

March 13, 1956

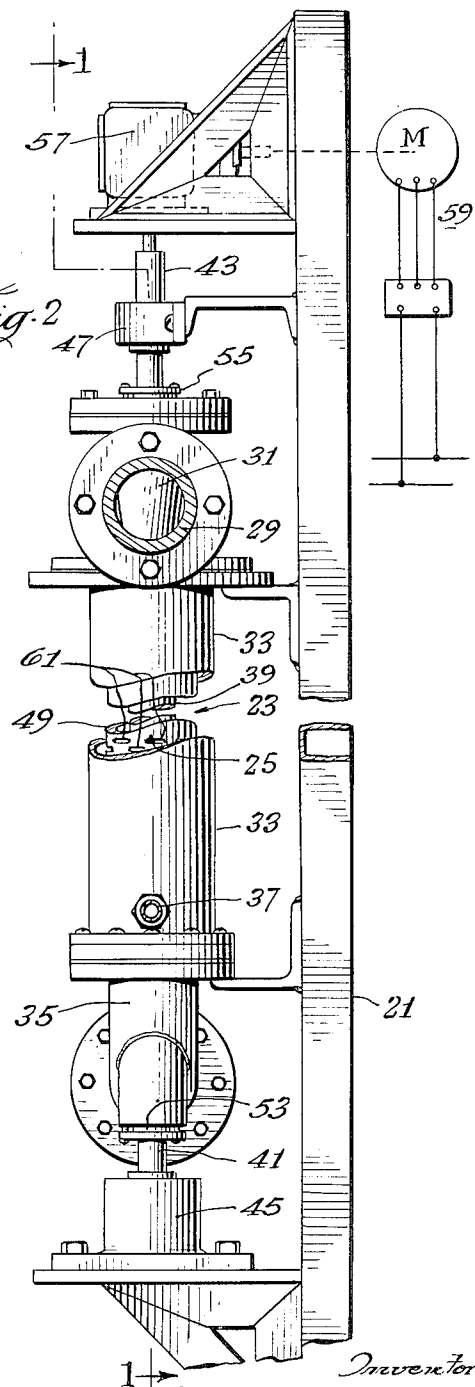
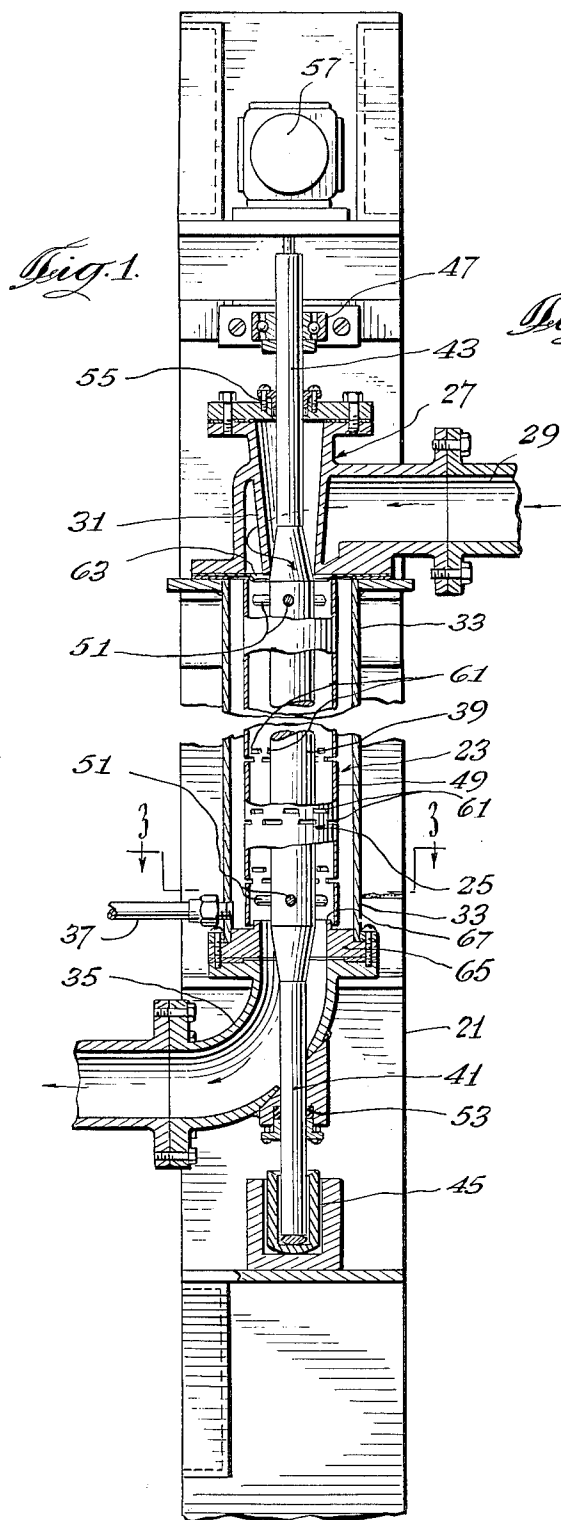
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2,737,857

HYDRAULIC APPARATUS

Filed July 1, 1950

8 Sheets-Sheet 1



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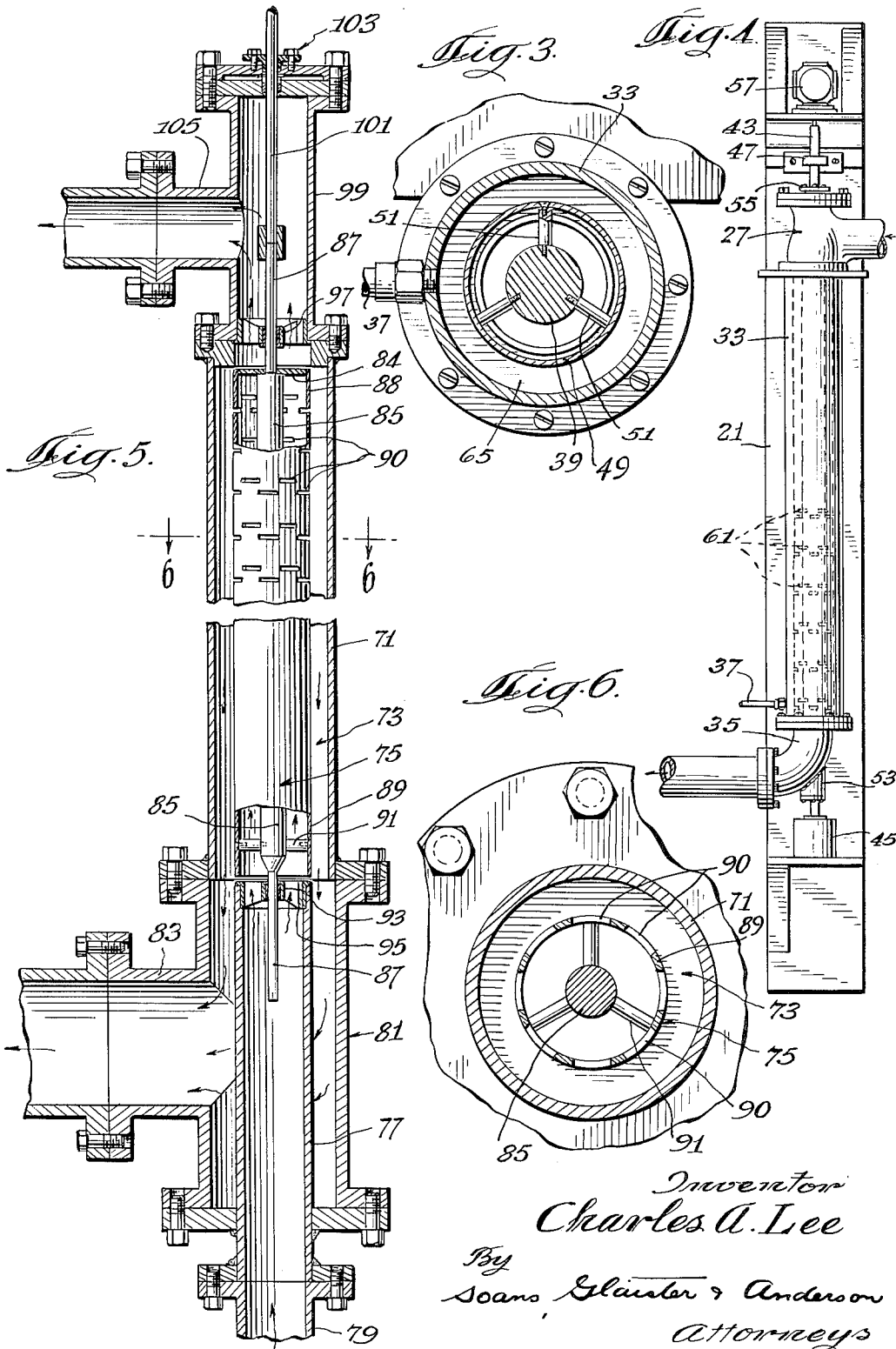
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HYDRAULIC APPARATUS

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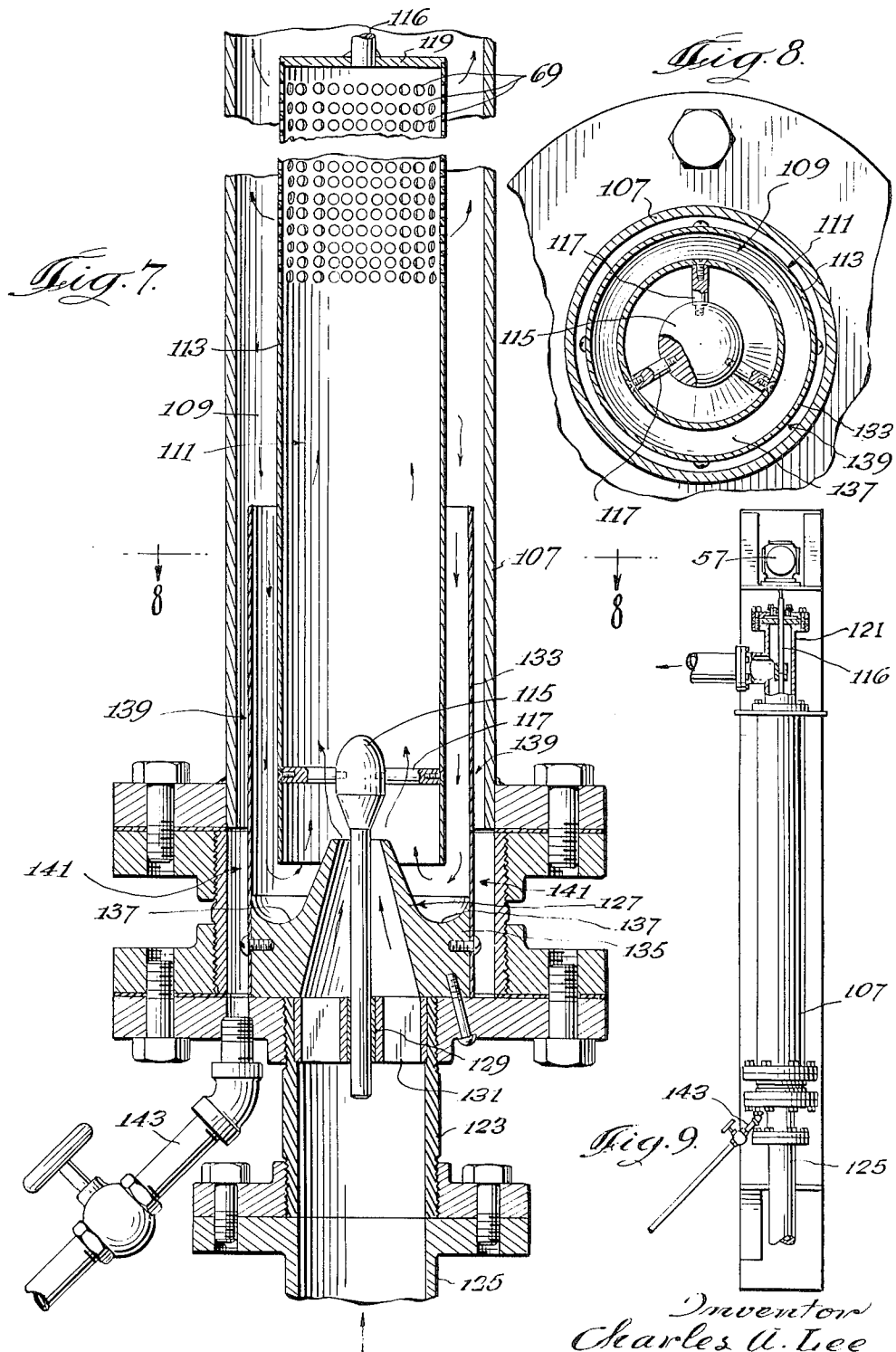
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HYDRAULIC APPARATUS

