to define therebetween) a nozzle throat 40 essentially tangential to the roll 10. The throat end of the bottom lip 36 is preferably a replaceable component (see FIGURE 2) to facilitate repair in the event of wear. The upper lip 38 at its rearward or inlet end mounts a cylindrical cross bar or rod 42 which is pivotally adjustable in a complemental socket formed in a two-piece mounting member 44 secured to the leading end of the upper plate of the inlet section 32, pivotal adjustment of the cross bar 42 being facilitated by one or more adjustable jacks 46 extending between the forward end of the lip 38 and the nozzle mounting frame 20.

The jack or jacks 46 are preferably connected to the top lip 38 of the throat by a two-piece mounting member 48 similar to the member 44, whereby to define a cylindrical support rod 49 provided at the rearward or inlet end of the nozzle roll or connecting portion 50. The connecting portion 50 is juxtaposed to and has a predetermined relationship to the forming wire supported by the roll 10, as will be described presently, and terminates in an outlet tip 52. The tip 52 is adjustably supported relative to the roll by a pivotal connection 54 similar to those previously described and adjustable jacks 56 extending between the connection 54 and the mounting frame 20. If desired, the connecting portion 50 may be subjected to a pre-stressing load by means of a compression spring 58.

Mounted on the frame 14 in circumferentially spaced relation to the outlet tip 52 of the nozzle 30 (by conventional means not shown) is a suction pick-up or couch roll 60 over which a pick-up felt 62 is movably guided, whereby the web of paper formed on the roll 10 may be picked off and carried away from the roll on the lower side of the felt.

Surrounding the periphery of the roll in the space intervening between the pick-up roll 60 and the inlet portion of the stock supply mount 20 is a water collection box or sump-all 64 for collecting and suspending the suspension fed to the roll. Throw-off water collected in the box is returned to the white water system.

Referring to FIGURE 2, the roll 10 is shown in greater detail as comprised of a cylindrical shell 69 of significant thickness having a plurality of closely spaced radial holes or cells 70 therethrough whereby the shell is typified as cellular in that each hole 70 defines a water receiving cell. Radiating from the surface of the shell 69 are a plurality of circumferentially spaced longitudinally extending support ribs or flanges 71, which support a foraminous surfacing material (not shown in detail) and over this material is disposed the forming wire. If desired, a traveling Fourdriner wire could be employed, as illustrated in Ostertag and Boylan 2,418,600, but I prefer that the wire be in the form of a sleeve 72 intimately engaged with and constituting the periphery of the roll 10.

The shell 69 is so constructed and journaled on the stanchions 12 (all in manner known in the art) that the shell rotates about a stationary insert 73 disposed within the shell. The insert 73 may comprise one or more conduits, such as the tube 74 illustrated in FIGURE 2, connected respectively to sources of predetermined vacuum pressures (not shown).

The suction conduits, such as tube 74, mount circumferentially adjustable baffles or partitions 75 which extend from end-to-end of the roll and are each provided with a seal 76 engaging the inner surface of the shell 69. The partitions 75 being stationary in use define a plurality of respective vacuum chambers or sectors, such as the sectors 77, 78 and 79 depicted in FIGURE 2. The number of chambers may vary from one to several depending upon various circumstances, and the degree of vacuum in each may be predetermined or adjusted for a variety of particular purposes, now known in the art or to become known from the following description. At a minimum, there are at least two partitions defining at least one vacuum chamber, and the vacuum chamber area extends from approximately the nozzle throat 40 to approximately suction pick-up roll 60.

The purpose of the vacuum chambers is to assist in or cause de-watering of the stock suspension and to retain the water drained from the stock against centrifugal expulsion through the formed web. To this end, the chamber 77 may be evacuated to a predetermined degree to give assistance in initial de-watering and to pull the drained water into the cells 70 in the perforated shell 69. The chamber 78 may then be subjected to a somewhat higher degree of evacuation to assist in de-watering the
web (which is now at least partially formed within the nozzle area) and to overcome the resistance of the web to drainage. At the outlet tip 52, the degree of vacuum may be increased, further to de-water the web, or may be decreased so that only sufficient vacuum pressure is exerted in chamber 79 to retain drained water within the cells 70. Then, at the suction pick-up roll, at about the point where the web leaves the forming roll, the chamber 79 terminates whereby the water is released and thrown centrifugally from the roll into the water collection box 64 without contact with the formation.

