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[54] APPARATUS FOR THE REMOVAL OF LIQUIDS
FROM FIBROUS MATERIALS
15 Claims, 9 Drawing Figs.

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100/74, 73, 75, 98, 37, 39, 110, 116, 117, 126,
127, 43, 111, 112, 95

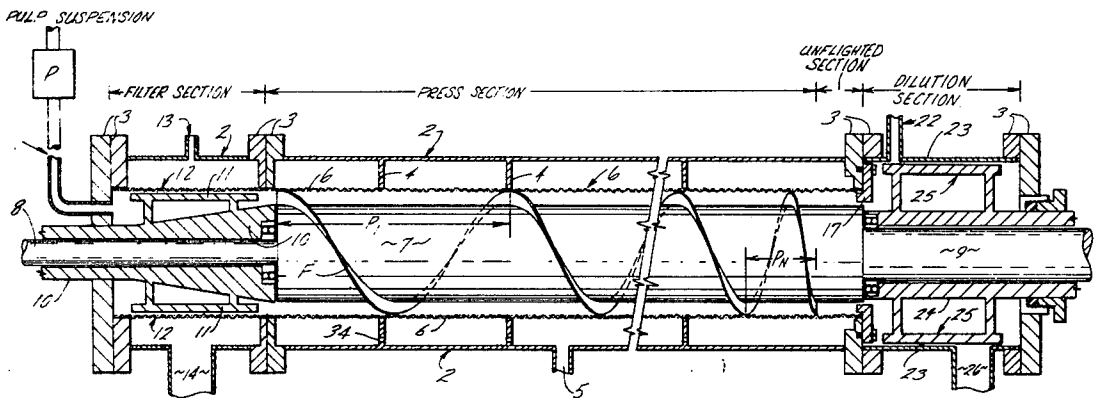
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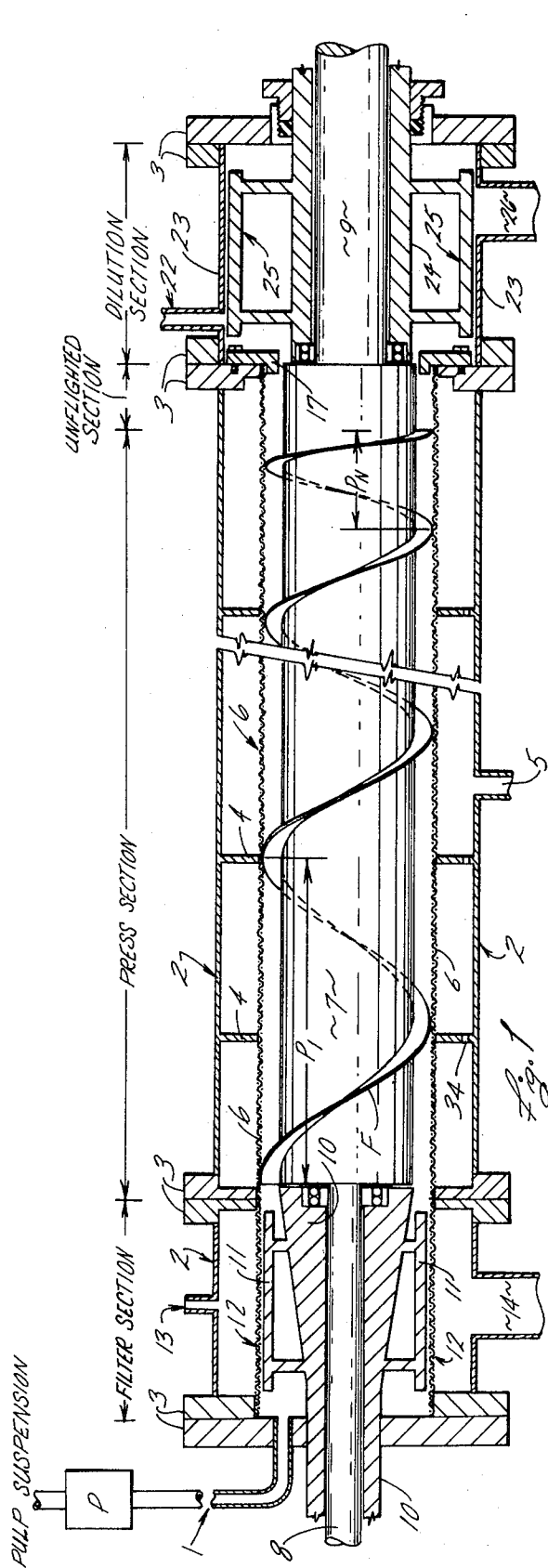
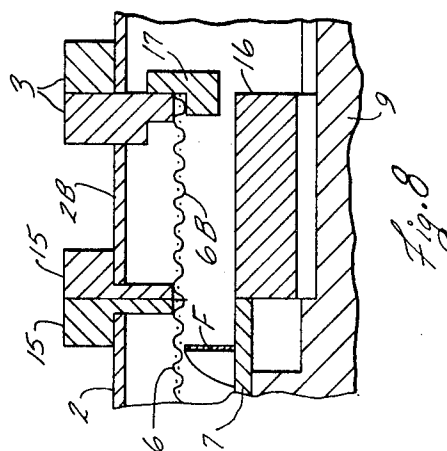
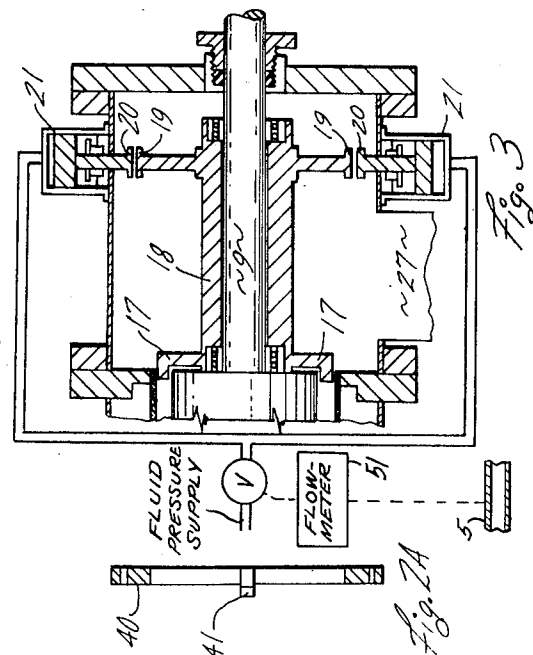
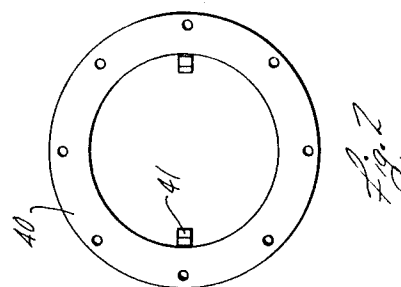
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ABSTRACT: An apparatus for removing liquid from a suspension of liquid and fibrous solids comprising a screw press which may have associated therewith a preliminary filtration section to remove a substantial amount of the liquid before the suspension enters the screw press, an unflighted section at the discharge end of the screw press for increasing the pressing effect, fingers at the discharge end of the screw press to stop rotation of the press cake and a dilution section for mixing a dilution liquid with the press cake, while excluding gas therefrom, so that as the fibers expand the dilution liquid is sucked into the fibers.



