

April 29, 1958

G. C. BOONE ET AL
METHOD OF IMPROVING FLOW OF STOCK FROM
THE STOCK INLET OF A PAPER MACHINE

2,832,268

Filed July 29, 1954

3 Sheets-Sheet 1

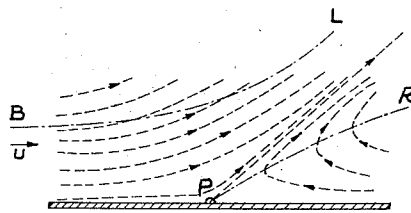


FIG. 1



FIG. 2

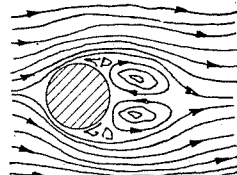


FIG. 3

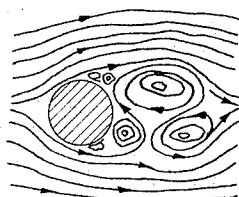


FIG. 4

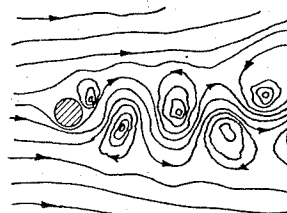


FIG. 5

April 29, 1958

G. C. BOONE ET AL

2,832,268

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3 Sheets-Sheet 2

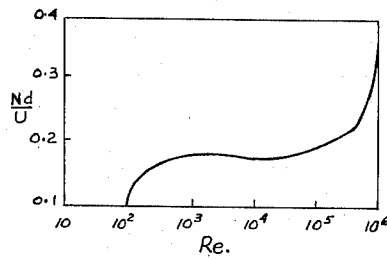


FIG. 6

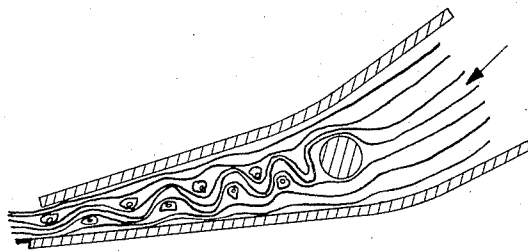


FIG. 7

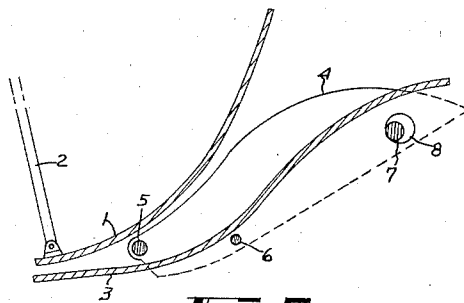


FIG. 8

April 29, 1958

G. C. BOONE ET AL
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3 Sheets-Sheet 3

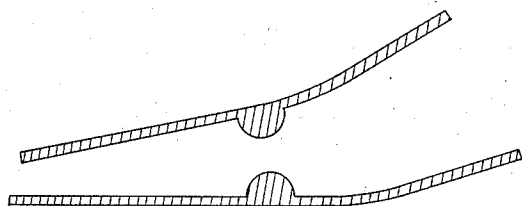


Fig. 9

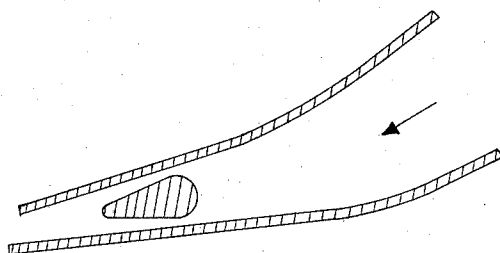


Fig. 10

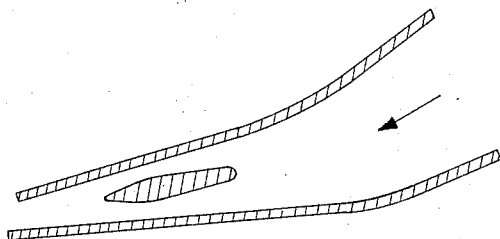


Fig. 11

1

2,832,268

METHOD OF IMPROVING FLOW OF STOCK FROM THE STOCK INLET OF A PAPER MACHINE

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Application July 29, 1954, Serial No. 446,566

9 Claims. (Cl. 92—44)

This invention relates to paper making and more particularly to a method of controlling the condition of the stock as it is introduced upon the forming table of a Fourdrinier paper machine.