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3 Sheets-Sheet 3



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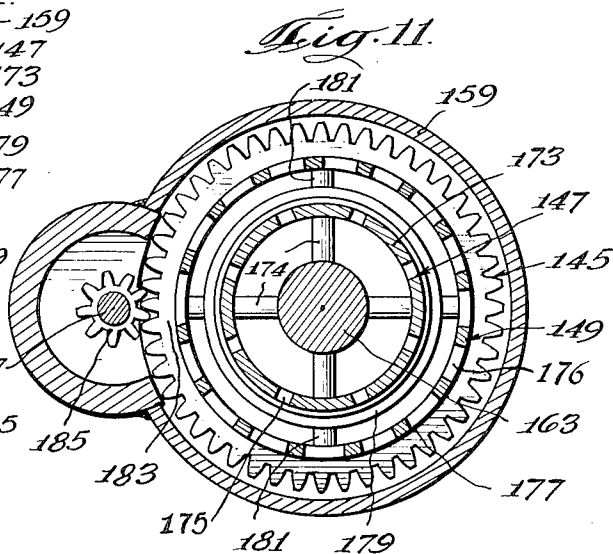
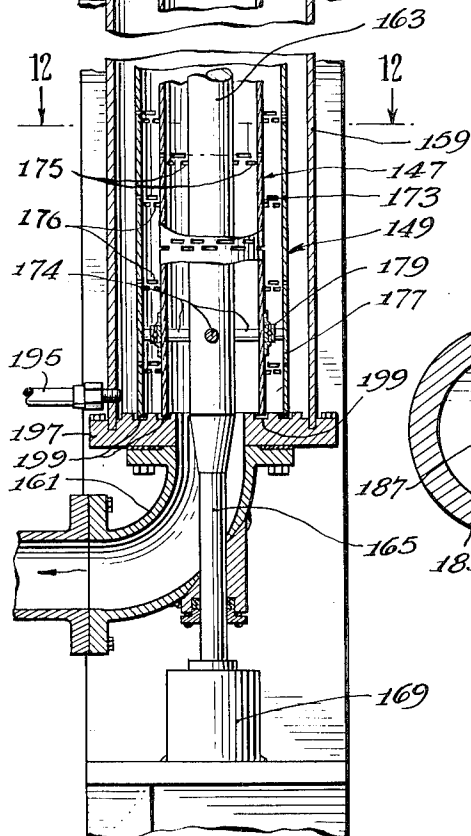
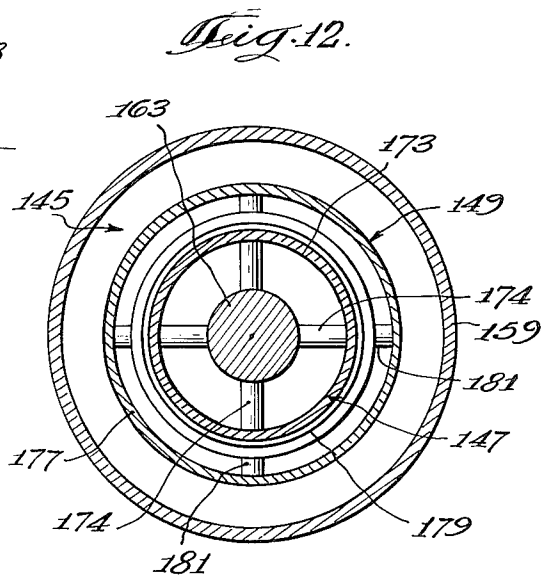
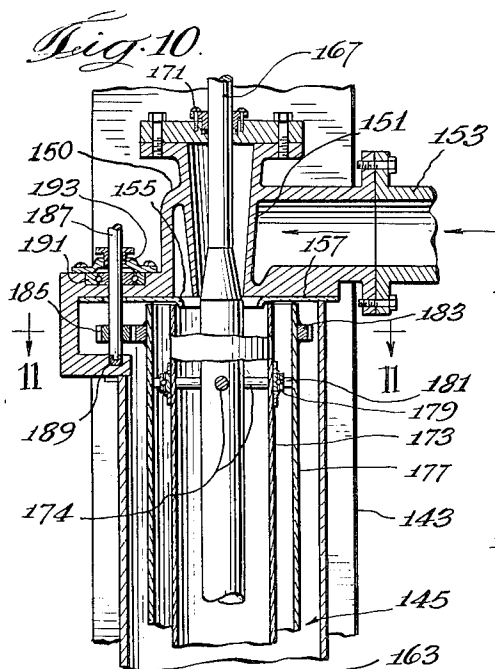
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3 Sheets-Sheet 4



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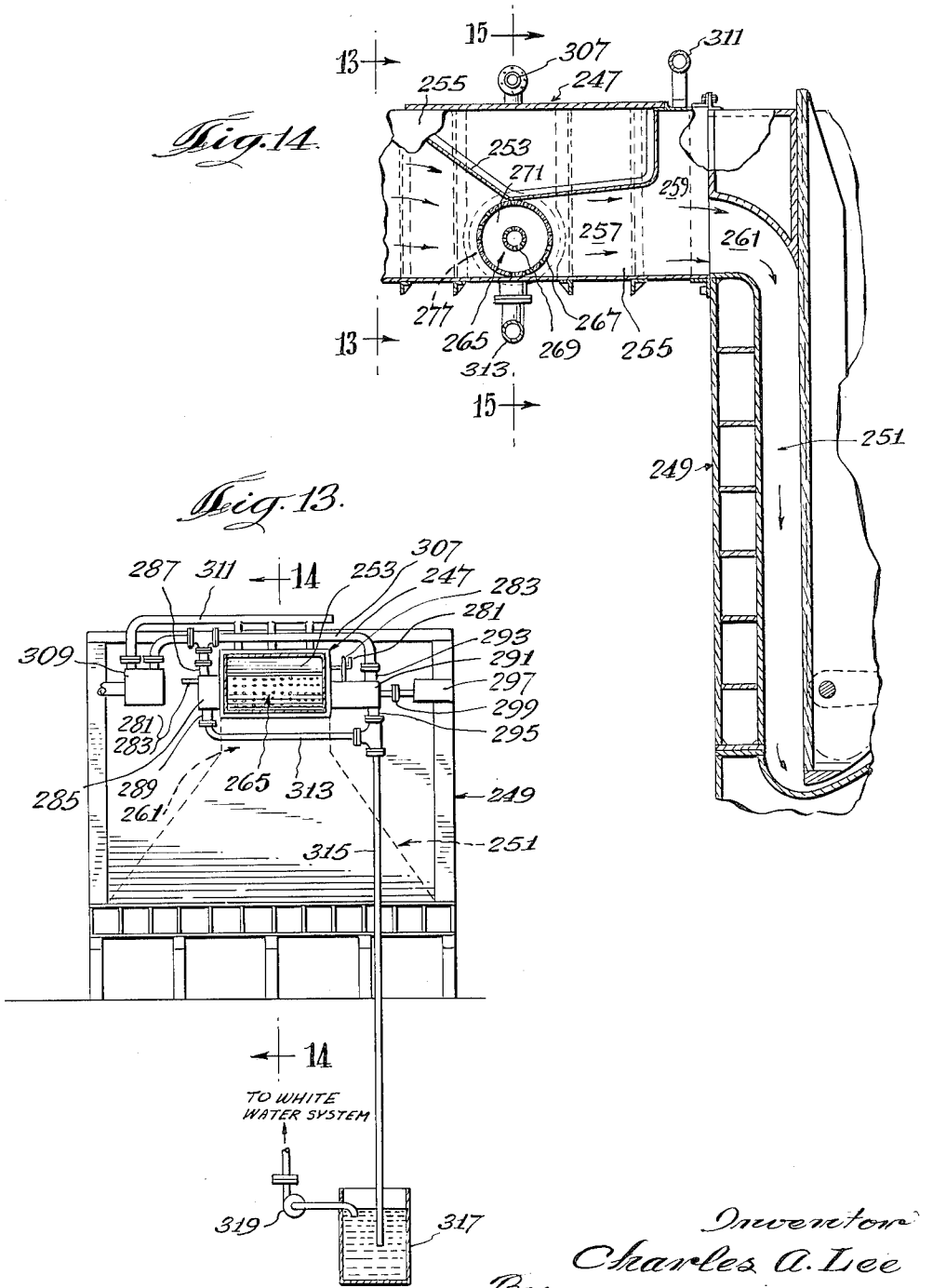
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3 Sheets-Sheet 5



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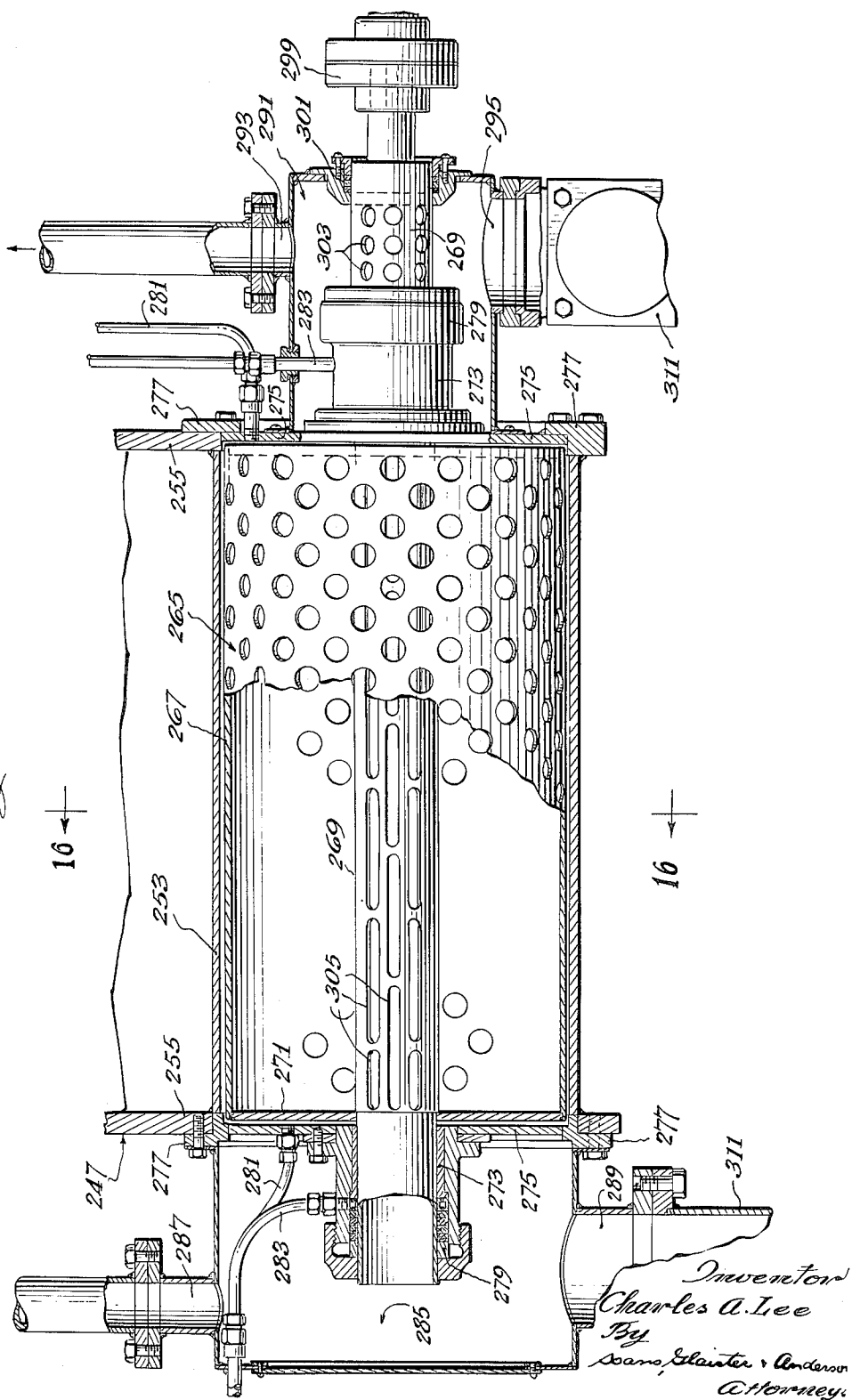
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Fig. 15.