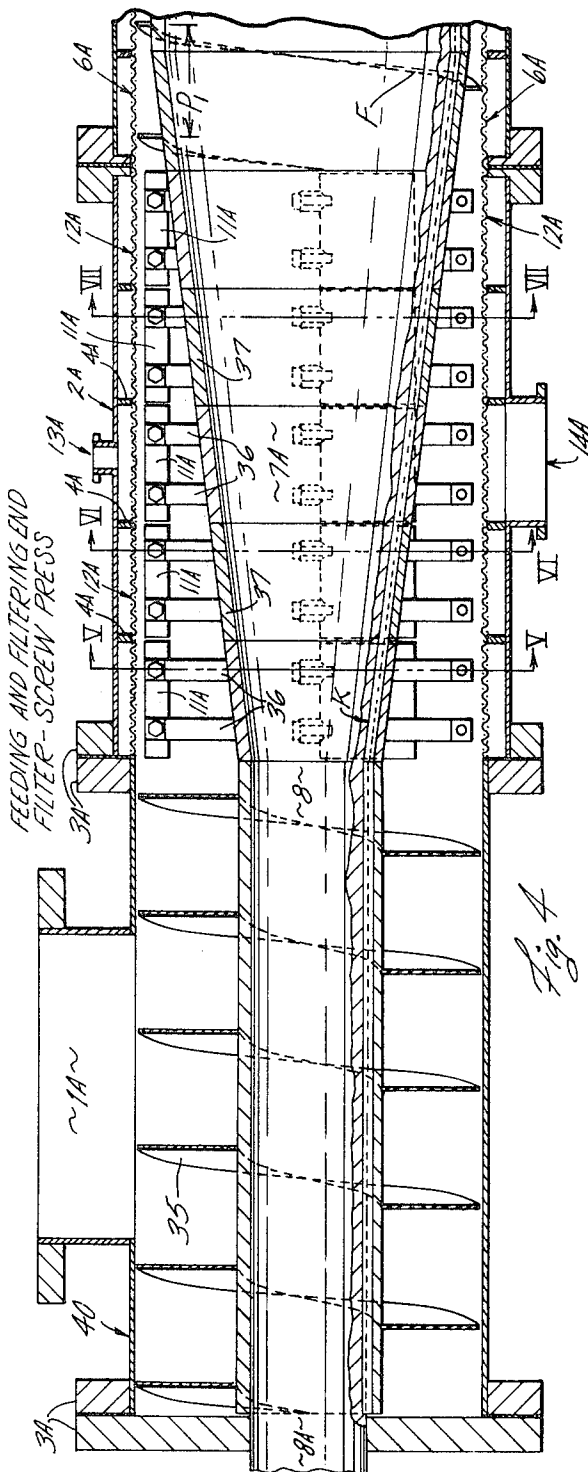
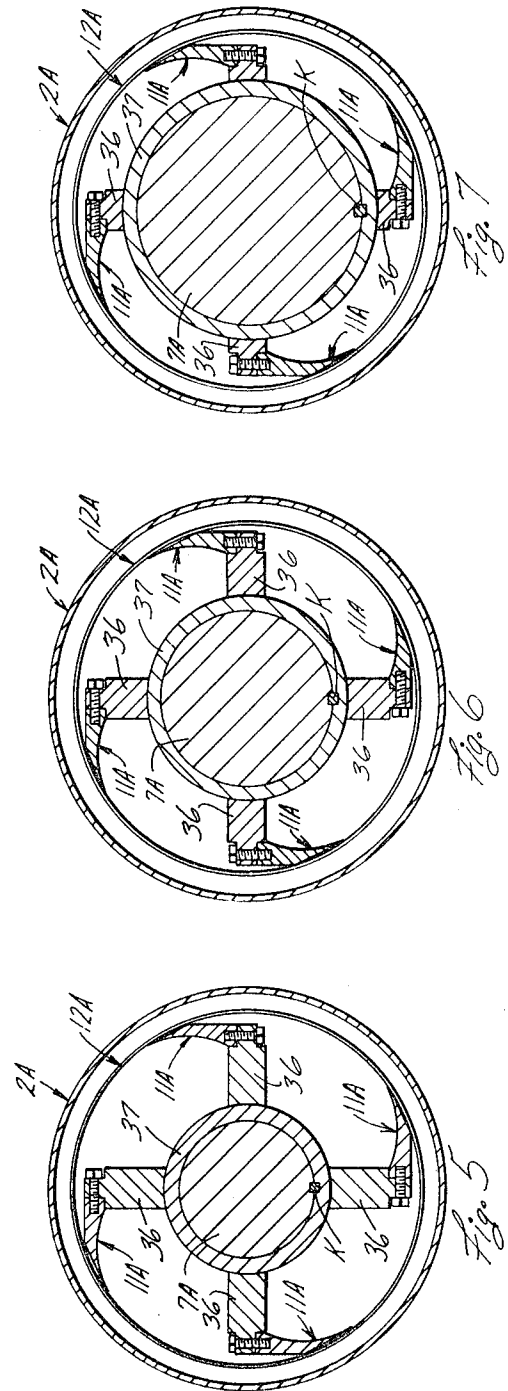