The invention consists essentially in the provision of new and improved devices forming part of the stock inlet of a paper machine as hereinafter more particularly described. These devices and the effects which they produce are illustrated in the accompanying drawings in which:

Figure 1 illustrates the phenomenon of separation of flow occurring at a surface along which there is an adverse pressure gradient;

Figure 2 illustrates the rolling up of two thin vortex layers behind a cylinder disposed transversely in a stream of viscous liquid at low values of the Reynolds number;

Figure 3 shows a stage in the transition of the flow pattern as the velocity of the stream of viscous liquid past the cylinder is increased;

Figure 4 shows the further stage in the transition of the flow pattern with increasing velocity at which vortices break away into the main stream of the liquid;

Figure 5 illustrates the final stage in the transition with increasing velocity showing the Kármán vortex street which is formed;

Figure 6 shows the relation between the Reynolds number and the frequency of discharge of the vortices;

Figure 7 shows a Kármán vortex street confined within a converging channel;

Figure 8 illustrates means for varying the position of the flow-modifying member;

Figure 9 illustrates a preferred embodiment of our invention;

Figure 10 illustrates a variant of a form of non-streamlined flow-modifying member; and

Figure 11 illustrates a substantially streamlined flow-modifying member.

In paper making, the functions of a stock inlet are to receive the stock and project the stock onto the moving wire cloth in a suitable state of agitation, with uniform volume per unit time and with uniform consistency, direction of flow and velocity. In conventional practice, stock inlets include various devices designed to promote one or more of the above functions. A particular device may, however, be favourable to one function and unfavourable to another so that in the aggregate, the construction of stock inlets in commercial use includes provisions which effect a compromise between the various ideal requirements. Thus, for example, the flow of stock to the paper machine may be spread from a single pipe across the full width of the machine by first dividing the flow into two streams which are then fed into the stock inlet from opposite sides. This arrangement provides fairly uniform distribution of the stock across the machine but introduces undesirable cross-flow eddies. In an effort to compensate for this undesirable feature, perforated rolls or similar devices may be interposed in the

2

stock inlet at a point between the stock entry point and the slice. These are, however, only partially effective and, if placed too close to the slice, cause the flow of stock from the slice to divide into a number of separate streams. A further method is to employ a series of flat vertical plates or flow-eveners close to the slice in order to reduce cross-eddies in the stock flow. The introduction of such flow-eveners tends, however, to divide the flow into a series of separate streams across the width of the machine. A device which is thus introduced to reduce cross-eddies in the flow, therefore, itself promotes an undesirable systematic variation in the condition of the stock as this is discharged across the width of the paper machine. In existing machines, these various devices have been used or combined in a measure of compromise to provide a relationship tending in the aggregate toward a preferred type of flow at the point of discharge. As the speed of a machine is increased, such compromises become less satisfactory and, in many cases in practice the maximum operating speed of a machine is restricted by the inability of the stock inlet to provide a suitable flow of stock onto the wire.

In particular, the flow onto the wire may have thick and thin streaks which are caused by the nature of the flow to the slice and which cannot be corrected by adjustments in the opening of the slice. Further, some of the flow-eveners and other devices preceding the slice in the line of flow, as hereinbefore mentioned, produce disturbances which persist through the slice onto the wire. Finally, the condition of the stock as it flows onto the wire changes as the speed of the machine is increased. Thus, for example, the fibres become more highly orientated parallel to the machine direction and it becomes more difficult to make the desired quality of paper.

We have discovered that these limitations of stock inlet design may be overcome and the machine speed increased by several hundred feet per minute. In order to illustrate our invention, two particular embodiments of means will be described, but it will be realized that it is possible to employ other means to achieve the same result without deviating from the spirit of the invention as herein described and claimed.