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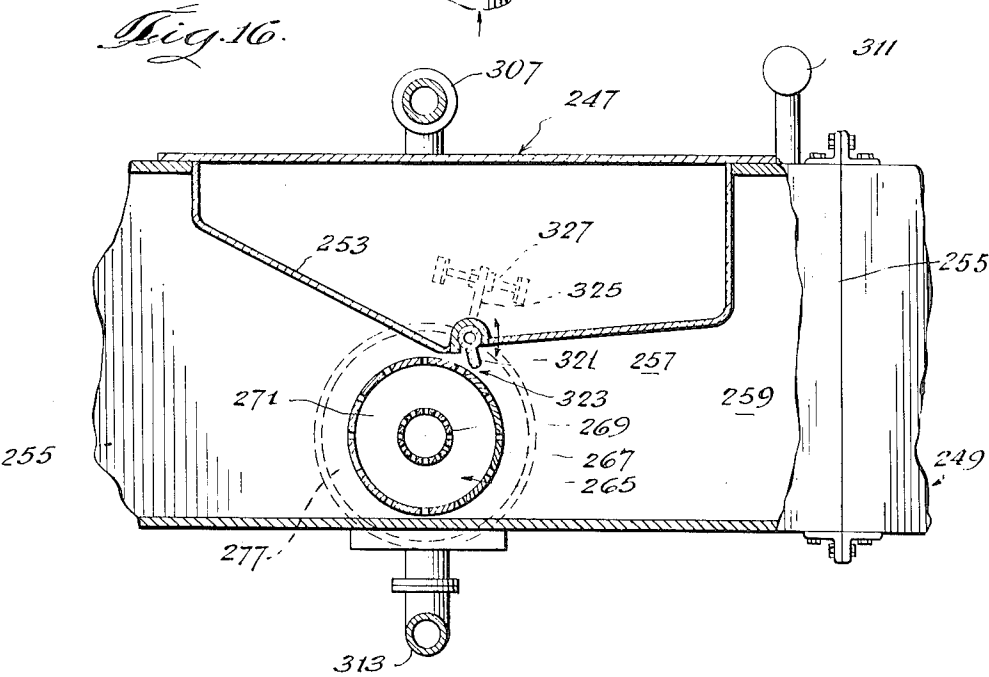
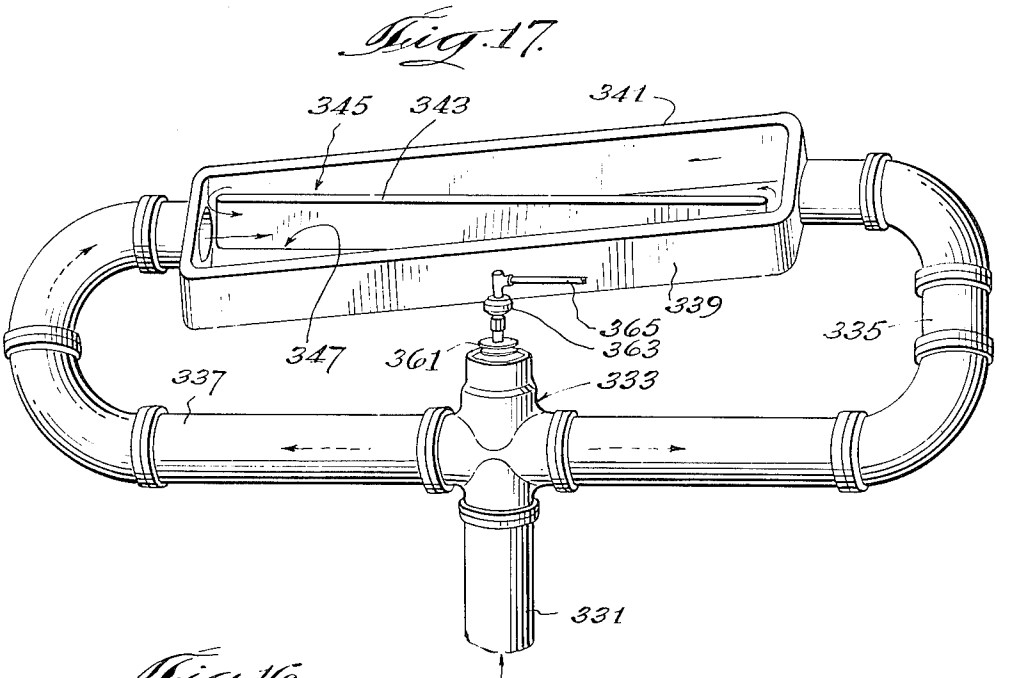
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8 Sheets-Sheet 7



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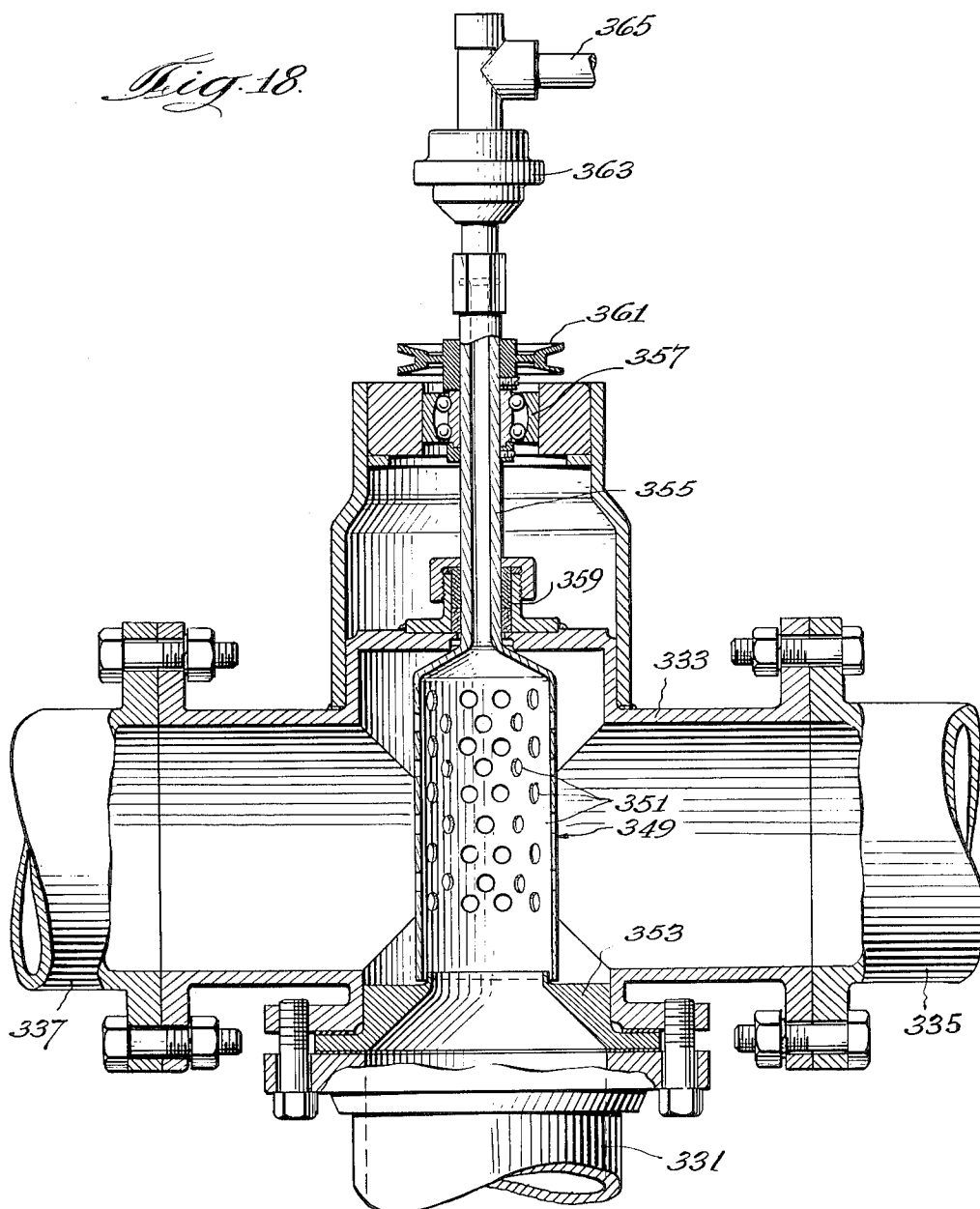
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HYDRAULIC APPARATUS

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Application July 1, 1950, Serial No. 171,772

14 Claims. (Cl. 92—28)

The present invention relates generally to hydraulic apparatus. More particularly, the invention relates to vorticular hydraulic apparatus which is operable to effect the separation of solid or gaseous materials from liquids in which such materials are suspended or dissolved, and for other purposes.

In the carrying out of various types of manufacturing operations, it is frequently advantageous to be able to effect the separation from a carrier liquid of various types of solid and gaseous materials, such as sand, dirt specks, air, etc., and various mechanisms have been proposed for this purpose. For example, in the manufacture of pulp and paper, it is very important that relatively heavy, high density foreign materials, such as sand, be removed from suspensions of pulp and from the paper stock, which is the dilute, aqueous suspension of fiber and other materials used in the manufacture of paper, before the pulp is screened, or before the delivery of the stock to the web-forming region of the paper making machine.

It is also of great importance in the manufacture of pulp and paper to remove from pulp suspensions and from paper stock various types of low density materials, such as bark specks, which may have a specific gravity closely approaching the specific gravity of the fiber and other useful material in the suspension.

Various types of vorticular and other separating mechanisms have been suggested for these purposes. These mechanisms are reasonably efficient separators of materials having a specific gravity which is substantially greater than the specific gravity of the fiber and other useful materials in the stock, but at best, these mechanisms are relatively inefficient for effecting satisfactory separation from a stock suspension or other liquid of materials which have a specific gravity which approaches at all closely the specific gravity of the fiber or other useful material to be retained in the carrier liquid. To illustrate, most, if not all, of the known separating mechanisms, whether of the vorticular or other type, are completely unsuited for effecting the removal from stock or from pulp suspensions of foreign materials such as bark specks, which have a specific gravity differing only slightly from the specific gravity of the fiber.

It is also of great importance in the manufacture of paper and in other manufacturing operations, to be able to control the amount of air which is present in the stock or other suspension. In some paper-making operations, for example, it is desirable to remove air from the stock, and in other instances, it may be desirable to add air. While this problem, like the problem of removing dirt and other unwanted materials, has been known to the art for many years, here again, no completely satisfactory apparatus has heretofore been developed for this purpose, especially as a continuous operation in a flowing stream of liquid.

There are numerous other instances and operations wherein the separation of materials of only slightly different or of comparable densities from fluid suspensions

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are required or could desirably be accomplished. To mention a few, separations of this character are frequently required in the refining of ore and in the processing of various solid or semi-solid chemical materials.

Thus, there is, and for many years there has been, a real need for apparatus adapted to be included into hydraulic systems of various types, which is capable of efficiently separating materials, the specific gravity of which may differ only very slightly. Also, there is a similar need for apparatus which is capable of removing dissolved air or other gases from liquids and liquid suspensions, and which is capable of adding air and other gases to liquids and liquid suspensions, in order that the amount of such gas can be controlled continuously and held within definite limits.

The provision of a simple, easily operated apparatus, capable of accomplishing the above stated separations and additions under continuous flow conditions, constitutes the principal object of the present invention.