The complete construction of the forming roll 10 is neither illustrated nor described herein as the roll and its operational characteristics are known in the art and are not the crux of the illustrated embodiment of the apparatus of the invention. Reference is made by way of example to the previously mentioned Patent 2,418,600, the patent to Cirrito and Reitze 2,991,218 and Canadian Patent 621,881, issued June 13, 1961, to John R. Curtis and me.

The pick-up felt 62 and the suction cloth roll 60 are of conventional construction, the felt suitably consisting of a porous cloth web and the roll being perforate and mounted therein a suction box 80 facing the roll 10 for causing the felt 62 to pick the paper web off the forming wire 72 on the roll.

In an apparatus, the pick-up roll 60 is preferably located in the upper half of the forming roll on the downward coming side so gravity can assist in water throw-off, and the nozzle 30 is located in the upper half of roll 10 on the upcoming side.

To seal the nozzle at its sides, side seals 81 are mounted on each side of the connecting portion 50 of the nozzle. The seals extend from the oncoming side of the nozzle throat 49 to the outlet tip 52 and each comprise (as shown in FIGURES 3 and 4) a guide plate 82 secured to and extending upwardly from the respective side of the nozzle connecting portion 50, a seal plate 83 slidably engaging the guide plate and slidably sealed, preferably by an O-ring, to the side edge of the nozzle portion 59, a seal 84 of triangular cross-section engaged with the wire at its lower edge and with a beveled lower edge portion of the seal plate 83 at its inner side, and a plurality of seal setting and locking screws 85 adjustably clamped at spaced locations to the plate 82 and area on the outer side of the seal 84. To facilitate proper adjustment of the seals relative to the roll and the nozzle, following the several adjustments provided for the nozzle components, an arcuate slip joint 86 is incorporated in each side seal, the arc of the joint being struck from a pivot axis 22 of the bearings 18 (see FIGURES 2 and 3). Thus, each seal may be precisely adjusted so that its lower edge bears with just the proper pressure on the surface of the forming wire on the roll.

At the same time, the nozzle 30 is mounted for pivotal movement toward and away from the roll 10 to facilitate adjustment of the lower lip 36 of the nozzle relative to the forming wire and to accommodate spacing of the nozzle from the roll to facilitate replacement or repair of the forming wire. Adjustment of the lip relative to the roll is preferably such that leakage or back-up stock suspension at the lower lip amounts to a small fraction of total flow, due to a combination of the viscosity of the stock, the speed of rotation of the roll and the spacing of the lip from the roll. Actual contact of the lip with the forming wire is carefully avoided to mitigate damage to or excessive wear of the wire or other machine components.

In use of the apparatus, stock suspension or furnish is supplied under pressure via the pipes 26 and transition pieces 28 to enter the nozzle 30 as a thin uniform slice spread evenly across the width of the nozzle, the stock being confined at the side edges of the nozzle by the seals 81. The stock suspension supply means preferably is of variable capacity and the roll is driven by variable speed drive means, whereby the speed of the stock and the peripheral speed of the roll may be varied within the range of about plus or minus 25% of equal speeds, for imparting various characteristics to the paper being formed, especially with respect to the web formation.

The stock suspension is fed under pressure substantially tangentially of the roll onto the area of the forming wire then entering the suction zone 77, whereupon the pressure differential causes de-watering of the stock through the wire and consequent formation of a web on the wire. As the wire and stock proceed through the area of confinement by the connecting portion 59, the lip 36 and the side seals 81 of the nozzle 30, the stock is progressively drained through the wire and a continuous web is formed on the roll. Both the pressure maintained on the stock by the connecting portion 59 and the vacuum exerted via chambers 77 and 78 hastens de-watering of the stock suspension so that the web is substantially completely formed on the wire within the area of the connecting portion 50.

Water drained from the stock and retained in the cells 70 of the forming roll 59 is held within the suction in chambers 77, 78 and 79 until the formed web is picked off the wire by the felt 62. The web then proceeds to subsequent processing steps and the filtrate is released from the cellular roll and centrifugally thrown into the collector box or save-all 64. Formation of a web on the forming wire thus proceeds continuously as the roll 10 rotates, whereby a continuous web of paper is transported from the roll by the felt 62. As is known in the art, the roll 10 may be of substantially any selected width to facilitate formation of a web of paper of any conventional or desired width.