It is well-known in fluid dynamics, that when a viscous liquid flows along a fixed boundary there is a thin layer, called the boundary layer, in contact with the boundary in which the viscous stresses are appreciable without being predominant. The liquid in immediate contact with the boundary is theoretically at rest. The motion of the liquid in the boundary layer is governed by three factors. It is retarded by friction at the boundary wall, it is pulled forward by the rest of the liquid through the action of viscosity, and it is retarded or accelerated accordingly as the pressure gradient along the surface is adverse or favourable. If the gradient is favourable it continues its forward motion and the thickness of the layer remains small. If the pressure gradient is adverse, however, the retarding forces predominate and the boundary flow is first halted and then the adverse gradient may cause flow in the reverse direction. This reverse flow causes the boundary layer to widen and the main flow to separate from the boundary. These phenomena are illustrated diagrammatically in Figure 1 in which the characteristics of motion of thin strata of fluid are indicated. The fluid flowing from left to right in Figure 1 with velocity U encounters an adverse pressure gradient. At the point P the forward stream leaves the surface and a back flow in the direction of the pressure gradient occurs. The chain-dotted line $B-L$ indicates the limit of the boundary layer and the chain-dotted line $P-R$ the limit of the region of back flow. Broken lines in the figure marked by arrow heads indicate the course of

stream-lines. The point of separation is the point at which the boundary flow reverses. With viscous liquids the flow of the liquid in a boundary layer gives rise to vorticity. If no separation of flow occurs at the edges of the boundary layer then the vorticity is confined to the boundary layer proper. When separation occurs, however, the vorticity is shed into the main stream. If no separation of flow occurs from the surface of a body then the body is said to be streamlined. In practice the term "streamlined" is extended to include those bodies for which separation of flow at the surface, when it does occur, does so very near to the downstream extremity so that the fluid closes in again behind the body producing only a very narrow wake. When we use the word "streamlined," we refer to the extended definition as above.

This invention describes a method whereby the phenomenon of separation and resulting diffusion of vorticity into the main stream may be advantageously utilized to appreciably assist in overcoming many of the previously discussed undesirable features in the flow of stock onto the wire. The conditioning of the stock produced by our invention arises from a rapid oscillatory movement between adjacent regions of the stream of stock. The amplitude of these movements affects the quality of formation in the sheet of paper produced. For a given amount of energy introduced into the flow the formation improves as the amplitude of the movement is reduced. A second purpose of this invention is to ensure that the vortex system is of high frequency and that the energy required in the stream to condition the stock produces relative motion of small amplitude. Our invention may first be illustrated by reference to one embodiment of the means employed by us in the operation of the invention.

When a viscous fluid flows past a circular cylinder, two symmetrical lines of separation occur on the downstream side. From them two thin vortex layers leave the cylinder and roll round on themselves, the vorticity becoming more pronounced in the rolled-up portion, as illustrated in Figure 2. If the velocity of the liquid is gradually increased the size of the vortices increases and they move further away from the cylinder, as illustrated in Figure 3. Eventually a stage is reached at which the system becomes unstable, the vortices break away into the main stream, and the formation of other vortices then takes place, as illustrated in Figure 4. In the case of a circular cylinder the vortices are successively discharged from alternate sides and form a double layer of vortices in the wake of the cylinder in which the vortices from one separation line are spaced between the vortices from the other line. Such an arrangement is technically known as a Kármán vortex street and certain of its properties are understood. Such a system is illustrated in Figure 5.

Such knowledge as previously existed relative to a Kármán vortex street was largely restricted to its behaviour in a liquid in which boundary surfaces other than that of the cylinder are so far removed as to have only a negligible effect on the flow adjacent to the cylinder. In such a case the frequency N at which the vortices are discharged, the diameter d of the cylinder, the velocity U of the stream, the viscosity μ and the density ρ of the fluid are related and the experimental results are best summarized graphically by the inter-dependence of two dimensionless functions, namely, the Reynolds number "Re" that is

$$\frac{Ud\rho}{\mu} \text{ and } \frac{Nd}{U}$$

This inter-dependence has been discussed in "Modern Developments in Fluid Dynamics," edited by S. Goldstein, Oxford University Press, 1950, vol. 2, sections 184 and 247, and is illustrated in Figure 6. According to this reference for values of Re between 10^2 and 10^5 the discharge of vortices is periodic; above that range the discharge is

aperiodic and there is a sudden increase in the average frequency.