Other objects of the invention include: the provision of an improved hydraulic separating apparatus of the vorticular type, which is operable to effect the efficient separation from a liquid suspension, or mixture, or materials which have a specific gravity which differs only slightly from the specific gravity of the other materials contained in the suspension and particularly, the removal of bark specks from a suspension of groundwood pulp; and the provision of improved hydraulic apparatus which is operable to effect the continuous removal of dissolved air from an aqueous or other liquid dispersion or suspension, or the continuous addition of air to such a dispersion or suspension, whereby the total amount of air in such dispersion or suspension may be controlled continuously within predetermined limits. An additional and even more specific object of the invention is to provide apparatus adapted to be embodied into the stock supply system of a paper-making machine, which is operable to effect simultaneous control of the rate at which the stock is delivered to the machine and the amount of air which is dissolved or otherwise entrained in such stock.

These and additional objects and various of the advantages of the invention will be made more apparent in the following description of certain illustrative embodiments of the invention, and in the accompanying drawings of those structures.

In the drawings:

Figure 1 is a cross sectional view of a vorticular separation apparatus in accordance with the invention, which is particularly adapted for effecting the separation and removal from a stock or pulp suspension, or the like, of dirt specks and other low density foreign materials;

Figure 2 is a side, elevational view of the apparatus shown in Figure 1;

Figure 3 is an enlarged, sectional view on the line 3—3 of Figure 1;

Figure 4 is a reduced scale, front elevational view, showing the relative proportions of the apparatus illustrated in Figures 1 and 2;

Figure 5 is a sectional view, similar to Figure 1, of apparatus in accordance with the invention, which is particularly adapted for effecting the continuous removal of air from flowing streams of liquid, as for example, a flowing stream of stock as used in the manufacture of paper;

Figure 6 is an enlarged cross-sectional view on the line 6—6 of Figure 5;

Figure 7 is another sectional view, which is generally similar to Figure 1, and which shows a second apparatus in accordance with the invention, especially adapted to effect the continuous removal of low density materials from a flowing stream of liquid;

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Figure 8 is a sectional view on the line 8—8 of Figure 7;

Figure 9 is a reduced scale, front elevational view of the apparatus illustrated in Figure 7;

Figure 10 is a sectional view, also generally similar to Figure 1, which shows still another type of apparatus in accordance with the invention, especially adapted to effect the continuous removal of low density materials from a flowing stream of liquid;

Figure 11 is an enlarged, sectional view taken on the general line 11—11 of Figure 10;

Figure 12 is an enlarged, sectional view taken on the general line 12—12 of Figure 10;

Figure 13 is a diagrammatic, end elevational view of the headbox end of a papermaking machine. The view illustrates the stock inflow conduit in cross section, and the apparatus includes mechanism in accordance with the invention for effecting simultaneous control of the rate of delivery of stock to the machine and of the amount of air which is contained in the stock;

Figure 14 is a vertical, cross sectional view on the general line 14—14 of Figure 13;

Figure 15 is an enlarged, sectional view taken on the general line 15—15 of Figure 14, illustrating certain of the details and features of the combined flow control and aeration control mechanism embodied in that apparatus;

Figure 16 is a reduced, sectional view, taken on the general line 16—16 of Figure 15, which illustrates certain of the features of a gap-adjusting mechanism which may be embodied in the apparatus;

Figure 17 is a diagrammatic, perspective view, showing a stock delivery system of the so-called "cross flow" type; and

Figure 18 is an enlarged, sectional view, illustrating the application of aerating or deaerating mechanisms in accordance with the present invention to a stock delivery system of this type.

As will hereinafter appear, the present invention is based in large part on the discovery that greatly improved operation of vorticular-type hydraulic separating apparatus can be accomplished by so constructing the apparatus that a free vortex, or a combined vortex having characteristics which approximate those of a free vortex, is generated in the apparatus during its operation. To elaborate, in a free vortex, under ideal conditions, the product of the fluid velocity at any given point in the vortex and the radial distance to that point is equal to the product of the fluid velocity at any other point in the vortex and the radial distance to that other point. Expressed mathematically, $V_1 R_1 = V_2 R_2 = a$ constant, wherein V_1 is the fluid velocity at a point which is at a distance R_1 from the eye or center of the vortex and V_2 is the fluid velocity at a point which is at a distance R_2 from the eye of the vortex.

An ideal vortex follows the theory of potential flow. Hence, in an ideal vortex

$$\frac{\rho V^2}{2} + P = a \text{ constant}$$

for any given streamline, ρ being equal to the density of the liquid, V being equal to the velocity of flow and P being equal to the pressure intensity. Solving the equation for the velocity pattern of a free vortex, it will be found that the pressure at the eye or center of a free vortex tends to approach extremely low values, and increases, outwardly from the eye of the vortex, to approach the static head of the system when no rotational force is present. It is also a characteristic of a free vortex that the velocity at the eye of such a vortex is very high and decreases outwardly from the eye. The relationships are in direct contrast with the pressure velocity relationships in a forced vortex, wherein the velocity at any given point in the vortex is proportional to the distance between that point and the eye of the vortex (i. e. $V_1 : r_1 :: V_2 : r_2$), and wherein the pressure at the center or

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eye of the vortex is equal to the static head of the system (i. e. the head when no rotational force is present), and increases to values considerably above this pressure outwardly in the vortex.

It will be appreciated that a free vortex is a theoretical condition, capable of existing only in ideal fluids, and it is not possible to produce a free vortex which exactly follows the ideal equations with any known apparatus or equipment. More specifically, mechanically-produced vortices partake of a combined nature, being in part free vortices and being in part forced vortices. It is possible, however, to produce a combined vortex which approximates the action of a free vortex, and it is by the production of controlled vortices which approximate the action of free vortices that the improved operational characteristics of the apparatus of the present invention are made possible. In this connection, it should be noted that the type of vortex utilized in the practice of the invention normally requires the continuous addition of power to the vortex, in one of more regions of the vortex. The attainment of the invention also requires, in some instances, the utilization of apparatus of particular shapes and relative dimensions, various of which features are important and marked departures from the prior practices in this field.

As previously stated, the apparatus of the present invention is directed toward the accomplishment of two primary functions. These are: one, the removal or separation of unwanted constituents from dispersions or suspensions containing useful materials which have a specific gravity closely approaching the specific gravity of the material to be removed, for example, the removal of bark specks from paper stock and pulp suspensions; and two, the continuous removal or addition of air or other gases to flowing streams of liquid, as for example to paper stock and to pulp suspensions. In general, while either type of operation may be carried out in substantially the same apparatus, certain structures are preferred for one purpose or the other, and usually there will be certain variations in the operating conditions, depending upon the end result which is to be obtained. For example, when the apparatus is being operated to effect the removal or addition of air, it may be found desirable to produce in the apparatus a vortex which is open either to a vent or to a source of air, depending upon the type of operation desired. In contrast with this, when the apparatus is being used for the separation of materials having specific gravities which are quite close to each other, the apparatus will generally be operated completely filled with liquid.

Basically, however, apparatus in accordance with the present invention comprises a conduit or receiver, sometimes of elongated shape, through which the liquid to be treated may be caused to move under conditions approaching potential flow, i. e., with a minimum of turbulence. Disposed within the conduit, there are provided one or more rotating members, each of which usually comprises a hollow, perforated cylinder. The rotating member or members are of such dimensions and are so positioned with reference to the outer conduit walls and associated equipment, that rotation thereof at predetermined speeds relative to the rate of flow, or other characteristics of the system, is effective to produce a vortex having characteristics approximating those of a free vortex, within the treating region of the apparatus. Various additional and associated mechanisms, such as jet inlets, separation baffles, cooperating throttling barriers, and the like, may be added to and used in conjunction with the basic apparatus. However, the provision of a suitably proportioned apparatus which includes power driven rotating means operable to produce a vortex having characteristics which approximate the characteristics of a free vortex is common to all of the mechanisms.

In view of the fact that the apparatus is of particular utility in the manufacture of pulp and paper, the illustrated examples of the invention are especially designed for use in this field. It will be understood, however, that

the use of the invention is not limited to the manufacture of pulp and paper.

In Figures 1 to 4 of the drawings, there is illustrated an apparatus in accordance with the invention, which is particularly adapted for effecting the removal of various types of low density impurities from paper making stock, paper stock being, as previously described, the aqueous dispersion of fibers and other materials used in the manufacture of paper. This mechanism, which is conveniently operated in a vertical position, includes a suitable frame structure 21 which may be of structural steel, conduit means for conveying the fluid to be treated into and through a generally cylindrical, elongated treating chamber 23, and an elongated, hollow cylindrical, rotor member 25, which is slotted or otherwise perforated at one end and which is located within the treating chamber 23. The conduit means includes a nozzle fitting 27 disposed at the upper end of the mechanism and adapted to be connected to a supply line 29 for the material to be treated. The nozzle fitting 27 is provided with an inner baffle portion 31 which defines a spiral passageway so arranged that the fluid is discharged downwardly in the direction of the treating chamber 23 with substantial radial velocity. The outer wall of the treating chamber 23 is defined by a cylindrical tube 33, which extends between the nozzle fitting 27 at the inlet end of the apparatus and a suitable cooperating outlet fitting 35, mounted at the other end of the apparatus. A drain connection 37 is provided at the lower end of the treating chamber defined by the cylindrical tube 33.

The hollow, cylindrical rotor 25, which is arranged to rotate within the treating chamber 23, is illustrated particularly in Figure 1. As there shown, the rotor 25 includes a cylindrical shaft 39 having reduced end sections 41 and 43, which extend outside the path of fluid flow through the apparatus to engage suitable thrust and guide bearings 45 and 47. A relatively thin-walled, perforated tube 49 is mounted on this shaft by means of suitable spaced spider arms 51, as shown in Figure 3, and the dimensions of the tube 49 are such that it extends the entire length of the treating chamber 23 with rather close tolerances at either end. The mechanism also includes suitable gland seals 53 and 55 for preventing leakage around the rotating shaft.

The upper end 43 of the supporting shaft 39 is mechanically connected to a speed control unit 57, whereby the speed of rotation of the rotor 25 can be accurately controlled. The speed control unit 57 is intended to be connected to a motor and source of power, as illustrated diagrammatically at 59 in Figure 2.

As shown particularly in Figures 1 and 4, the perforations in the tubular outer portion of the rotor 25 are concentrated at the lower end of the rotor and comprise staggered slots 61. In one illustrative embodiment of the invention, wherein the cylindrical rotor had a length within the treating chamber of approximately 46 inches and a diameter of 4 inches, the slots 61 were provided in approximately the lower half of the rotor, and comprised six equally spaced, double rows of rectangularly shaped, staggered slots, as illustrated in Figure 1. In this structure, each of the individual slots was $1\frac{1}{4}$ inches long, measured along the outer circumference of the rotor and was $\frac{3}{8}$ of an inch in width. Each of the double rows of staggered slots was spaced $\frac{1}{2}$ inch from the adjacent double row of slots, and the double rows were spaced about 4 inches apart. In this same mechanism, the treating chamber 23 had an over-all diameter of 6 inches, and the inlet and outlet fittings were adapted for connection to a 6 inch pipe. The rotor shaft in this mechanism had a diameter within the treating chamber of 2 inches.

During operation of this apparatus for effecting the removal of such materials as bark specks from pulp suspensions, the inflowing stock was admitted through the spiral inflow nozzle 27 into the interior of the hollow rotor 25 at the upper end thereof. To aid in directing

the inflowing liquid into the hollow rotor, a deflector 63, having the general shape of a short, truncated cone is provided at the upper end of the treating chamber 23, as shown in Figure 1. The lower end of the tube 49 which defines the outer periphery of the rotor 25 extends into close proximity to the end fitting 65 at the outflow end of the main treating chamber 23, and that fitting is desirably provided with a raised flange 67, which extends into the tube 49. This construction minimizes any tendency of the settled material to flow from the settling region (i. e. the region between the lower end of the rotor and outer defining wall of the treating chamber) back into the rotor.

During operation, the stock or other material to be treated is introduced into the upper end of the hollow, cylindrical rotor 25, while that member is being rotated at relatively high speeds. For example, in an apparatus having the dimensions set forth above, for a stock flow of 50 gal. per minute, the rotor was driven at a speed within the range of from about 1500 R. P. M. to 2000 R. P. M. The stock or other material to be treated flows through the apparatus continuously, and the operation of the hollow, cylindrical rotor produces within the treating chamber 23 a vortex having approximately the characteristics of a free vortex. The action of this vortex is such that the low density foreign material to be removed is moved downwardly and outwardly within the vortex, finally coming to rest in the settling region intermediate the lower end of the rotor and the adjacent wall of the treating chamber. The foreign material is continuously removed from this region through the drain pipe 37, the flow through this pipe being of the order of about 5-10% of the total flow through the treating apparatus.