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APPARATUS FOR THE REMOVAL OF LIQUIDS FROM FIBROUS MATERIALS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an apparatus for removing water, aqueous solutions or other liquids from suspensions of compressible, fibrous solids such as cellulose fibers, wood fibers, asbestos, and the like. This invention is particularly concerned with the removal of water, waste cooking liquor, and bleach solutions from wood pulp fibers, such as kraft, sulfite, neutral sulfite and groundwood pulps.

Although the invention is capable of use in a variety of fields, it was primarily developed for use in paper mills and the like for pulp washing purposes. Therefore, the following description will refer primarily to this field of use. However, this specific description is given for illustrative purposes only and it will have no limiting significance.

2. Description of the Prior Art

In the past, the washing of waste liquor from cellulosic pulps has been carried out in false-bottomed tanks (diffusers), vacuum filters, and screw presses. The diffuser washer can be very efficient in carrying out liquor removal, but several hours are required for countercurrent washing because the process depends on the slow diffusion of concentrated liquor from the hollow lumens of the fibers through the cell wall into the diluting liquor moving past the fibers. This process is much too slow for modern, high tonnage pulp mills.

Vacuum filters are normally used in pulp mills today, usually three or four vacuum filters connected in series, to carry out liquor removal. Such filters require that the pulp be diluted to less than 1.0 percent consistency (lb. dry fiber per 100 lb. suspension) in order to form a uniform cake on the filter drum. Furthermore, the pulp cake coming off the drum cannot be deliquored beyond 14—15 percent consistency. I have found that delignified cellulose trachieds, or fibers, will hold, in the hollow lumens of these fibers, about 4.0 lb. water, or $4.0 \times$ specific gravity of liquor. This means that the cellulose fibers, with all exterior liquor, i.e. liquid not held in the fiber lumens, removed, should form a filter cake of 20 percent consistency. Since the vacuum filter discharges its fiber cake at 14—15 percent consistency, the fibers discharged from the first filter must contain substantially all of the strong liquor originally in the lumens plus a small amount of the exterior liquor. The fiber mat from the first filter is mixed with dilute waste liquor and is pumped immediately to the vat of the second filter. No time is allowed for the strong liquor inside the fibers to diffuse into the surrounding dilute liquor. Therefore, the washing efficiency of vacuum filters is poor. That is, an undesirably large amount of the strong liquor remains in the fiber lumens.

Screw presses, on the other hand, are highly efficient because they take advantage of the compressibility of the hollow cellulose fibers. If the press operates with a discharge consistency of 40 percent, not only is all the exterior liquor removed, but also much of the liquor inside the fiber lumens is squeezed out. At the point where fiber compression starts (about 20 percent consistency), each lb. of dry fiber contains 4.0 lb. of liquor inside the fiber. At 40 percent consistency, each lb. of dry fiber contains only 1.5 lb. of liquor. Therefore, 2.5 lb. of the interior liquor has been squeezed out, amounting to 62.5 percent of the total interior liquor. If the pulp discharged from the press is at 65 percent consistency, 86.5 percent of the interior liquor will have been squeezed out.

As the compressed fiber cake leaves the compression zone of the press, the fibers which are resilient will spring back, at least partially, to their original form. Screw presses presently in use allow these fibers to expand in air, with dilution liquor being added after fiber expansion takes place. Therefore, a definite time interval is required for dilution liquor to diffuse into the fibers and replace the air picked up in the initial fiber expansion.