According to the present invention, web formation is significantly enhanced and the formation of book papers on cellular suction forming rolls is facilitated by the performance of a particular process pertaining principally to the supply of the stock suspension and the maintenance of certain fluid dynamic conditions within the forming zone defined by the connecting portion 50 of the stock nozzle 30. These dynamic conditions, the process steps of this invention, are summarized as follows:

(1) The stock suspension must be maintained under positive pressure throughout the entire forming area.

(2) From the inlet end to the outlet end of the forming area or zone, the pressure on the stock suspension must progressively decrease, approaching zero at the outlet.

(3) There should be no inflection points or abrupt changes in the progressive decrease in pressure on the stock.

(4) The rate of drainage of the suspension should preferably be logarithmic.

(5) The average velocity gradient through the suspension at the inlet should not be less than 5,000 inches per minute per inch of thickness.

(6) The average velocity gradient should increase progressively from the inlet to the outlet of the forming zone.

When the above steps are fulfilled, I have found that book paper of excellent characteristics is formed on a cellular suction forming roll. Also, adherence to the fluid dynamic conditions stated results in significant improvement in the formation of other papers on suction forming rolls, notably tissue and lining.

While the above process steps may be performed in various manners, I believe the mode most convenient and practical at this time to reside in appropriate formation of the stock nozzle 30, and the preferred embodiment of the apparatus of my invention is characterized by a stock nozzle having particular structural relation to the forming roll, the furnish, the intended speed of operation, etc.

The length of the forming area may be varied within wide limits and is frequently selected on the basis of the skill of an expert in the art of paper making. However, the forming length, i.e., the length of the connecting portion 59 of the nozzle, may be determined pursuant to the formula:
where:

W is the basis weight of the paper to be formed;
\( u \) is the viscosity of the stock suspension;
S is the specific filtration resistance of the stock suspension;
V is the velocity of the forming wire;
K is the ratio of the average forming weight to the final weight of the paper;
R is the percent retention of the stock on the wire;
X is the percent consistency of the stock;
P is the friction pressure drop across the paper; and
p is the density of the stock suspension.

Similarly, the dimension of throat 40 and the clearance of tip 52 from the wire may be selected within the skill of the art. Preferably, the tip 52 is spaced from the wire by a distance slightly greater than but substantially equal to the caliper or thickness of the wet sheet to be formed within the nozzle, and the throat dimension may be determined by the formula:

\[
\frac{W \times 12 \times 10^6}{3300RX \times 62.4}
\]

where:

W is the basis weight of the paper to be formed in pounds per 3300 square foot reel;
R is the percent retention of the stock on the wire; and
X is the percent consistency of the stock.

Referring to FIGURE 5, the throat dimension is designated C; the spacing of the tip 52 from the wire is designated E; the length of the forming zone, i.e., the length of the nozzle connecting portion 50, is designated L; the portion 50 is divided into a plurality of equally spaced stations numbered in sequence and collectively designated A; and the clearance of portion 50 at each of the stations A is designated D. The terminal end of the lower lip 36 constitutes the zero or starting one of the stations. Thus, in FIGURE 5 the designations A, C, D and E have the following meaning:

A is the linear distance of station lines from the throat or zero station.
C is the throat dimension.
D is the clearance between the nozzle profile and the breast roll O.D. at the various stations.
E is the clearance between the end of the nozzle and the O.D. of the breast roll.

By application of the skill of the art and/or the above formulas, the three starting dimensions of forming length, throat dimension and end clearance may be determined or decided upon, and the stock supply devised to supply the suspension to the throat at a pressure equal to the maximum desired forming pressure.