The apparatus has proved quite effective in accomplishing the separation from the carrier liquid of low density foreign materials, i. e. materials having a specific gravity which is very close to the specific gravity of the carrier liquid or the material which is to be retained in the carrier liquid. As previously indicated, the apparatus finds particular utility in connection with the removal of bark specks from suspensions of groundwood pulp. Bark specks normally result from the enclosure within a growing tree of the bark of the dead limbs which become knots, and these specks are a source of very serious trouble in the manufacture of groundwood pulp. This is due to several reasons. Bark specks are very difficult or almost impossible to bleach, and they are equally difficult to eliminate from pulp or stock suspensions in existing separating apparatus, apparently because the specific gravity of bark specks differs by not more than a few percent, and sometimes by even less than 1%, from the specific gravity of the pulp fiber.

In effecting the removal of bark specks and similar, low density foreign materials from pulp and stock suspensions by the use of apparatus in accordance with the present invention, the rate and efficiency of removal is determined, at least in part, by the gravitational forces which are produced within the induced free vortex. During use of such apparatus to effect the removal of bark specks from groundwood pulp suspensions having concentrations within the range of from .05 to 1.5%, good results were obtained under operating conditions which produced centrifugal or acceleration forces within the vortex equivalent to from about 200 to 1500 unit gravities.

In the separation of low density materials, it has been found that the dimensions of the treating chamber (i. e. the dimensions of the vortex) are not particularly critical. Also, it is not essential that the treating chamber be arranged in a vertical or other fixed position. Generally, however, it will be found desirable, in apparatus of the type illustrated in Figure 1, to use a treating chamber which has a length which is several times the diameter of the rotor. These proportions not only aid in the obtaining of the desired separation with a minimum expenditure of power, but in addition, they tend to mini-

mize turbulence within the vortex region, with resulting increased efficiency of separation.

In the apparatus illustrated in Figures 1 to 4, it will be noted that the spaced, rectangular perforations 61 are located in approximately the lower half of the rotor tube 49. This dimension represents an optimum average value. In separation apparatus in accordance with the invention of this general type, the perforations in the roll should desirably be provided in at least the lower third of the hollow rotor and may extend to include the lower two thirds of the rotor. The upper portion of the rotor tube, which is the portion of the tube into which the liquid to be treated is first admitted, should be imperforate in most instances.

It is not necessary that the rotor perforations be of a particular shape. The perforations 61 in the rotor of the Figure 1 apparatus constitute, as described above, rectangular slots, and this is a particularly advantageous shape. However, they may comprise symmetrically spaced, circular openings, as shown at 69 in the apparatus illustrated in Figure 7, or they may have other shapes or outlines.

It is usually preferable to operate separation equipment of the type illustrated in Figures 1 to 4, with the treating chamber completely filled with the liquid under treatment. However, this is not essential and the apparatus may be operated in a partially filled condition, with highly satisfactory results under some conditions.

The apparatus illustrated in Figures 5 and 6 is particularly adapted for accomplishing the continuous control of the air content of flowing streams of liquids, such as, for example, the flowing stream of stock which is delivered to a papermaking machine during the manufacture of paper. This apparatus, similar to the mechanism just described, includes a stationary, tubular member 71 which defines an elongated, generally cylindrical treating chamber 73. A hollow, cylindrical rotor 75, having a diameter which is about two-thirds the diameter of the treating chamber 73, and a length which may be several times its own diameter, is positioned concentrically within the tube 71 defining the walls of the treating chamber. The rotor 75, as in the previously described structure, is adapted to be driven so as to create within the treating chamber 73 a vortex having substantially the characteristics of a free vortex.

In this apparatus, it is intended that the stock or other material to be treated shall be introduced into the bottom of the apparatus by way of a centrally disposed inlet pipe 77, which is connected at its outer end to a stock delivery pipe 79 and is supported within a T-shaped housing or fitting 81, as shown in Figure 5. The T-shaped housing 81 also serves as the main fluid outlet for the apparatus, the stock or other liquid being treated passing upwardly through the hollow rotor 75, downwardly through the space between the rotor and the tube 73, and thence through the T-portion 83 of the housing 81, as shown by the arrows.

The hollow, cylindrical rotor 75 is closed at its upper end by a disc 84, as shown in Figure 5, and includes a cylindrical shaft 85 having an enlarged, central portion and reduced end portions 87, substantially the same as the shaft 39 of the previously described embodiment. The outer periphery of the rotor 75 is defined by a thin-walled cylindrical tube 89, which is supported on the shaft 85 by the solid disc 84 at the closed upper end and by one or more spider arms 91, as illustrated. The tube 89 includes perforations 90 in the upper portion thereof, which may be similar in dimensions and spacing to the perforations 61.

The lower end portion 87 of the rotor shaft 85 engages a suitable guide bearing 93, supported on a stationary spider 95, integrally attached to the discharge end of the tubular inflow pipe 77. There is a similar bearing 97 at the upper end of the shaft, this bearing being supported

at the lower end of a second T-fitting 99, which is employed as the air outlet.

The supporting shaft 85 for the rotor 75 is driven by a suitable, variable speed drive (not shown) which is connected to a drive shaft 101, keyed to the upper end portion 87 of the rotor shaft. A gland seal 103 is provided at the upper portion of the T-fitting 99 to prevent leakage around the drive shaft 101, and suitable thrust bearings (not shown) may be provided, as required, to hold the rotor in position.

During operation of the apparatus, as previously stated, the stock or other liquid to be treated flows into the lower end of the hollow, cylindrical rotor 75 by way of the inlet pipe 77, and the openings in the spider 95. The rotor 75 is driven at sufficient speed to produce a vortex within the tube 71, having characteristics which approximate those of a free vortex, and there is a continuous flow of liquid upwardly within the rotor and out through the slot perforations 90 in the upper portions of the rotor tube 89. This liquid flows down through the space between the rotor and the outer defining wall of the treating chamber, and thence through the lower or outlet fitting 83 out of the apparatus. When air is being withdrawn from the stock or other liquid being treated, this air passes out through the central portion 105 of the discharge fitting 99 which may be connected to a vacuum pump or other source of reduced pressure.

In order to effect continuous removal of air, it is desirable that the vortex created within the treating chamber 73 shall be in connection with a liquid free space from which the air may be withdrawn. This space is conveniently obtained by locating the apparatus vertically, as shown, although apparatus of the type illustrated can be operated with very satisfactory results in a horizontal position.

The amount of air which is being removed at any given time is determined to a considerable degree by the speed at which the rotor is driven. Hence, the apparatus is particularly adapted to effect the continuous control of the amount of air contained in flowing streams of liquid suspensions of various types.

As an example of the importance of this feature of the apparatus, it is generally accepted that control of the amount of air contained in paper stock of various types is of very great importance in accomplishing reliable operation of paper making machines, and in determining the formation and other qualities of the paper which is being made. For example, it has been determined that paper stock for use in the manufacture of such papers as newsprint, book paper and tissue, should contain not more than about .3 to .5% of air by volume. Further, if the air content of the stock can be controlled continuously within rather close limits, important improvement in formation and other product characteristics, with higher permissive speeds of operation, can be effected. Since the amount of air removal accomplished by the operation of the apparatus of the invention can be accurately controlled by varying the speed of the rotating cylinder, the invention makes possible not only greatly improved operation of paper making equipment, but in addition, by the use of speed control apparatus for the rotor, which is made automatically responsive to the air content of the stock, it becomes possible to effect, automatically and continuously, very accurate control of the air content of the stock delivered to the machine.

In general, satisfactory air removal within the limits normally encountered in the treating of paper stock, can be effected by operation of the rotor to produce a vortex wherein the pressure differential is at least as much as about 10 inches of mercury. In one operative example of the apparatus, wherein the treating chamber had a diameter of 6 inches and a length of 48 inches, and the rotor shell had an external diameter of 4 inches and was supported on a 2 inch shaft, it was found that the air content of stock could be reduced from 3% to about .5%

by volume, at a flow rate of 10 gals. per minute, with an operating speed of 500 R. P. M. This speed of the rotor is equivalent to a centrifugal or acceleration force within the vortex of about 500 unit gravities. Other types of air removal operations may require different operating conditions as previously suggested. Variation in the rate of flow may also be used to vary air content, although this is not always practical in apparatus used in such operations as papermaking, which require generally uniform flow rates for any given operating condition.

The tube 89 which defines the outer shell of the rotor 75 used in the air removal apparatus shown in Figures 5 and 6, as in the previously described mechanism for removing dirt, may be provided with slotted, round or other perforations, depending upon the material being handled and the operational characteristics required. As in the dirt removal apparatus, perforations should be provided along at least one-third of the length of the tube, and usually for not more than about two-thirds of the length of the tube. The cross sectional area of the perforations provided in rotors for use in air removal operations (and the same is true in rotors for use in dirt removal equipment) may constitute from about 20 to 80% of the total peripheral area of the tube in the region of perforations.

Figures 7, 8 and 9 illustrate another embodiment of apparatus in accordance with the invention, which is especially adapted for use in effecting the separation and removal from a carrier liquid of materials having a specific gravity which closely approaches the specific gravity of that liquid or of materials which are to be retained in the carrier liquid. This apparatus includes various refinements and additional features not included in the previously described structures.

In its general structural arrangement, the apparatus illustrated in Figures 7, 8 and 9 is similar to the apparatus illustrated in Figures 5 and 6; it includes an outer cylindrical tube 107 for defining an elongated, cylindrical treating chamber 109, and a hollow, cylindrical rotor 111, which extends the full length of the treating chamber 109 and which is arranged for rotation within that chamber, concentrically with the tube 107. The outer periphery of the rotor 111 is defined by a tubular shell 113, and the shell 113 is supported for rotation by a pair of short shaft sections 115 and 116, which are connected to the shell 113 by spider arms 117, and by a disc 119. The disc 119 also serves to close the upper end of the rotor. The lower shaft section 115, which is disposed within the path of flow of liquid into the rotor, is streamlined to minimize turbulence, as illustrated. The use of the two short shaft sections 115 and 116 makes possible the elimination of the central shaft from the main body of the rotor. This, in turn, makes possible the attainment of a vortex which more nearly approximates a free vortex than is possible in structures, such as the apparatus of Figures 1 to 4, wherein there is a central shaft extending the full length of the rotor.

The shell 113 of the rotor 111 is provided with perforations or slotted openings 69 in the end opposite to that into which the liquid being treated enters the rotor, and these perforations extend along at least one-third of the length of the rotor. The upper end of the tube 107 which defines the walls of the treating chamber is connected by a T-fitting 121, which is exactly the same as the fitting 99 of the previously described structure. In this apparatus, the fitting 121 is utilized as the outflow conduit for the liquid being treated.

The inflow portion of this apparatus is illustrated particularly in Figure 7, and as there shown, it includes a tubular fitting 123, which is adapted to be connected to the stock delivery pipe 125 or other source of liquid to be treated, and a nozzle inflow connection 127 which engages the fitting 129 and which extends into the lower end of the rotor 111. A suitable guide bearing 129 for the rotor shaft 115 is mounted on a spider 131, positioned at the discharge end of the inflow fitting 123.

The mechanism also includes a stationary, cylindrical

tube 133, which is attached to the base or hub portion 135 of the nozzle 127 and which extends upwardly into the lower end of the treating chamber 109 for a distance which is at least approximately equal to the diameter of that chamber. The tube 133, which acts as a flow directing baffle, is concentric with the rotor 111 and with the outer defining wall 107 for the treating chamber, and it is located a somewhat greater distance from the rotor than it is from the outer wall of the treating chamber. The end surfaces 137 of the hub portion 135 of the nozzle 127 are curved to provide a smooth, flow passageway, whereby fluid flowing downwardly between the rotor 111 and the stationary, tubular baffle 133 will be returned to the interior of the rotor 111 with a minimum of turbulence. The annular passageway 139 created between the tubular baffle 133 and the outer wall of the treating chamber 109 communicates with a somewhat larger annular passageway 141 within the body of the nozzle structure, and the passageway 141 connects, in turn, with a discharge pipe 143 for removing reject material from the system.