SUMMARY OF THE INVENTION

The first feature of this invention is directed to the elimination of this air pickup. According to this feature, the discharge end of the press is completely enclosed, except for piping to admit dilution liquor and to discharge the diluted pulp. The discharge section is kept completely full of pulp and liquid, thus excluding contact of the press cake, i.e. compressed fibers plus trapped liquid, with air. As the fibers expand, dilution liquor is immediately drawn into the hollow lumens of the expanding fibers. Agitators in the discharge section insure breakup of the cake into a uniform suspension for discharge from the press. By this treatment, every lb. of dry fiber pressed to 40 percent consistency will absorb 2.5 lb. of dilution liquor which will mix with the 1.5 lb. of strong liquor remaining in the fiber lumens. Additional dilution liquor is added to provide fluidity for discharging the fiber mass. The press discharge is now ready for immediate introduction into a second press for the second stage of pressing. It can thus be seen that a screw press, properly designed, is a much more efficient and rapid liquor removal device than either diffuser tanks or vacuum filters.

One major difficulty encountered in screw press designs lies in the very large volume changes which must be built into the press. The following example will illustrate the magnitude of these volume changes. Consider a cellulose pulp suspension initially at 3 percent consistency (3.0 lb. dry fiber per 100 lb. suspension). It is required to deliquor this suspension to 40 percent consistency. Per 100 lb. dry fiber, assuming for purposes of illustration that the specific gravity of the suspension is equal to 1.0, the initial volume is $(100/0.03 \times 8.33) = 40.0$ gal. The final volume, at 40 percent consistency, with the same assumption of unity specific gravity, is $(100/0.40 \times 8.33) = 3.0$ gal. The decrease in volume between these two terminal conditions is $40.0 - 3.0$ or 37 gal. **If such a change in volume is to be carried out in a screw press, a very difficult design problem is involved in providing 13.3 times as much volume at the feed end as at the discharge end.**

Using this same example of 100 lb. o.d. pulp being concentrated from 3.0 percent to 40.0 percent o.d. consistency, the following tabulation will show how the volume changes with consistency. Basis: 100 lb. o.d. pulp—assuming all suspensions have sp.gr. = 1.0. Entering consistency 3.0 percent o.d. fiber; 40 gal/1000 o.d. fiber. Final consistency 40 percent o.d. fiber; 3.0 gal/1000 o.d. fiber. Total volume change 37 gal.

Intermediate consistency (percent o.d. fiber)	Intermediate volume (gal./100 lb. fiber)	Volume change from 3 percent (gal.)	Percent of total volume change
4.0.....	30.0	10.0	27.0
6.0.....	20.0	20.0	54.2
8.0.....	15.0	25.0	67.5
10.0.....	12.0	28.0	75.7
25.0.....	4.8	35.2	95.2
40.0.....	3.0	37.0	100.0

It can thus be seen that over 75 percent of the total volume change takes place in increasing the consistency from 3 percent to 10 percent. If it were possible to carry out this deliquoring from 3.0 percent to 10.0 percent by a filtration process, the screw press itself would have to take care of only a relatively small volume change. In such a case, the volume at the entrance end would only have to be 4.0 times as large as the exit volume, as compared to a figure of 13.3 times when the press carries out all of the deliquoring.

The operating principle of a screw press is well known. A series of screw flights, mounted on a central, rotating spindle, forces pulp through a cylindrical tube or barrel whose walls are made up of a filter (pervious) medium, either wire screen, punched plates or closely spaced bars placed longitudinally along the barrel. Mechanical pressure from the rotating screw is brought to bear on the pulp suspension, forcing the pulp through a progressively diminishing cross section, from the feed end to the discharge end of the press. This decrease in

cross section can be brought about by increasing the diameter of the spindle toward the discharge end or by decreasing the diameter of the barrel. Further compression is brought about by a progressive decrease from the feed end to the discharge end in the pitch of the screw flights. The forces set up by the pitch of the screw flights and the speed of the screw provide the energy to propel the pulp through the press. The diminishing cross section and screw pitch expel liquid from the fibers through the pervious barrel and bring the fibers closer together.

If the mechanical configuration of the press is known, it is possible to calculate the theoretical deliquoring for any feed rate and entering consistency. If the annular cross section between the barrel and the spindle at the feed end is designated as A_1 and the screw pitch at the feed end is represented by P_1 , the entering volume per revolution is A_1P_1 . Similarly, representing the cross section and pitch at the discharge end, respectively, as A_2 and P_2 , the discharge volume per revolution is A_2P_2 . Therefore, the theoretical volume of liquid expressed per revolution of the press is $A_1P_1 - A_2P_2$. The volume of liquid removed per minute would be $(A_1P_1 - A_2P_2)R$, where R is the number of revolutions of the screw per minute.

In the above table in which was listed the percent change in volume with change in consistency, it was shown that a 13.3 fold change in volume was required to press a pulp suspension from an initial value of 3.0 percent consistency to a final value of 40.0 percent. It can readily be seen that extremely radical changes in both the spindle diameter and in the flight pitch would be required to bring about this volume decrease. I have found that too steep a taper on the spindle shaft, in order to bring about a large decrease in volume, can result in excessive power requirements and even plugging of the press.