While the above formulas have been given as reasonable guides to determination of forming length and throat dimension, it is to be appreciated that there are many variables in the formulas subject to selection by those skilled in the art. It is well recognized that the relationships between forming length, throat dimension, forming pressure, machine speed, stock speed and stock characteristics (principally specific filtration resistance) are quite complex, and that the above formulas are necessarily predicated upon a rough or generalized analysis of the existing relationships. Consequently, the formulas are not to be interpreted as rigid specifications for the stock nozzle of this invention, but simply as reasonable guides to design of acceptable nozzles. For example, the formula for forming length reveals that the forming length is approximately proportional to the square of the sheet weight, but that the length varies in accord with variations in the net effect of variations in filtration resistance, machine speed, forming pressure, etc. For example, an increase in machine speed (normally requiring increased forming length) could be offset by increase in forming pressure (which usually would decrease forming length). Thus, variations from the formulas are expected.

In general, forming length L, i.e., the length of the connecting portion 50, will be within the range of from about 4 inches up to about 36 inches, depending upon the expressed variables. Tip clearance E is never less than the caliper of the wet sheet issuing from the nozzle, and is preferably equal to wet sheet caliper. However, the tip may have a slight extra clearance, say .005 inch, so as to avoid interference with the wet mat, accommodate a lubricating effect between the mat and the lip, and mitigate spouting. In general, L will lie within the range of .010 to .060 inch. The throat dimension C, which has been discussed in detail above, will generally lie within the range of .25 to 1.25 inches; and the spacing of the bottom lip 36 of the throat from the roll will lie within the range of about .630 to .735 inch depending upon the weight of the sheet formed, stock consistency, machine speed and the cleanliness of the forming wire (plugging under the bottom lip due to inadequate clearance for fiber retained on the wire could create serious problems).

With the foregoing in mind, and by application of the skill of the art and/or the above formulas, the three starting dimensions L, C and E may be determined. Then, the critical dimensioning of the connecting portion 50 may be determined.

According to the present invention, automatic performance of the process is facilitated by the provision of a stock nozzle that converges progressively and smoothly toward the peripheral surface of the roll according generally to a logarithmic function. Such convergence tends to force drainage of the stock at a rate the logarithm of which is an inverse function of time and assist in maintaining the stock under positive pressure throughout the forming area or zone. The smooth progression of the convergence toward the roll is also compatible with the objective of progressive decrease in stock pressure without inflection points. Whatever the reasons in their entirety may be for attaining the result, I have found that if the connecting portion of the nozzle converges toward the roll according to a logarithmic function, I am able to produce high quality book papers on cellular suction forming rolls.

Specifically, I have ascertained that excellent production results are attained if the connecting portion 50 of the nozzle progresses from the throat 40 to the outlet tip 50 in general accord with the formula:

\[
\log D = kA + \log C
\]

where:

D is the clearance of the connecting portion from the forming wire at any point along the length of the forming area;
A is the linear distance of the point from the nozzle throat;
C is the throat dimension; and
\( k \) is a constant equal to the logarithm of the tip clearance minus the logarithm of the throat dimension divided by the length of the connecting portion, i.e., with reference to FIGURE 5, Log E minus Log C over L.

Similar to the other formulas presented in this application, the above formula for dimension D permits reasonable variation from the precise dimension determined thereby. For example, I have found in practice that deviation from the formula may run 30% and even up to a maximum of 45%, without resulting in inoperativeness or unacceptable sheet formation, provided changes in curvatures are not abrupt. The capability for deviation, is, of course, a commercial advantage since fabrication and maintenance of the connecting portion to precise dimensions can prove difficult.
As illustrated in FIGURE 5, the points at which D is determined, i.e., the stations A, may be selected as equal increments (say one inch) from the zero station to the outlet tip, the dimension D determined for such stations, and the graph plotted from the resulting points. However, I have further discovered that a simple graph may be prepared on semi-logarithmic paper whereby nozzle dimensions may simply be picked from the graph to facilitate construction of the nozzle connecting portion 50.

For example, in FIGURE 6, I have illustrated a graph, the abscissa of which is evenly divided into increments representative of and denoting nozzle stations A at one inch increments along a 17-inch nozzle, and the left-hand ordinate of which is a logarithmic scale denoting Log D. The graph is readily prepared since its abscissa is equal to the connecting portion length (previously determined per the formula above given), the lowest required point on the ordinate is the lip clearance E (previously determined) at the last station, station 17, and the highest required point on the ordinate is the dimension C at the throat or zero station (C having already been determined per the foregoing). Since the ordinate is a logarithmic scale, the calibrations or graduations thereon give the dimension D directly. While the graph ordinate and abscissa are thus appropriately calibrated or graduated, throat dimension C (in this case .469 inch) is entered above the station and the appropriate ordinate of the left-hand ordinate, tip clearance E (in this case .015 inch) is entered above the last station, station 17, opposite the appropriate graduation on the left-hand ordinate, and a straight line is struck between these two points, as illustrated by the solid line D in FIGURE 6. Then, the clearance of the incoming portion 50 at any of the stations A (and all desired intermediate stations), may be picked directly off the graph using line D and the left-hand ordinate, thereby to facilitate fabrication of the required nozzle.