During operation of the apparatus, the liquid to be treated is introduced into the interior of the hollow, cylindrical rotor 111, at its lower end, via the nozzle 127. The liquid flows upwardly within the rotor shell and outwardly through the perforations 69 into the space between the rotor shell and the tube 107, as shown by the arrows. The rotor 111 is driven at such speed that a vortex having characteristics which approximate the characteristics of a free vortex is created within the rotor shell. The liquid passing through the apparatus is discharged through the fitting 121, as previously described.

The jet effect produced by the nozzle 127 at the lower end of the hollow rotor causes a certain amount of liquid passing through the perforations 69 to be drawn downwardly into the space between the stationary tubular baffle 133 and the outer periphery of the rotor and to flow back into the lower end of the rotor. At the same time, the dirt or other material which is separated by the vortex action in the treating chamber 109 is caused to hug the inner periphery of the stationary tube 107 which defines the walls of the treating chamber. This material settles down into the annular spaces 139 and 141, from whence it is removed from the system via the pipe 143. This combination of structural features and especially the provision of means whereby a jet is produced at the lower or inflow end of the rotor, together with the stationary baffle intermediate the rotor and the outer wall of the treating chamber, is of particular value in effecting the efficient separation at relatively high flow rates of material having a specific gravity which closely approaches the specific gravity of material which is to be retained in the carrier liquid. The apparatus is preferably operated in a vertical position, although it can be used in other positions, since it is ordinarily operated with the liquid to be treated completely filling the treating chamber.

In instances where simultaneous removal of dirt and control of the air content are to be effected, it will generally be found most convenient to utilize two or more serially connected units, each of which accomplishes one of the two desired functions. This arrangement is preferred over the arrangements effecting simultaneous removal of dirt and air control for the reason that the optimum operating conditions for either type operation may differ rather substantially from the optimum condition for the other type operation to be accomplished.

In the operation of each of various mechanisms previously described, the function of the rotor which is disposed within the vorticular treating chamber is to so control the vortex formed during the operation of the apparatus that the characteristics of that vortex approximate the characteristics of a free vortex. Thus, it is desired that the product of the fluid velocity at any given point in the vortex and the radial distance from the center or eye of the vortex to that point shall be equal to the product of the fluid velocity at any other point in the vortex and the radial distance to that other point, i. e. $V_1R_1=V_2R_2=a$

constant. The actual vortex which is produced does not follow this mathematical relationship, but rather merely approximates the desired relationship. In general, the degree to which this approximation approaches the relationship existing in a free vortex is a measure of the efficiency of operation of the apparatus.

In instances where single rotor mechanisms of the type which have been described in the foregoing do not accomplish separation of the material which is to be removed from the carrier fluid at a sufficiently high degree of efficiency, improved operation can be accomplished by the use of a plurality of concentrically disposed rotors within the treating chamber. Because of the variable hydraulic relationships which may exist during the operation of the apparatus, it is desirable in instances where a plurality of rotors are used, to provide means for individually driving each of these rotors at individually controllable speeds, although in a stable system, the two rotors may be driven at fixed relative speeds.

Apparatus embodying two, separate, individually driven rotors within the treating chamber is illustrated in Figures 10, 11 and 12. As might be expected, this apparatus makes possible much more accurate and much more effective control of the characteristics of the vortex, which is created within the treating chamber during the separating operation. Since the speed of rotation of each of the cylinders is individually controllable, the amount of power which is added to the vortex, as a result of the operation of the rotors is thereby susceptible of much more accurate control than is possible with a single rotor, and, as a result, it is possible in the multi-rotor type apparatus, to attain a vortex having characteristics which approach the characteristics of a free vortex much more closely than is the case in the single rotor embodiments of the invention.

It will be understood that there is no particular limit to the number of rotors which can be used. Under ordinary circumstances, the efficiency of the mechanism and the nearness to which its operational characteristics approach the operational characteristics of a free vortex will be closely related to the number of rotors. Mechanical considerations, however, render it desirable that as few rotors as possible shall be used in any given apparatus.

In all instances, the speed of each of the rotors should be such that the velocity relationships existing in a free vortex will be approximated as closely as possible. This means that the relative velocities of the rotors should be substantially in accordance with the velocity relationship existing in a free vortex, or stated mathematically, $v_1/r_1 = v_2/r_2 = a$ constant, wherein v_1 is the peripheral velocity of the rotor which is at a distance r_1 from the axis of rotation of the rotors (or center of the vortex) and v_2 is the peripheral velocity of the rotor surface which is at a distance r_2 from the axis of rotation of the rotors.

Except for the structural differences necessarily resulting from the multiple-rotor construction, the apparatus illustrated in Figures 10, 11 and 12 is essentially the same as the apparatus illustrated in Figures 1 to 4. It includes a suitable frame 143 which may be of structural steel, conduit means for conveying the fluid to be treated into and through a generally cylindrical, elongated treating chamber 145, an inner, hollow cylindrical, rotor member 147, which is slotted at the lower or downstream end thereof similar to the rotor 25, a second rotor member 149, which is supported for rotation within the treating chamber 145 concentrically of the first rotor 147.

The conduit means includes a nozzle fitting 150 disposed at the upper end of the mechanism and adapted to be connected to a supply line 153 for the material to be treated. The nozzle fitting 150, similar to the fitting 27, is provided with an inner baffle portion 151, which defines a spiral passageway so arranged that the fluid is discharged downwardly in the direction of the treating chamber 145 with substantial radial velocity. An annular deflector

fitting 157, having a conical flow direction portion 155, is positioned immediately beneath the outflow end of the nozzle fitting 151 for directing the inflowing liquid into the inner rotor member 147. The outer wall of the treating chamber 145 is defined by a cylindrical tube 159.

The inner rotor member 147 is supported for rotation within the treating chamber 145 concentrically thereof. The rotor member 147, in the illustrated apparatus, includes a cylindrical shaft 163 having reduced end sections 165 and 167, which extend through the end fittings 150 and 161 outside the path of fluid flow through the apparatus. The lower end portion 165 of the shaft 163 is engaged and supported by a suitable thrust bearing 169, and the upper end portion 167 which extends through a gland 171 is engaged by a suitable guide bearing similar to the guide bearing 47 (not shown). The upper end portion 167 of the rotor shaft is adapted to be connected to suitable, variable speed drives, which may comprise a speed control unit and a motor similar to the units 57 and 59.

It will be understood that two short shaft sections, similar to the short shaft sections 115 and 116, shown in Figures 7 and 8, may also be used to support the rotor member 147. This will be found desirable in instances where the improved operational characteristics made possible by the short shaft arrangement are needed to accomplish the desired separation.

The outer periphery of the inner rotor 147 is defined by a relatively thin-walled cylindrical tube 173, which is mounted on the shaft 163 by suitably spaced spider arms 174. The dimensions of the tube 173 are such that it extends the entire length of the treating chamber 145 with rather close tolerances at either end.

The lower or downstream end of the inner rotor 147 is provided with a plurality of staggered slot perforations 175. In this embodiment of the invention, the slots 175 are located in approximately the lower half of the rotor shell 173, and comprise six equally spaced, double rows of rectangularly-shaped slots, as illustrated in Figure 10. Similar slots 176 are provided in the outer rotor 149. The slots 175 and 177, similar to the slots 61, are 1/4 inch long, measured along the circumference of the rotors, and 3/16 inch in width. Each of the double rows of staggered slots is spaced 1/2 inch from the next adjacent double row of slots, and the double rows are spaced 4 inches apart. In this same mechanism, the treating chamber 145 has an overall diameter of 9 inches and the inlet and outlet fittings are adapted for connection to six inch pipe. The rotor shaft 163 in this mechanism has a diameter within the treating chamber of 2 inches.

The second, or outer, rotor 149 in this embodiment of the invention comprises a second thin-walled cylindrical tube 177, and the entire outer rotor structure is supported upon the tube 173, which defines the shell of the inner rotor 147, by means of spaced, annular bearings 179, mounted on the tube 173, and suitably, spaced apart spider arms 181, which extend from the bearings 179 to the tube 177, as shown in Figure 10. The annular bearings 179 are desirably of a low friction type, and they should be sealed against entry of the fluid which is passing through the apparatus. Also, since the tube 177 which defines the shell of the outer rotor, like the tube 173 which defines the shell of the inner rotor, extends the entire length of the treating chamber 145 with rather close tolerances at either end, it is important that the bearings 179 shall be of a precision type.

In order that the outer rotor 149 may be driven at controlled and determinable speeds, independently of the inner rotor 147, a ring gear 183 is supported upon the tube 177, which defines the shell of the outer rotor, at the upper end thereof. The ring gear 183 is arranged to be engaged by a pinion gear 185, which is supported upon a shaft 187, which, in turn, is supported upon the end fitting 150 by means of suitable thrust and guide bear-

ings 189 and 191. The mechanism also includes a gland 193 for sealing the shaft 187.

The pinion shaft 187, like the shaft 167, is connected to a suitable, variable speed drive (not shown) which may include a speed control unit and a motor, such as the units 57 and 59 in the Figure 1 apparatus. In the event that the liquid passing through the apparatus may contain any substantial amount of abrasive material, the gears 183 and 185 are desirably fabricated from fibrous or other abrasive-resistant material.

The material separated out during the operation of the apparatus is removed from the treating chamber 145 by means of an outlet 195, which is located adjacent the lower end fitting 197. This fitting which is disposed between the tube 159, which comprises the outer wall of the apparatus, and the outlet fitting 161, is provided at its upper surface with a plurality of concentric grooves 199. The grooves 199 are of such dimensions that the lower ends of the rotor tubes 173 and 177 fit therewithin with rather close tolerances. The arrangement minimizes any tendency for the material which has been separated out during operation of the apparatus to flow from the outer portion of the treating chamber 145 back into the rotors.

During operation of the apparatus, the material to be treated, which might, for example, be a pulp suspension, is admitted to the interior of the inner rotor 147 through the nozzle inflow fitting 150 and the deflector 155. The operation of the rotors, each of which is independently driven at such speeds that the relationship $v_1 r_1 = v_2 r_2 = a$ constant is substantially maintained within the treating chamber, is such that very high efficiency of operation is accomplished within the mechanism. The material from which the unwanted impurities have been removed passes out through the outlet fitting 161 as a continuous operation, and the rejected material which is separated out within the apparatus is removed by way of the discharge pipe 195. The flow through the discharge pipe 195 may be continuous or intermittent. Usually, about 10 percent of the total flow through the apparatus will be withdrawn through the discharge pipe.

By providing a plurality of separate rotors, each of which is independently driven, it is possible to achieve a vortex within the apparatus which much more closely approximates the characteristics of a free vortex than is the case in apparatus using a single rotor, and this, of course, is the reason for the improved operational characteristics of the apparatus. As previously indicated, when a plurality of separate rotors are used, the rotor speeds are adjusted to such values that the velocity relationship within the vortex approximately follows the free vortex relationship, i. e. $v_1 r_1 = v_2 r_2 = a$ constant, wherein v_1 is the peripheral velocity of the rotor which is at a distance r_1 from the axis of rotation of the rotors (or center of the vortex) and v_2 is the peripheral velocity of the rotor surface which is at a distance r_2 from the axis of rotation of the rotors. In effecting the separation of materials having a specific gravity which is very close to the specific gravity of the carrier liquid or of the material which is to be retained in the carrier liquid, increased efficiency can be realized by eliminating the central shaft, as above described. Also, as above described, the gravitational forces which are produced within the vortex will affect, and to some extent determine, the rate at which the unwanted material is separated out, and hence, the rate at which liquids can be passed through the apparatus. Gravitational forces within the vortex of from about 200 to 1500 unit gravities appear sufficient to effect the separation from water of a considerable number of different types of materials. It will be understood, as above noted, that more than two rotors may be employed when desired. Regardless of the number of rotors, the peripheral velocity should follow the velocity equation for the free vortex as closely as possible.

As previously stated, the apparatus of the present invention is particularly adapted for use in the control of the air content of stock which is being supplied to a paper-making machine, and when used for this purpose, the apparatus may also be employed to accomplish a simultaneous throttling function. In this connection, it should be noted that the use of a rotating cylinder to accomplish a throttling function is, of itself, a very important feature of the invention, as will be hereinafter pointed out.