An analysis of the problem of liquor removal from fibrous material will show that two distinct operations are involved. At low consistencies, up to a consistency range of about 10–15 percent, depending on the characteristics of the fiber involved, the suspension behaves as a hydraulic fluid. Liquid can flow around the fibers and fibers can flow past one another to a limited extent. In such a case, the principal resistance to flow of the liquid through the filter medium is caused by the felted fibers left behind on the filter medium as the liquid passes therethrough. If these felted fibers or cake offer little resistance to flow, most of the liquid will flow through the fiber mat, leaving behind a solid mat, wet with the remaining liquid, and now exhibiting the characteristics of a solid phase rather than a hydraulic fluid. The remaining liquid in this mat can only be removed by mechanical pressure or by drying. The flowing away of the easily removed liquid through the filter medium is referred to herein as filtration while the expressing of the liquid bound in the mat or filter cake is referred to herein as pressing. The distinct separation of these two mechanisms of liquid removal is the second feature of this invention.

The fiber mats or cakes, built up from pulp fibers do not have negligible resistance to flow. As the thickness of the cake increases, the resistance to flow of the liquid through the cake becomes greater. This resistance of the cake to liquid flow therethrough varies with the type of fiber being filtered: for instance, kraft fiber mats provide much less resistance to flow than semichemical pulp mats and semichemical pulp mats offer very much less resistance to flow than cakes made from groundwood fibers. Therefore, it would be highly advantageous to remix the cake or fiber mat into the pulp suspension as rapidly as it is formed on the filter medium, thus keeping resistance to liquid flow through the filter medium at a minimum while the pulp is being thickened. This continual remixing of the newly formed fiber mat or cake into the mass being thickened is the third feature of this invention.

A fourth feature relates to the magnitude of the driving force which can be utilized to force liquid through the filter medium while the filtration phase of the operation is being carried out. In a conventional rotary vacuum filter, the driving

force is limited to one atmosphere or less, depending on the temperature and consequent vapor pressure of the liquid being removed. In this invention hydraulic pressure can be applied from a pump to the fluid entering the press. The capacity of the pump must be large enough to insure that this hydraulic pressure remains substantially constant along the filtration section of this apparatus. In addition, the filtrate collection housing around the barrel is of a pressure-tight construction so that the filtrate can be drained through a pump or a barometric leg, thereby maintaining a high vacuum on the interior of the housing. Thus, by applying hydraulic pressure on the interior or suspension side of the filter medium and a vacuum on the discharge or filtrate side, much higher driving forces can be applied for filtration than are available in conventional filters.

When filtration has been carried out as far as possible, that is, to the point where the thickened material ceases to act as a hydraulic fluid and, instead, begins to act as a semiplastic solid, the principles of filtration no longer apply. Instead, mechanical forces must be applied so that the semiplastic material can be compacted into a diminishing volume as it moves through the apparatus. Here the resistance to liquid flow is not found in the cake on the filter medium. Rather, the resistance to liquid flow is in the main body of the semiplastic, fibrous body itself. Forces are required to push the fibers into very close proximity, including flattening out the approximately cylindrical cellulose fibers, collapsing the hollow center or lumens of fibers and forcing the liquid contained therein out through the cell wall. Additional forces are also required to propel the liquid thus displaced through the interstices of the closely packed fibers and thence through the filter medium.

Experiments with screw presses have shown that continuous flights, with a diminishing pitch toward the discharge end, are preferable to the interrupted flights which are commonly used in screw presses. Such continuous flights, properly designed, will insure that a thickened cake will always be discharged without the aid of plugs or other devices at the discharge end to buildup such a thickened discharge. The consistency of this discharge can be controlled by screw speed and feed rate to the press. Interrupted screw flights on the spindle of the press, on the other hand, have two serious disadvantages. First, the discharge end must be plugged until the cake has been thickened. Second, the stationary bars or similar devices, placed in the spaces provided by the interruptions in the screw flights to prevent rotation of the pulp with the screw, actually create such high shearing forces in the thickened pulp that the discharged cake is always very hard and dense. Intermediate, lower consistencies of the discharged cake cannot be obtained. In other words, control of the discharge consistency is lost when screws with interrupted flights are used.

It has been found further that filter media made up of closely spaced, longitudinal bars are undesirable. It has been claimed by others that these parallel, longitudinal bars act as splines, which prevent rotation of the pulp with the screw. It seems doubtful that such is the case but, nevertheless, it has been found that some controllable rotation of the pulp with the screw is highly desirable. This partial rotation of the pulp cake with the screw results, in effect, in a shorter pitch than is actually built into the screw. For example, consider a case in which one flight in the series of flights on the spindle has a pitch of 6.0 in. If there is 100 percent slip between the leading surface of the flight and the pulp, the pulp cake will move forward 6.0 in. per revolution of the screw. If, however, there is sufficient friction between the flight surface and the pulp it is pushing forward, there will be some rotation of the pulp with the screw. In this same flight of 6.0 in. pitch, if one-sixth of the force exerted by the flight is converted to rotary motion of the pulp and only five-sixths is converted to longitudinal motion of the pulp, the pulp cake will move forward only 5.0 in. per revolution of the screw. Assuming equal throughput of dry pulp in both cases, the pulp which rotates with the screw will lose one-sixth of its volume through the perforate barrel as ex-

pressed liquid as compared to no liquid expressing action in the case when no rotation of pulp occurs. Thus, the deliberate application of forces resisting pulp movement at the discharge end of the press can set up a controllable friction between the flight and the cake and cause this desirable partial rotation and the accomplishment of greater changes in cake volume than would be expected from only cross-sectional and screw-pitch changes. Therefore, it is preferred to use screens or punched plates as a drainage surface, rather than closely spaced heavy longitudinal bars. The construction is more economical and better control of the pressing operation can be achieved.