In actual use of a nozzle closely approaching the straight line D in FIGURE 6, the hydraulic pressure at each of stations A was determined by pressure gauges installed in apertures in the connecting portion 50 at the respective stations and the readings taken revealed that the pressure condition of the stock suspension between the nozzle portion 50 and the forming wire was essentially that depicted in dotted line P in FIGURE 6, the pressure being plotted against the uniformly divided right-hand ordinate in inches of water pressure. The resultant curve is an excellent representation of the fluid dynamic conditions to be maintained in the nozzle according to the present invention, i.e., the pressure decreasing progressively from the inlet or throat C to the outlet tip E without inflection points and approximating or approaching zero pressure at the outlet tip. The result was production of excellent book paper.

In FIGURE 7, I have shown a second graph, this time of an 11-inch long nozzle having a throat dimension C of .469 inch and a tip clearance E of .015 inch. The two dimensions are shown as properly marked on the graph paper at stations zero and 11, respectively, and a straight line D (solid line) drawn therebetween. Again, using line D the abscissa and the left-hand ordinate, the dimensions D along the entire connecting portion 50 of the nozzle are quickly determined.

With a nozzle structure closely approaching the configuration dictated by line D of FIGURE 7, and again measuring fluid pressure at the stations A and plotting the results, I have a uniformly divided right-hand ordinate, another example of an excellent pressure plot resulting in excellent paper formation is depicted by dotted line P-1. With another nozzle, a substantially straight line pressure plot was obtained, such as depicted by chain line P-2 in FIGURE 7. While the pressure plot P-2 is substantially a straight line, the pressure plot P-1 is an exponential curve and the pressure plot P of FIGURE 6 is a logarithmic curve, all three represent several common characteristics which are the essence of this invention, i.e., positive pressure on the stock throughout the forming area, progressive decrease in stock pressure from the inlet to the outlet, absence of the inflection points (more particularly a smooth curve) and an approach to zero pressure at the outlet. With these characteristics, enhanced sheet formation is obtained, and formation of book papers on cellular suction forming rolls is facilitated.

Book paper is a smooth surfaced printing paper for books, magazines, etc., generally characterized by even formation, good uniform finish and opacity. Basis weight runs from about 28 to 120 pounds per 3300 square feet. The paper may have a machine finish from very low to very high, it may be calendered with or without being sized, it may be utilized as the base stock for coated papers, and it may be made in numerous grades. Terms such as smoothness, opacity, finish, brightness, etc., are relative terms not completely definitive of the paper, but the characteristic feature of opacity is generally attained by the presence of a mineral filler. Herein, it is intended as a rule-of-thumb to regard book papers as those having not less than about 3% mineral filler content and usually (though not always) containing groundwood.

Formation of book paper is rendered difficult by virtue of the resistance to filtration of the stock suspension or furnish from which the fibers, the fibers of the furnish having high bondability. Book paper furnish comprises, in general, an aqueous suspension of chemical fibers, groundwood and mineral filler having a Canadian Standard freeness in the order of from about 125 cc. to about 175 cc. The relatively low freeness indicates the resistance to filtration, as contrasted for example to a tissue suspension freeness of 300 to 350 cc. Due at least in part to filtration resistance, it has not been feasible heretofore to form book paper on cellular suction forming rolls due to the limited time and space available for web filtration.

In contrast, the present invention provides for formation of excellent book paper directly on the surface of a cellular suction forming roll. Typical data for formation of a twenty-six pound book paper base reveals a 12-inch long forming area, average forming pressure of 30 inches of water, a through dimension of .438 inch, a tip clearance of .024 inch, and a machine speed of 1200 feet per minute. The result is excellent book paper.