The headbox end of a papermaking machine embodying rotary apparatus in accordance with the invention for accomplishing simultaneously air control and throttling functions is illustrated diagrammatically in Figure 13. In this view, and in Figures 14 and 15 there is illustrated at 247 the trough or conduit which conveys the stock from the screens to the headbox 249 of the machine. The trough 247 is of rectangular cross section and is fabricated from suitable sheet, angle and other structural members, so as to provide an enclosed passageway leading from the discharge end of the screens to a flow spreader 251 or other connection with the headbox 249 and web-forming region of the machine.

The stock conduit 247 is provided with a flow directing or throttling baffle 253, which extends between the side walls 255 of the conduit to define a flow passageway having the general cross sectional outline shown in Figure 14. The baffle 253 thus effects an initial progressive reduction in the cross sectional area of the flow passageway, following which there is a section indicated at 257 wherein the area of the conduit gradually increases, following which the area of the flow passageway abruptly increases, in the section 259, to the full cross sectional area of the conduit.

The area of the inlet portion 261 of the flow spreader, which is illustrated in section in Figure 14, is equal to the exit area of the gradually enlarging portion 257 of the flow passageway. The baffle arrangement in the stock conduit 247 thus provides a passageway for the stock wherein there is an initial, progressive acceleration in the rate of flow, following which there is a gradual deceleration.

In order to effect control of the air content of the stock which is passing through the stock conduit 247 and to provide a throttling control for that flow, the apparatus includes a perforated, cylindrical rotor 265, which extends across and substantially completely occupies the flow passageway, desirably at the region of minimum cross sectional area, as shown in Figures 14 and 15. The cylindrical rotor 265 is hollow, as in the previously described embodiments of the invention, and includes a perforated, tubular shell 267 which is mounted upon a hollow shaft 269 by means of suitable discs 271 or equivalent supports.

The hollow shaft 269 is, in turn, supported upon the sides 255 of the stock conduit by suitable bearings 273, the left hand one of which is illustrated in section in Figure 15. Each of the bearings 273 is mounted on a removable bearing support and cover member 275, which fits into a suitable, cooperating opening in one of the side walls 255 of the conduit, each of the cover members being held in place by a clamp ring 277, as shown. Each of the bearings 273 also includes a gland 279, which aids in preventing outflow of stock during the operation of the mechanism and in preventing fiber from working into the bearings and other regions of close tolerance. The mechanism includes pipes 281 and 283 through which fresh water is delivered, under pressure, to the space between cover members 275 and the ends of the rotor 265, and to the glands. This also aids in keeping fiber out of the bearings 273 and prevents fiber accumulations at the ends of the rotor.

At the left hand side of the machine (Figs. 13 and 15), the hollow supporting shaft 269 for the rotor 265 opens into a box-like enclosure 285, which is provided with two oppositely disposed pipe connections 287 and 289, the

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enclosure being otherwise pressure-tight. The other end of the hollow shaft 269 extends into and through a similar enclosure 291, which is also provided with oppositely disposed pipe connections 293 and 295. Since power is supplied to the rotor 265 at this end of the mechanism, the shaft is closed at this end and is arranged to be connected to a suitable, variable speed drive 297 by a coupling 299. The closed end of the shaft 269 passes out of the enclosure 291 through a gland seal 301. The closing of the end of the shaft also makes it necessary to provide openings, as illustrated at 303, in order that the interior of the shaft may communicate with the interior of the right hand enclosure 291. The interior of the rotor shaft 269 communicates with the interior of the rotor itself by means of suitable, spaced, longitudinally extending slots 305, which are machined therein.

During normal operation of the apparatus, the hollow rotor 265 is driven at a sufficiently high speed to create a vortex, internally of the perforated rotor shell 267, having properties approximating those of a free vortex. By this means, it becomes possible to withdraw air from, or to add air to, the flowing stream of stock, under such conditions that extremely accurate control of the air content can be continuously effected.

When air is being withdrawn from the flowing stream of stock, the up-draft connections 287 and 293 in the end enclosures 285 and 291 will be connected by suitable piping 307 to a pump or other source of reduced pressure 309, as illustrated diagrammatically in Figure 13. This may be the same means which is connected to the manifold and piping 311 for maintaining reduced pressure in the enlarged portion 259 of the flow conduit. Since a certain amount of liquid may flow outwardly through the rotor shaft 269 during operation of the apparatus, the down-draft connections 289 and 295 to the enclosures 285 and 291 are also connected by piping 313 to means, such as a barometric column 315, whereby the desired reduced pressure can be maintained within the enclosures. The liquid which flows through the barometric column 315 is collected in a tank 317 and returned to the white water system of the paper making machine, as by the pump 319.

To illustrate the operation of equipment of this type, one commercial embodiment of the invention utilizes a rotor 265 having an outside diameter of 18½ inches, the perforations in the rotor shell being circular and about 1 inch in diameter, and being symmetrically spaced to provide a surface which is approximately 25% open. The rotor in this equipment has a length between the sides 255 of the stock conduit of 5 feet. The inner shaft 269 has a diameter of 4 inches and the slots 305 are approximately ½ inch wide and of such length and spacing that the hollow inner shaft 269 is approximately 60% open. When used in a papermaking machine manufacturing newsprint from a stock having a consistency of from about .5-1.0%, which stock is supplied at the rate of approximately 4-5000 gals. per minute for a wire speed of 900 feet per minute, it was found that the rotor could be operated at speeds varying from 700 to 1700 R. P. M. with very efficient and very satisfactory control of the air content. Also, it was observed that varying the speed of the rotor within the above stated limits provided a highly satisfactory stock throttling mechanism, regardless of whether or not the apparatus was employed to effect simultaneous control of the air content. It was also found that the mechanism is of great value in effecting thorough intermixing of the stock delivered from the screens, and that this function alone effected substantial improvement in the formation and other characteristics of the resulting sheet.

In the operation described above, the relative dimensions of the rotor and the flow passageway within the stock conduit are such that somewhat in excess of about 90% of the flow through the conduit was required to pass into and through the rotor. For the satisfactory

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control of the air content in paper stock and pulp suspensions, containing up to 5.0% of air by volume, it appears necessary that the flow through the vortex region created by the rotor should be at least 90% of the total flow through the stock conduit. As a specific example of the operation of apparatus having the dimensions described above, the air content of the stock, at a temperature of 90° F. and having a consistency of .65%, was reduced from 1.8% by volume to .7% by volume, at a flow rate of 7500 gallons per minute, when the rotor speed was within the range of about 300 to 350 R. P. M. In this same operation, about 300 gallons of liquid per minute flowed through the barometric column, and the pressure within the end enclosures was held to about 5 inches of mercury absolute.

The relative spacing of the rotor shell and the defining walls of the flow conduit in the apparatus described in the foregoing are substantially fixed, and to that extent, the operational range of the apparatus, either for the accomplishment of an air removal function or the accomplishment of a throttling function, or both, is limited. To extend this operational range and to provide a more flexible overall arrangement, the apparatus may be provided with means for varying the spacing of the rotor shell and the defining walls of the flow conduit, this being of especial value when the mechanism is used in accomplishment of a throttling function alone.

Various means can be used for this purpose. For example, as illustrated in Figure 16, the apparatus may be provided with a transversely disposed, adjustable vane or blade 321 which is rotatably supported on the side walls 255 of the flow conduit 247, in the region of the depressed, central portion of the baffle 253. The vane 321 extends completely across the flow conduit and is in such position with respect to the rotor 271 that it may be rotated toward or away from the peripheral surface of the rotor so as to vary uniformly the width of the gap 323 existing therebetween. Conveniently, the means for rotating the vane 321 and for locking it in place comprises an adjusting arm 325 and a screw locking means such as is indicated at 327.

The provision of an adjustable means for varying the gap between the rotor surface and the defining walls of the flow conduit makes it possible to vary, within quite wide limits, the amount of liquid which is caused to pass through the rotor, and this variation can be used either to vary the amount of air which is removed, or to vary the throttling effect. The arrangement greatly extends the effective range of operation of the apparatus. Also, the provision of means for varying the gap between the rotor surface and the defining walls of the flow conduit with a variable speed drive for the rotor is particularly effective when the apparatus is being used for accomplishing the throttling function.

It will be understood that the use of a hollow rotor in accordance with the invention for effecting the control of the air content of flowing streams of liquid, or for obtaining a throttling effect, or for accomplishment of both functions simultaneously, is applicable to stock delivery mechanisms of various types. Also, it is important to note that the mechanism inherently accomplishes very efficient mixing of stock or other materials which pass therethrough, and may thus be used as a means for combining the flow from two or more liquid sources, for example, the stock flow from two sets of Bird screens.

As an example of the use of the invention with one of the more highly specialized types of stock delivery mechanisms, the unit illustrated in Figures 17 and 18 is designed for inclusion in a "cross-flow" stock delivery mechanism, which follows the general arrangements shown in U. S. Patents No. 2,347,717 and No. 2,347,850 to Staeger. This apparatus includes a main stock delivery conduit 331 which is connected to the fan pump or other source of supply (not shown). The conduit 331 connects at its outflow end with a T-fitting 333, wherein the

flowing stream of stock is divided into two, oppositely disposed, flowing streams of substantially equal size. The two streams emerging from the T-fitting 333 are conducted, by suitable pipe sections 335 and 337, to the cross flow mechanism 339, that mechanism comprising essentially a box-like structure 341 having a central baffle 343, a pair of conduits, which define wedge-shaped, interconnected flow passageways 345 and 347, disposed side by side, as illustrated in Figure 17.

In the use of apparatus in accordance with the present invention in connection with cross flow stock delivery system, generally it will be found most convenient to locate the hollow rotor adjacent the delivery end of the main stock conduit. Also, it is desirable that the stock shall be delivered to the interior of the rotor via a nozzle mechanism in order that the maximum possible amount of liquid shall pass through the rotor.

In the apparatus illustrated in Figures 17 and 18, the rotor 349 comprises a hollow, cylindrical shell which is open at its lower end, and which is provided with a plurality of spaced perforations 351 in the upper portion thereof. The rotor 349 is supported in a vertical position within the T-fitting 333, and a nozzle unit 353 is provided at the inflow side of the fitting 333 for directing the stock into the open lower end of the rotor shell. The perforations 351 in the rotor surface may extend along as much as two-thirds or even three-fourths of the length of the rotor shell, which is in contrast with some of the previously described arrangements. However, perforations should not be provided in the portion of the rotor shell which is immediately adjacent the region of stock inflow.

In the particular apparatus illustrated in the drawings, the rotor 349 is closed at the end opposite to that into which the stock is delivered, except for the passageway provided through the hollow, supporting shaft 355. Suitable guide and support bearings 357 and a gland seal 359, not shown in detail, coast with the shaft 355, in order that the rotor 349 will be supported in proper operating position within the T-fitting 333. The interconnected rotor and shaft may be driven by any convenient means, as for example, the drive pulley, illustrated at 361. It will be understood that the pulley 361 or equivalent means, is connected to a variable speed drive in order that the speed of the rotor 349 can be adjusted to the optimum operating value. The upper end of the drive shaft is arranged to be connected, by means of a rotary joint 363 and suitable piping 365, to a pump or other source of reduced or increased pressure, as may be required.

In the operation of apparatus of this type, in connection with a cross-flow inlet machine used in the manufacture of book paper, stock having a consistency within the range of approximately .5 to 1.2%, is delivered to the T-fitting 333 via a 30 inch line, the delivery rate varying from about 5000 to 6000 gals. per minute for machine speeds of approximately 1000 feet per minute. The two diverging lines 335 and 337 which are connected by means of the T-fitting also have a diameter of 30 inches. During operation, rotor speeds of the order of from 500 to 1000 R. P. M. were employed with a rotor 16 inches in diameter and 36 inches long. Substantial removal of air was effected via the line 365, which was connected to a source of reduced pressure. In addition, very effective intermixing and uniforming of the stock was accomplished in its passage through the apparatus.

In connection with apparatus of this type, it will be appreciated that the period of time during which the stock is retained within the vortex and the rotor is relatively short, as compared with the period of retention that is attained in apparatus of the type illustrated in Figures 1, 5 and 7. For this reason, the amount of air removal that can be effected in apparatus such as is illustrated in Figures 17 and 18 may be very much less than is the case in mechanisms where longer retention periods are possible.