Two methods have been discovered for increasing the forces resisting forward motion of the pulp at the discharge end of the press. The first of these consists of an unflighted section of the spindle at the discharge end. This is not to be considered as being an interrupted flight. There are no further flights on the spindle between the unflighted section and the point of discharge of the pulp cake. The cross section through which the pulp flows in this section should be constant. Since there is no flight in this section to push the pulp forward, the force required to cause this forward motion must come from the last flight before the unflighted section. This additional force between the flight and the pulp cake will cause some additional friction which will result in partial rotation of the cake. It is important that the drainage barrel be extended over this unflighted section as some drainage will occur, caused by the increased pressure being applied.

This unflighted section has the disadvantage that it cannot be changed during operation. Once installed, it can only be lengthened or shortened by dismantling the discharge end of the press. Its most advantageous use comes as a modification in a press designed for a specific deliquoring problem. If it is desired to press the same material to a somewhat higher consistency than that covered by the original press design, the pressing range of the press can be increased by installing this feature. It can also be used when the press is to be changed over to a new material which is more difficult to deliquor than the material previously pressed. It can also be incorporated in the initial press design to permit the use of considerably higher spindle speeds, resulting in lower torque and consequent lighter weight spindles, flights and bearings.

Another means will now be described for increasing at the discharge end of the press, the forces against which the flights must operate. This method has the advantage of being controllable, that is, the resisting forces may be made greater or less while the press is in operation. This method takes advantage of the fact that there is always some rotation of the cake as it leaves the press. If one or more fixed bars or fingers are placed so that they extend longitudinally in the cake discharge opening, the moving cake must flow past these bars. A sharp edge on each of these bars, facing the oncoming pulp, will ease the flow of pulp past the bars. However, since the bars are stationary, the rotary motion of the pulp is stopped completely, the only cake motion being longitudinal into the discharge section.

This braking or stopping of the rotary motion of the pulp at the discharge end of the press will create large shear stresses in the pulp cake. Upstream of the stationary bars, the pulp is rotating. After the pulp passes the leading ends of the bars it can have no rotation. Therefore, the bonding or adhesion between the fibers must be broken by a force sufficiently great to bring about this shearing action in the pulp cake.

If these bars or fingers are fixed to the press frame, the force creating pulp shear is fixed and the corresponding force which the press flights must exert is also fixed. If, however, these fingers are mounted on a quill shaft surrounding the spindle shaft, with antifriction bearings being provided between the quill shaft and the spindle shaft, the fingers protruding into the pulp cake will rotate with the cake and the only force developed in the cake will be that necessary to cause the cake to flow past the fingers. If, now, a brake drum is mounted on this quill shaft and mating brake shoes are fixed on the

discharge housing, the application of pressure to hydraulic cylinders operating the brake shoes can decrease or completely stop the rotation of the fingers. In this manner, the increased forces which the screw flights must transmit to the pulp become controllable. Other devices, such as a worm and worm wheel, driven at controlled speed, can be used instead of the brake drum and brake shoes.

It has been found that these fingers have a significant effect on screw press performance. For example, if the press is operated at such a feed rate of kraft pulp of a fixed consistency and at such a spindle speed as to discharge a cake of 25 percent consistency, the addition of two fixed fingers in the cake discharge will increase the cake consistency to 30–32 percent o.d. Also, it has been possible to use these fixed fingers and maintain cake discharge consistency constant at 25 percent o.d. by increasing spindle speed by about 25 percent. This increased spindle speed, of course, brings about an increase in the press capacity.

The use of fingers, which can be restrained against rotation by an adjustable force, in the press discharge has another great advantage in addition to making the press operation more flexible. They make it possible to bring about an automatic control of the screw press operation. For example, let it be assumed that pulp is being fed at a constant feed rate to the press and a constant discharge consistency is desired. A slight change in filterability of the fibers would normally bring about a change in the exit consistency and a corresponding change in the filtrate volume. A flow meter in the filtrate line would sense the change in the filtrate flow rate and send a corrective signal, electronic or pneumatic, to the cylinders controlling the braking effect on the shaft to which the fingers are attached. Thus, the forces exerted by the spindle screw on the pulp mass can be increased or decreased accurately and automatically to control discharge consistency.

Preferred embodiments of the invention are illustrated in the accompanying drawings, in which:

FIG. 1 is a central sectional view of the complete apparatus, the filtration section being at the left, the press section at the right.

FIG. 2 is an elevation view of two stationary fingers, attached to a ring which bolts on the discharge housing of the press.

FIG. 2A is a central sectional view of the ring of FIG. 2.

FIG. 3 is a fragmentary schematic representation of a modification in which rotation of the fingers is controllable during operation.

FIG. 4 is a fragmentary central sectional view of a modified construction of the feed and filtration section of the apparatus.

FIG. 5 is a sectional view taken along the line V–V of FIG. 4.

FIG. 6 is a sectional view taken along the line VI–VI of FIG. 4.

FIG. 7 is a sectional view taken along the line VII–VII of FIG. 4.