In the course of our investigations we have applied this knowledge to the paper making art and have discovered that, when a Kármán vortex street is confined within a converging channel such as exists in a stock inlet, and as illustrated in Figure 7, certain features of the behaviour of vortex streets may be so regulated and controlled as to be of advantage in the production of paper on high speed machines. We have found that the same form of inter-dependence between the two quantities Re and

$$\frac{Nd}{U}$$

occurs with stock flowing past a cylinder in a converging channel. Under the high velocity gradients, in a stock inlet slice the viscosity of stock has been found to be fairly close to that of water at the same temperature and for the purposes of our invention the viscosity of water may be used in the calculations. We have discovered that in a stock inlet slice some modifications are introduced because other boundary walls are no longer remote from the cylinder. The value of U now becomes the velocity which would have occurred at the position of the cylinder had the latter not been present. We have found that, while the form of the curve of inter-dependence is similar to that shown in Figure 6 the curve is displaced horizontally to an extent which depends on the geometry of the walls of the slice and the cylinder. We found, for example, that in the case of a stock inlet slice the displacement was such that the transition from periodic to aperiodic discharge of vortices occurred at a value of Re of the general order of 5×10^4 and the transition point moved slightly towards higher values of Re on increasing the diameter of the cylinder.

A system of vortices is only stable under special conditions and it is an important feature of this invention that the conditions be chosen to give an instability in the system of a specific nature. It will be obvious to those skilled in the art that unless the conditions described in this invention are carefully observed the resulting effect on the flow of stock onto the wire, rather than permitting an increase in the machine speed, may cause it to be seriously retarded.

Instability may arise from several causes although two are especially important in the operation of this invention. First, if the velocity of the liquid is not uniform and is greatest at the position of the cylinder in the stock inlet slice, then a two-dimensional instability arises. Secondly a form of instability arises from disturbances along the length of the cylinder. Such a disturbance could arise from non-uniform flow in the slice. The second form of instability causes a distortion of the vortex pattern, in which the vorticity spreads into the system ultimately destroying the pattern. It is an important feature of this invention that the conditions for creating the particular type of instability required in the system be so chosen by selection of suitable location and dimensions of the cylinder that the spreading of the vorticity is almost entirely carried out under control, while the stream is still confined within the walls of the stock inlet slice. Unless this is done the issuing stream of stock bursts into a spray at the end of the slice. Such an issuing stream would require a large region of the wire with negligible drainage so that it might reform, otherwise the paper would have a very patchy formation and trouble would be experienced from air bubbles trapped in the stock.

The choice of the cylinder dimensions and location is governed by several criteria:

(1) It is desirable, in order to obtain the maximum advantage from the invention, to work with aperiodic discharge of vortices, i. e., with Re's in excess of 5×10^4 . We have found that Reynolds numbers as low as 10^4 may be effective but we prefer that Reynolds number be

in excess of 5×10^4 as above. With existing machines in which the profile of the stock inlet slice approach is predetermined the Re for a cylinder at any position can be calculated in terms of the viscosity of the stock and its velocity at the stock outlet.

(2) The frequency of discharge of the vortices should be as high as possible. This is attained by either working in the aperiodic zone as above or by using a small diameter cylinder or by a combination of both.

(3) The cylinder must be located at a distance back of the slice outlet sufficient to allow the vortex street to expand to the entire thickness of the stream before discharge. If the vortex street remains merely in the central portion of the stream the expansion of the vortex system continues outside the slice at such a rate as to cause the stream to break up, which is undesirable.

(4) The diameter of the cylinder must not be so small as to cause fibers to cling onto it and so start lumps which will subsequently break away. The minimum diameter will vary with the nature of the furnish of the stock. In our work we have found that rods in excess of one half inch diameter will stay clean in a newsprint furnish.

(5) When the flow across a section of the stock inlet back of the slice is not uniform, i. e., the value of U varies, then the system of vortices obtained is sensitive to the position of the cylinder relative to the two walls of the stock inlet.

(6) It is undesirable that the elements supporting the cylinder extend substantially beyond the cylinder towards the slice.

In the application of our invention to paper machines where it is desirable to operate over a range of operating speeds and where such range is sufficient to introduce changes in the flow distribution in the region of the slice, our invention may be more readily applied if a device is provided which permits adjustment of the position of the flow-modifying member to maintain the desired conditions of flow as herein set forth under various conditions of machine speed. An example of how this may be accomplished is shown in Figure 8 in which 1 is the slice lip held in position by adjusting rod 2 with relation to apron plate 3, 4 indicates one of those flow-eveener plates which have been extended to support the flow-modifying member 5. The extended flow-eveener plates such as 4 are disposed on hinged shaft 6 and shaft 7 mounted in eccentric bearing 8 which latter eccentric bearing permits adjustment of the extended flow-eveener plates and thus of the relative position of the flow-modifying member 5.