As previously pointed out, apparatus in accordance with the invention can also be utilized for the introduction of air or other gases into flowing streams of liquid, as for example the introduction of air into pulp suspensions or paper stock as used in the manufacture of paper. When an apparatus such as that illustrated in Figures 5 and 6 is being used to introduce a gas into a liquid passing therethrough, the mechanism should be operated only partially full, and a rather deep vortex, which is open to the air or other gas being used, should be produced within the treating chamber. Also, instead of maintaining a reduced pressure in the region above the vortex, which is the normal mode of operation when the removal of air is to be effected, it will generally be found desirable to maintain the gas present in that region under pressure. The magnitude of this pressure, maintained above the vortex, will depend on the amount of gas to be added to the liquid being treated, the temperature of that liquid, and other operating conditions.

In the foregoing, there have been illustrated and described a number of embodiments of vorticular hydraulic apparatus, in accordance with the present invention. Certain of these various illustrative structures are designed and are operable to accomplish the separation and the removal from liquid dispersions of materials having a specific gravity which closely approaches the specific gravity of the useful materials which are to be retained in the carrier liquid, as for example, the removal of bark specks from pulp suspensions. This capability of separation apparatus in accordance with the invention is of particular importance, for the reason that the efficient separation of low density difference materials of this character has heretofore been substantially impossible of accomplishment in vorticular hydraulic apparatus.

Vorticular apparatus in accordance with the invention is also of great value as a means for removing gas from, or for adding gas to, flowing streams of liquid. A particularly important application of the invention in this connection is the control of the air content of the flowing stream of stock which is delivered to a papermaking machine during its operation. In this use, the ability of apparatus in accordance with the invention to effect continuous control of the air content of the stock is especially advantageous.

A further, very important, feature of the invention is the disclosed use of rotor mechanisms of various types as throttling means for the control of flowing streams of liquids. In this use, the rotor mechanism acts to interpose an adjustable hydraulic resistance of a very uniform and very stable character into the hydraulic circuit, with the result that greatly improved control is attained.

Other features of the invention, which are likewise of particular value in the manufacture of paper include the ability of the apparatus to effect the control of the air content of a flowing stream of liquid, while simultaneously acting as a throttling mechanism, and the ability of the apparatus to effect improved intermixing of liquid materials flowing therethrough.

In each of the various examples of the invention described in the foregoing, the same basic principle of operation is utilized, that is the apparatus accomplishes its desired function as a result of the provision in its operating zone of a vortex having characteristics which at least approximate the characteristics of a free vortex. Also, in the accomplishment of this type of vorticular action, it will be observed that each of the mechanisms include means for continuously supplying power to maintain the desired vorticular action.

Various of the features of the invention believed to be new are set forth in the accompanying claims.

I claim:

1. Vorticular separation apparatus of the class described comprising means for defining the walls of an elongated, generally cylindrical treating chamber, a plurality of hollow, cylindrical rotor members, means support-

ing said rotor members in concentric relationship for independent rotation within the treating chamber, each of said rotor members including a cylindrically-shaped outer shell that is provided with spaced perforations at at least one end thereof, means for conducting the liquid to be treated into and through said concentrically disposed rotor members, means for removing the material which is separated out in said treating chamber during the operation of said apparatus, and drive means operable to rotate said rotor members at such differential speeds that a vortex having characteristics which approximate the characteristics of a free vortex may be established within said treating chamber.

2. Apparatus as defined in claim 1, wherein the outer rotor member is supported upon the inner rotor member by means including annular bearings.

3. In apparatus of the class described, means defining the walls of an enclosed fluid conduit, a hollow rotor which includes a perforated outer shell and a hollow shaft which is open to the interior of said shell, means supporting said rotor within said conduit in the path of fluid flow therethrough, one end of said hollow shaft projecting through one of the defining walls of said conduit, a housing which is disposed about and which connects with said projecting end of said rotor shaft, means for driving said rotor at predetermined speed during the operation of said apparatus, and means for maintaining a predetermined pressure within said housing.

4. In a stock supply system for use in conjunction with a papermaking machine, means defining the walls of an enclosed stock conduit, a hollow, cylindrical rotor which includes a perforated shell and a hollow shaft which is open to the interior of said shell, means supporting said rotor within said stock conduit in the path of flow therethrough, the relative dimensions of said rotor and said conduit being such that at least about 90% of the cross-sectional area of said conduit is occupied by said rotor, one end of said hollow shaft projecting through the defining walls of said conduit, a housing which is disposed about and which connects with said projecting end of said rotor shaft, means for driving said rotor at predetermined speed during the operation of said apparatus, and means for maintaining a predetermined pressure within said housing.

5. In a stock supply system for use in conjunction with a papermaking machine, means defining the walls of an enclosed stock conduit which is substantially rectangular in cross-section, a hollow, cylindrical rotor which includes a perforated shell and a hollow shaft which is open to the interior of said shell, means supporting said rotor within said stock conduit in the path of stock flow therethrough, the relative dimensions of said rotor and said stock conduit being such that at least about 90% of the cross-sectional area of said conduit is occupied by said rotor, both ends of said hollow shaft projecting through the defining walls of said conduit, a pair of housings, one of which is disposed about and connects with each of the projecting ends of said rotor shaft, means for driving said rotor at predetermined speed during the operation of said apparatus, means for emptying said housings of stock which may flow therein during the operation of said apparatus, and means for maintaining a predetermined, reduced pressure within said housings during the operation of said apparatus.

6. Apparatus for throttling a flowing stream of liquid comprising means defining the walls of an enclosed flow conduit intermediate the ends thereof, a rotor positioned in said conduit, said rotor being of such dimensions that it occupies at least the major portion of the cross-sectional area of said conduit, drive means operatively connected to said rotor for driving said rotor at a predetermined speed sufficient to effect controlled throttling of the flowing stream passing through said conduit, and means operable to change the relative spacing between a surface of said rotor and at least one of the defining walls of said flow

conduit without changing the hydraulic characteristics of the flowing stream of liquid approaching the rotor.

7. Apparatus for throttling a flowing stream of liquid, comprising means defining the walls of an enclosed flow conduit which is substantially rectangular in cross-sectional outline, a hollow, cylindrical rotor, the periphery of which is provided with a plurality of spaced perforations extending across, and occupying the major portion of the cross-sectional area of, said flow conduit intermediate the ends thereof, drive means operatively connected to said rotor for driving said rotor at a predetermined speed, sufficient to effect controlled throttling of the flowing stream passing through said conduit, and means, which comprises a movable element constituting a part of one of the defining walls of said flow conduit, operable to effect relative variations in the spacing between a surface of said rotor and the adjacent surface of said flow conduit without changing the hydraulic characteristics of the flowing stream of liquid approaching the rotor.

8. The method of separating material from a liquid carrier containing such material, which comprises subjecting the total mass of liquid from which the separation is to be effected, while such liquid is in continuous flow, to the action of a rotating cylindrical surface which produces an elongated vortex, which has characteristics approximating the characteristics of a free vortex, and which is maintained and controlled by the continuous and direct addition to the vortex, along a major portion of the axial length of the vortex, of substantial amounts of energy by said surface, the rate of energy addition being independent of the pressure and velocity energy of the liquid entering the vortex.

9. The method of continuously separating material from a flowing stream of liquid containing such material, which comprises causing the liquid from which the separation is to be effected to continuously flow axially into, and become part of, an elongated vortex, which vortex has characteristics approximating the characteristics of a free vortex and is maintained and controlled by the continuous and direct addition to the outer region of the vortex, uniformly along a major portion of the axial length thereof, of substantial amounts of energy, the rate at which energy is added to said vortex being independent of the pressure and velocity energy of the flowing stream entering said vortex.

10. The method of separating material from a liquid which contains that material and other material having a specific gravity which closely approaches the specific gravity of the material to be separated, which comprises subjecting the total mass of liquid, while in continuous flow, to the action of a rotating cylindrical surface which produces an elongated vortex having characteristics which approximate the characteristics of a free vortex, and wherein centrifugal forces equivalent to a gravitational force of at least from about 200 to 1500 unit gravities are maintained, said vortex being maintained and controlled by the continuous and direct addition to the vortex uniformly along a major portion of the axial length of the vortex of substantial amounts of energy by said surface, the rate at which energy is added to said vortex being independent of the pressure and velocity energy of the liquid flowing into said vortex.

11. Vorticular separation apparatus comprising means for defining the walls of an elongated, generally cylindrical treating chamber, which is closed except for a liquid inlet means at one end of said chamber, a liquid outlet means at the other end of said chamber, and a discharge means through which the material to be separated is removed from said chamber, a hollow rotor which comprises an elongated, tubular shell having a plurality of rows of axially-spaced perforations provided therein, the inner and outer surfaces of said shell being substantially free of projections, said rotor having a length approximately equal to the length of said treating chamber and having a substantially unobstructed, cylindrically-shaped

passageway extending axially therethrough, whereby liquid introduced into said rotor can be placed in unobstructed vorticular flow having characteristics which approximate the characteristics of a free vortex about the axis of said rotor by rotation of said rotor, conduit means connected to said inlet means for conducting the liquid to be treated into one end of said rotor, means supporting said rotor for rotation within said treating chamber, drive means operable to rotate said rotor, conduit means connected to said outlet means for conducting treated liquid out of said treating chamber, and other conduit means connected to said discharge means for conducting the material separated from said liquid out of said treating chamber.

12. Vorticular separation apparatus comprising means for defining the walls of an elongated, generally cylindrical treating chamber, which is closed except for a liquid inflow opening at one end of said chamber, a liquid outflow opening at the other end of said chamber, and a discharge means through which the material to be separated is removed from said chamber, a hollow rotor which comprises an elongated, cylindrically-shaped, tubular shell having a plurality of axially-spaced perforations at at least one end thereof, said rotor having a length approximately equal to the length of said treating chamber, having a central passageway, which is substantially unobstructed, in the direction of rotation of said rotor extending axially therethrough, whereby liquid introduced into said rotor can be placed in unobstructed vorticular flow having characteristics which approximate the characteristics of a free vortex within said rotor by rotation of said rotor, conduit means connected to said inflow opening for conducting the liquid to be treated into one end of said rotor, means for supporting said rotor within the treating chamber, means including a tubular baffle member having a length which is substantially less than the length of said treating chamber and an inner diameter greater than the outer diameter of said rotor disposed in said treating chamber substantially concentrically with said rotor for defining a settling region, drive means operable to rotate said rotor, conduit means connected to said outflow opening for conducting treated liquid out of said treating chamber and other conduit means connecting said discharge means to said settling region for conducting the material separated from said liquid from said treating chamber.

13. Vorticular separation apparatus comprising a pair of spaced-apart conduit fittings, a cylindrical, tubular member which extends between said spaced-apart conduit fittings for defining the walls of an elongated, generally-cylindrical treating chamber, said treating chamber being closed except for a liquid inflow opening provided at one end of said chamber by one of said fittings, a liquid out-

flow opening provided at the other end of said chamber by the other of said fittings, and a discharge means through which the material to be separated is removed from said treating chamber, a hollow rotor which comprises an elongated, cylindrically-shaped, tubular shell having a plurality of axially-spaced perforations at at least one end thereof, the inner and outer surfaces of said shell being substantially free of projections, whereby the interior of said rotor is substantially unobstructed in the direction of rotation thereof, means supporting said rotor for rotation within said treating chamber, the shell of said rotor extending substantially the full length of said treating chamber, whereby the ends of said rotor extend into close proximity with said conduit fittings, drive means operable to rotate said rotor, the conduit fitting at the inflow end of said chamber including a flow directing means through which the liquid flowing through said inflow opening is contracted into a jet and directed into the interior of said rotor, the conduit fitting at the outflow end of said chamber conducting the treated liquid out of said treating chamber, the other conduit means connected to said discharge means for conducting the material separated from said liquid out of said treating chamber.

14. Apparatus as defined in claim 13, which includes a tubular baffle member having a length which is substantially less than the length of said treating chamber, and an inner diameter greater than the outer diameter of said rotor, disposed in said treating chamber adjacent the liquid inflow end thereof, substantially concentrically with said rotor, for defining a settling region that connects with said discharge means.

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