FIG. 8 is a view corresponding to a fragment of FIG. 1 and showing a modification.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings, a pulp suspension of low consistency, e.g. 2.0–4.0 percent o.d. fiber, is fed into the apparatus through an entrance pipe 1 in FIG. 1. The pump feeding the pulp to the apparatus may be operated at any desired pressure head.

The outer housing of the press, which provides structural strength and a containing wall for the filtrate, is indicated at 2. Flanges 3 are used for closure, compartmentation and strength. Inwardly projecting concentric rings 4 on the housing 2 supply support for the filter medium 6 which may be made from a punched plate or a screen mesh backed by a punched plate. Holes 34 are drilled at appropriate locations in these rings 4 to permit drainage of filtrate to the outlet 5 for

the press section. The press spindle is indicated at 7 and it has a shaft 8 (whose packing gland and outboard bearing are not shown) projecting axially through the filter section.

In FIG. 1, a separately driven quill shaft 10 is sleeved on and rotates around shaft 8. The shaft 10 is equipped with four scrapers, or doctor blades, 11 attached thereto. These scrapers 11 detach pulp cake from the filter medium 12 as fast as it is formed, and force this thickened pulp back into the more dilute main body of pulp. This separately driven quill shaft 10 is necessary when the speed of rotation of the main press spindle is low, say at 10 r.p.m. or less. When higher spindle speeds are used, up to 30—40 r.p.m., this separately driven quill shaft is not necessary. Instead, a design similar to that shown in FIG. 4 can be used.

FIG. 4 shows a modified design of the filter section. Parts corresponding to those described above with reference to FIG. 1 are identified by the same reference numerals with the suffix A added thereto. In FIG. 4 the pulp suspension is fed in through the branch 1A of the tee section 40. A flight section 35 is provided on the shaft 8A within the tee section 40 and this provides a more positive feed into the filtration section than does the arrangement illustrated in FIG. 1.

In FIG. 4 it can be seen that most, but not all, of the spindle diameter change takes place in the filter section. In this filter section, tapered collars 37 fit over the tapered spindle 7A and are connected to rotate with the spindle by one or more keys k. Attached to each collar section are four pairs of arms 36 to which the scrapers, or doctor blades, 11A are bolted. FIGS. 5, 6 and 7 show one possible design of the doctor blades 11A. As the spindle 7A rotates counterclockwise in FIGS. 5, 6 and 7, the pulp is scraped from the filter medium 12A and is pushed by the curved surface of the scrapers toward the center where mixing with the more dilute pulp occurs. The sectional or modular design of these collars 37 has a two-fold purpose. First, the length along the longitudinal axis over which the scraping action of the blades occurs may be varied by replacing one or more of the collars 37 shown with new collars of the same size but to which screw flights are attached. The pitch of such flights will be slightly greater than the pitch P_1 shown at the right of FIG. 4. Second, if any of the blade supporting arms 11A become broken, a single collar can be replaced without extensive repair costs.

The scraper blades 11A may be attached to their supporting arms 36 by weldments instead of by bolts, as shown. However, bolts or other devices permitting removal of worn blades seem preferable. Wear on the filter medium 12A can be prevented by attaching thin metal strips to the filter medium, either as circumferential hoops or as a spiral. Such an arrangement might also leave a thin layer of pulp against the screen after the scraper passes, said layer of pulp minimizing fiber losses in the filtrate. Allowing a definite small clearance between blade tips and the filter medium would accomplish the same purpose as the metal strips and reduce blade wear.

Both the quill shaft 10 in FIG. 1 and the collared spindle 7A in FIG. 4 are conically shaped, the diameter increasing in the direction of the pulp flow. This conical construction brings about a decrease in the annular cross section through which the pulp flows, partially compensating for the very large diminution in pulp volume which occurs during thickening, as pointed out above. It is not essential that all of this change in volume be compensated for by a decrease in the annular cross section for pulp flow. Some of this change in volume may be compensated for by decreasing the forward velocity of the pulp suspension, which suspension is reasonably fluid in the filtration section.

The purpose of this filter section is to remove as much liquid (filtrate) from the pulp as possible, while the pulp suspension still exhibits the characteristics of a hydraulic fluid. (The term hydraulic fluid is used, in this sense, to define a system in which the fibers may move as separate entities and in which an applied pressure is transmitted in all directions). It should be noted that filtrate removal pipe 14 or 14A is considerably larger than the filtrate removal pipe 5 of the press section. This difference in pipe size is necessary because the volume

removed in the filtering section in filtering from entering consistency to the range of 10 percent consistency is much greater than the volume removal in pressing to the final consistency. When a vacuum is applied at pipe 13 or pipe 13A, in order to increase the driving force of liquid removal during filtration, pipe 14 or 14A is connected either to a barometric leg and seal tank or to a filtrate pump.

In the press section of the apparatus, one or more spiral flights are shown attached to the spindle 7. The pitch of the first turn of the flight is indicated by P_1 while P_n indicates the pitch of the last turn of the flight, there being n turns of the flight on the spindle. It should be noted that in this flighted section of the press, the spindle 7 is shown as being of constant diameter. It is not essential that this diameter be maintained constant. It is desirable, wherever possible, to maintain this constant diameter because the pulp in this section has lost most of its fluidity and it resists the change in direction involved when an increasing spindle diameter is employed. However, it is sometimes desirable to use an increasing spindle diameter in order to decrease the cross section through which the pulp flows and consequent pulp volume in cases where the required change in volume cannot be reasonably brought about by decreasing the screw pitch alone. In such cases, the change in the spindle diameter should be made as gradual as possible and at the wet end of the press (leftward end in FIG. 1).