In a second or preferred embodiment of our invention, we have found that the development of two systems of vortices from flow-modifying members disposed on the slice lip and apron plate produces a stream of stock with less tendency to expand on projection from the slice onto the wire, the vortices discharged are always aperiodic, and the frequency of discharge is much greater than when the previously described embodiment is employed under similar conditions.

When a stream leaves the outlet of a converging channel it continues to contract in width for a short distance depending on the approach flow to the outlet, until the pressure of the stream is equal to that of the surrounding air and the direction of flow in the stream is uniform. A stable stream in the absence of retarding forces would then continue in this condition. In the presence of air, however, the stream is gradually retarded and, in order to maintain continuity, the stream broadens. The rate at which the stream broadens depends, inter alia, on the retardation produced by the air and this in turn varies with the condition of the surface of the stream. As previously explained, a rapidly expanding stream is very unstable and quickly disintegrates into spray. Such a stream entraps large quantities of air and in the case of a stream of stock flowing from a stock inlet slice, requires a long region of restricted drainage on the forming

wire to reform before substantial drainage can commence. One of the purposes of this preferred embodiment is to ensure that the stream of stock remains compact for a considerable distance after leaving the slice.

5 The preferred embodiment of our invention is illustrated in Figure 9. In place of the cylinder constituting the flow-modifier of the first embodiment of our invention, we dispose in the converging channel a plurality of projections (preferably two), one from each of the apron plate and slice lip, such projections being of non-streamlined surface and substantially hemispherical cross section. Constructionally these projections may be conveniently obtained by fixing cylinders of semi-circular cross section onto the plane surface of the channel. Alternatively one or both of the projections may form part of a hinge which permits movement of the slice lip or the apron plate, as the case may be. At the rate of flow encountered in paper machine slices separation occurs on the down stream side of both projections and vortices are shed into the body of the flow.

There are several important differences between the vortex system shed by two projections and that shed from a single cylinder in the channel, as previously described. In the case of a single cylinder the pressure distribution in the wake of the cylinder causes the vortices to be shed alternately from the two lines of separation to form a Kármán vortex street. This gives rise to a corrugated flow pattern from the slice and the resulting stream spreads more than would be the case without a cylinder. The improvements in the uniformity and condition of the stream produced by a cylinder however, outweigh the disadvantage of the reforming zone which is necessary on paper machines operating at high speeds. At very high speeds, however, the balance becomes adverse. The vortices in the two streams of vortices produced by the two projections are not alternately spaced, but are shed independently of one another. They do not combine, therefore, to produce a regular corrugated flow pattern. Furthermore, they are generated on the outside of the flow and diffuse inwardly. These two differences give rise to several distinct advantages from a practical papermaking point of view. We have found that if the system is designed to fulfill certain requirements, as hereinafter described, the stream is such as will enable stock in a condition suitable for paper making to be fed onto the forming wire at much higher speeds than heretofore. One of these advantages is that the stream shows less tendency to expand on leaving the slice than under conditions employing the previously described embodiment of our invention and therefore provides less opportunity for air entrapment at corresponding speeds. The desired energy for conditioning the flow for good sheet formation can be introduced with as little as one half of the amplitude of relative movement between adjacent segments of the stream as that produced by a single cylinder in the channel. The respective frequencies of discharge of the vortices on the two sides of the stream are aperiodic and independent of one another so that the vortices do not combine to produce corrugation of the whole stream. Finally, we have found that the frequency range in which the discharge of the vortices occurs is approximately twice that produced by a single cylinder under the same flow conditions.

Several criteria must be satisfied in the design of this preferred embodiment of our invention:

(1) The minimum cross-channel distance between the two projections (or between any two of such projections if more than two are employed) should be at least equal to the maximum vertical slice opening in order to avoid reducing the sensitivity of control exercised by the slice opening on the flow.

(2) The projections should be at a sufficient distance from the slice outlet to enable the two vortex streams to diffuse to the centre of the stream of stock, otherwise

the energy distribution is too high at the two surface layers of the stream and causes drops to break away.