Thus, a primary advantage of the present invention is seen to be the provision of an improved forming method for the manufacture of book papers, particularly lightweight publication papers and coating base sheets which will maximize printing performance of the coated sheets. A second advantage of the invention is a capability of fabrication of high quality publication and book papers having greater uniformity, both in the machine and cross directions, and having as well equal or uniform characteristics on both the wire and felt sides thereof.

Contributing markedly to attainment of the above stated advantages is the fact that the method and apparatus of the present invention result in remarkably high retention of fibers on the forming wire. High fiber retention has always been a goal in operating conventional Fourdrinier machines. In general, Fourdrinier machines have a fiber retention of about 50%, with 55% being considered a high level. The retention characteristic is closely associated with the distribution of groundwood fibers through the thickness of the sheet and the retention of fines in general. A conventional Fourdrinier sheet reveals a wide side low in groundwood content and high in chemical fiber content, while the felt side thereof shows a much higher concentration of groundwood and fines and a much lower concentration of chemical fibers.

In contrast to the results with Fourdrinier machines, the method and apparatus of the present invention result
in fiber retention from 75 to 90% as measured both by head-box and tray-water measurements, and by the total weight of the sheet made in a unit length of time. In contrast to the Fourdrinier sheet, the paper produced according to this invention has extremely high uniformity, both the wire and felt sides having substantially identical proportions of groundwood and chemical fibers, both sides having a retention of fines substantially the same as the felt side of a Fourdrinier sheet, and the sheet being particularly characterized by a wire side having extremely high groundwood content as compared to the wire side of a Fourdrinier sheet.

Furthermore, the physical strength of the sheet formed pursuant to the present invention appears to be entirely adequate, the sheet having significantly higher Mullen and about equal tear relative to a comparable Fourdrinier formed paper, and bulk also appears to be high or at least adequate on the basis of experimentation to date. All of these factors considered conjointly reveal attainment of a truly superior base sheet.

A third particular advantage of the invention is the formation of high quality book papers of greater uniformity and lighter weight than heretofore possible. In addition to inherent advantages, the capability of formation of lighter base weights for book papers means substantial savings in the mailing and handling of magazines, etc.

A fourth advantage of the invention is the development of new sheet forming equipment which is simple, of minimum cost, has predictable operation, and is compatible with other machine components such as presses, dryers, etc. The machine of the present invention meets all of these requirements. In the first instance, the forming apparatus provided according to this invention is only about 25% the size of a conventional Fourdrinier former required for production of book paper of generally comparable quality. Obviously, this results in substantial decrease in machinery costs and in the cost of buildings required to house the machinery, and also in the maintenance of the machinery and the buildings. Furthermore, the speed possibilities of the present invention are excellent. Good operation and excellent sheet formation have already been obtained on 26-pound base weight sheets at speeds of 1000 to 1800 feet per minute. While there are some physical limitations as to the length of the forming zone that can be employed and obtain good operability, experience indicates that the machine of the present invention has a high speed potential particularly for lighter grades of publication papers. Speeds of 3000 feet per minute are entirely reasonable.

The machine configuration afforded according to the invention also is entirely practical for commercial production as far as adjustment, maintenance and wear factors are concerned. Wear on experimental machines has been extremely slight, and it is further to be considered that the relatively small amount of forming wire material required according to this invention is so much less than that required for a Fourdrinier machine, that it is economically feasible to change the forming wire on the machine of this invention more frequently than on a Fourdrinier machine. The operability and repeatability of the machine have been excellent, and both are marked improvements over equipment in current commercial use.

While the above advantages have been described with reference to book papers, these advantages are also applicable to other formations of other papers and contribute substantially to the convenient, practical and uniform formation of papers previously formed on cellular suction rolls, notably tissue. For example, the present invention facilitates formation of lightweight tissue by utilization (for example) of a 7-inch forming length, an average forming pressure of approximately 15 inches of water, a throat dimension of .415 inch, a tip clearance of .030 inch, and a machine speed of 2800 feet per minute.

For formation of toweling of 32 pound basis weight, a suitable forming length would be 9 inches, average forming pressure 20 inches, throat dimension .450 inch, tip clearance .035 inch and machine speed 2400 f.p.m.