(3) The dimension of the projection is determined first by the energy required in the stream of stock and this depends on the design of the stock inlet as a whole. The greater the dimension of the projections, the greater the energy introduced. The energy introduced is a function of the velocity of the stream and the dimension of the projections. Secondly, the frequency range of the variations is a function of the Reynolds number, the diameter of the projections and the velocity of the stream. The frequency should be made as high as possible compatible with the other criteria.

It will be obvious that in all embodiments of our invention the designed contour of the flow-modifying devices should be substantially maintained during continuing use and such devices should therefore be constructed of materials which will resist corrosion and erosion.

When we use the term "cylinder" in this specification we mean a three-dimensional body which has a constant cross section perpendicular to an axis. When we use the term "cylindrical body" in the claims we mean a three-dimensional body which has a constant cross-section perpendicular to an axis and which is non-streamlined as herein defined.

In the embodiments of our invention as hereinbefore discussed and illustrated we have used as examples of the non-streamlined flow-modifying member, either a circular cylinder (Figures 2 to 5 and 7) or a semi-circular cylinder (Figure 9). Such simpler forms of non-streamlined cylinders are recommended for the convenience of their construction and operation. The flow characteristics consequent upon the use of such simpler forms are also more readily derived and it will be appreciated that extreme complexities of flow patterns may result from the use of more complicated non-streamlined shapes. In practice also it is difficult to obtain and maintain a constant cross section for non-circular shapes. Where a constant cross section is not maintained non-uniformities of the jet across the machine arise which are highly undesirable. For these practical reasons we prefer to use the simpler forms of non-streamlined shapes as herein illustrated. We have nevertheless employed and evaluated other shapes of flow-modifying members and by way of illustration Figure 10 shows a flow-modifying member of pear-shaped cross section which, subject to the limitations of its construction as noted above, being non-streamlined, was capable of adequately accomplishing the results of our invention as above described. In Figure 11, however, is shown a flow-modifying member the cross section of which is substantially streamlined i. e., streamlined within the definition of this term as used in this specification. In practice we found that the use of a member having this or a similar cross section failed to produce the desired effect.

It is to be understood that the invention is not limited to the above specifically-described embodiments of the invention and that changes may be made either in the design or form of the embodiments without departing from the scope of the invention which is defined in the appended claims.

What we claim is:

1. A method of improving the flow stock from the

stock inlet onto the Fourdrinier wire of a paper machine which comprises disposing in the stock inlet transversely of the flow of stock a stationary cylindrical body having at least two lines of flow separation thereon at a position such that the flow of stock past the said cylindrical body is characterized by a Reynolds number in excess of 10^4 whereby a series of aperiodic vortices is shed from each of said lines into the flow and, prior to projection of stock onto the wire, maintaining the flow in a confined channel until the diffusion of vortices is substantially complete.

2. A method of improving the flow of stock from the stock inlet onto the Fourdrinier wire of a paper machine which comprises disposing on each of the slice lip and apron plate of the stock inlet transversely of the flow of stock at least one stationary cylindrical body each such body having at least one line of flow separation thereon at a position such that the flow of stock past the said cylindrical body is characterized by a Reynolds number in excess of 10^4 whereby a series of aperiodic vortices is shed from each of such lines into the flow and, prior to projection of the stock onto the wire, maintaining the flow in a confined channel until the diffusion of vortices is substantially complete.

3. A method of improving the flow of stock from the stock inlet of a paper machine according to claim 1 in which the stationary cylindrical body is a circular cylinder.

4. A method of improving the flow of stock from the stock inlet of a paper machine according to claim 2 in which at least one of the stationary cylindrical bodies is a semi-circular cylinder.

5. A method of improving the flow of stock from the stock inlet of a paper machine according to claim 1 in which the Reynolds number is in excess of 5×10^4 .

6. A method of improving the flow of stock from the stock inlet of a paper machine according to claim 2 in which the Reynolds number is in excess of 5×10^4 .

7. A method of improving the flow of stock from the stock inlet of a paper machine according to claim 1 in which the diameter of the stationary cylindrical body is in excess of one-half inch.

8. A method of improving the flow of stock from the stock inlet of a paper machine according to claim 1 in which the stationary cylindrical body is supported by means not substantially extending beyond said body toward the slice.

9. A method of improving the flow of stock from the stock inlet of a paper machine according to claim 2 in which the cross-channel distance between any two of such stationary cylindrical bodies is not less than the maximum vertical height of the slice opening.

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