Thus, all of the objects and advantages of the invention and the full application thereof have been shown herein to be attained in a convenient, economical and practical manner.

While I have shown and described what I regard to be the preferred embodiment of the apparatus of my invention, and have described the preferred manner of practicing the method or process of my invention, it is to be appreciated that various changes in arrangement and modifications may be made therein without departing from the scope of the invention, as defined by the appended claims:

I claim:

1. In a papermaking machine of the forming roll type, a stock nozzle juxtaposed to a forming surface on the roll and having a throat, an outlet tip and side seals, said throat having a bottom lip and a top lip, and a stock inlet having an approach channel communicating with said throat, said approach channel carrying said bottom lip and being pivotally mounted on an axis parallel to the axis of the roll for adjusting said bottom lip relative to the forming surface, said side seals being slidably connected to said approach channel along an arc the axis of which coincides with the pivot axis of said channel, whereby said channel may be adjusted without affecting said side seals.

2. In a papermaking machine of the forming roll type, a roll shaft defining the axis of rotation of the roll, a stock nozzle juxtaposed to a forming surface on the roll and having a throat including a bottom lip and a top lip, said top lip projecting beyond said bottom lip, extending over the forming surface and terminating in a butt-end, said top lip converging toward the forming surface from said throat to said outlet tip, adjustable mounting means for independently adjusting said top lip radially of the roll, a stock inlet having an approach channel communicating with said throat, said approach channel carrying said bottom lip and being pivotally mounted on an axis parallel to the axis of the roll, and means for independently adjusting said approach channel for adjusting said bottom lip radially of the roll, said adjusting means accommodating movement of said nozzle away from the roll to facilitate servicing of the roll.

3. A method of forming on a suction forming roll printing papers and the like having a mineral content of not less than 3%, said method comprising the steps of physically confining a stock suspension against a forming surface on the roll, maintaining the pressure in the area of confinement so that said stock suspension is under positive pressure throughout the area of confinement, and progressively decreasing the pressure on said stock suspension from the inlet end to the outlet end of said area by regulating the following variables, (1) the convergence of a stock nozzle member which confines the suspension, (2) the rate at which the stock suspension is supplied, (3) the drainage resistance of the stock suspension, (4) the vacuum within the forming roll, and (5) the speed of the forming roll.

4. The method of claim 3 including the steps of regulating said variables to progressively decrease said pressure without inflection points from the inlet end to the outlet end of said area of confinement.

5. The method of claim 3 including the step of regulating said variables to produce drainage of the stock suspension substantially at a rate the logarithm of which is an inverse function of time.

6. The method of claim 3 including the steps of supplying the stock suspension approximately at the speed of the roll and 15 inches of water, and adjusting the suspension relative to the throat dimension of a stock supply nozzle so as to provide an average velocity gradient
through the suspension of at least 5,000 inches per minute per inch of thickness at the inlet end of the area of confinement.

7. The method of claim 4 for making book paper where said stock suspension is comprised of chemical fibers, groundwood and mineral filler and has a Canadian Standard Freeness on the order of from about 125 cc. to about 175 cc., including the step of regulating said variables so that said pressure approaches zero pressure at the outlet end of the area of confinement.

8. In a papermaking machine of the suction forming roll type, the improvement comprising a stock nozzle juxtaposed to a forming surface on the roll so as to deliver stock suspension to the roll in a direction substantially tangential to the surface of the roll, said nozzle having a predetermined throat dimension, an outlet tip spaced from the forming surface by a lesser dimension, and a nozzle connecting portion progressively converging toward said forming surface from the throat to the tip according generally to a logarithmic function.

9. The invention of claim 8 where said nozzle includes a lower lip which first approaches the surface of the roll in a non-tangential direction and is curved so that the end thereof is approximately tangential to the surface of said roll, and where said nozzle connecting portion progressively converges toward said forming surface from the throat to said tip in general accord with the formula:

$$\log D = \log kA + \log C$$

where:

- $D$ is the clearance of the connecting portion from the forming surface at any point along the length of said connecting portion,
- $C$ is the throat dimension,
- $A$ is the linear distance of the point from said throat and $k$ is a constant equal to the logarithm of the tip clearance minus the logarithm of the throat dimension divided by the length of the connecting portion.

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