Since the annular space between spindle 7 and the drainage screen 6 is shown as being of constant size in FIG. 1, the change in pulp volume brought about in this section becomes a function of P_1 and P_n . It is possible, by decreasing the pitch of each succeeding turn of the flight, to design a series of turns to bring about any desired change in consistency within the limits imposed by the entering consistency and the pulp characteristics. If the pitch is changing constantly, in contrast to a constant pitch per turn, changing with each turn, more efficient operation is obtained.

Knowing the cross-sectional area of the annular space, the pitch of the first turn and the consistency of the pulp entering the first turn, it is possible to calculate the theoretical weight of dry pulp that can be handled by the press at any given speed. Also, knowing the ratio of P_1 to P_n , the terminal consistency can be calculated. These calculations are based on the assumption that all of the forces set up by the rotation of the screw are converted into motion of translation of the pulp in the longitudinal direction of the press. However, especially at high consistency, there is sufficient friction at the contact points between the pulp and the screw surface to cause some rotation of the pulp with the screw. This drag actually operates in favor of increased dewatering capacity of the press in the following manner. If, in the last turn, the pulp actually rotates through 30° while the spindle is rotating through 360° , the forward motion of the pulp in this turn is a distance of

$$\frac{(360-30)}{360} \times P_n$$

The dewatering effect is the same as though the pitch of the last flight was $\frac{330}{360} \times P_n$ instead of P_n .

Advantage is taken of this principle of pulp rotation in the next section of the press, designated as the Unflighted Section. Here, the diameter of the spindle 7 remains constant but there is no flight attached to the spindle. The annular space between the dewatering screen 6 and the spindle 7 is filled with dense pulp. It must be pushed forward by the pulp behind it in the flighted (press) section. This increased resistance must be overcome by an increased force exerted by the flight on the pulp. This increased force or pressure will cause the pulp to take on more rotation and lose a little of its forward motion. Therefore, the resistance of this unflighted section causes a further apparent decrease in the flight pitch and a consequent increase in dewatering for a constant throughput of dry pulp. It should be noted that the dewatering screen 6 is still in place in this (unflighted) section so the liquid pressed out by the forces exerted can be taken away through the screen.

In FIG. 8, the unflighted section of the press is shown as being separable from the remainder of the press. For this purpose, flanges 15 are provided and a separable spindle section 16 is used. This provision is made so that the unflighted section can be made of selectable length to meet changing conditions of dewatering. The spindle shaft 9 is keyed and a matching keyway is provided for a solid cylinder 16 whose inside diameter is that of shaft 9 and whose outside diameter is that of the spindle 7 so that a section 16 of any desired length can be inserted. The outer barrel 2B and screen 6B surrounding the section 16 also are replaceable. This unflighted section, therefore, provides means for greater dewatering than can be attained by the terminal ratio of screw pitches alone.

Another device to increase the compressive action of the press is shown at 17 in FIG. 1 and in detail in FIGS. 2 and 2A. It consists of a metal, usually steel or stainless steel, ring 40 bolted to the flange of the press as shown. Attached to this ring are two flat, edged fingers or bars 41 which project into the space between the spindle 7 and the screen 6 to engage the pulp cake as it moves out of the annular space between the spindle 7 and the screen 6. As the pulp cake approaches these edged fingers 41 it is rotating at some fraction of the spindle rotation speed. As the cake passes these projections, rotation of the cake ceases and all further motion of the cake is one of translation longitudinal to the press. This termination of rotary motion causes the cake to shear, pulling fibers apart. This shearing action must be caused by energy imparted to the pulp by the flights. As a consequence of this device 17, the flights must exert increased forces on the pulp, more rotation is imparted to the pulp in the flights near the press exit and, in effect, an even greater ratio between P_1 and P_n is attained with consequent increase in dewatering. If increased dewatering is not desired, the stationary projections 41 into the pulp or "fingers" can be used to attain higher pulp throughput without increased final consistency by increasing the spindle speed.

FIG. 3 shows a modification of this device, in which the shearing action induced in the pulp can be made variable to match changes in operation conditions. The devices 17 projecting into the pulp are, in this case, attached to a quill shaft 18 which is free to rotate around the spindle drive shaft 9. Also attached to this quill shaft is a brake drum 19. Brake shoes 20, actuated by hydraulic cylinders 21, can exert pressure on the brake drum. If the full shearing effect of the fingers on the pulp is desired, sufficient pressure is applied to the hydraulic cylinders 21 to maintain the quill shaft 18 in a stationary position. If no shearing effect of the fingers on the pulp is desirable, all pressure on the cylinder is released and the fingers and quill shaft are free to rotate at the same speed as the rotating pulp cake. Any desired speed of rotation between these two extremes can be attained by varying the pressure on cylinders 21, resulting in a controllable resistance to pulp rotation. The pressure on cylinders 21 can be responsive to a suitable control in order to achieve automatic adjustment in response to changes of operating conditions. For example, as illustrated in FIG. 3, the pressure supplied to cylinders 21 is adjusted in response to a signal received from a flowmeter 51 in the filtrate outlet 5.

Returning to FIG. 1, the last, or discharge section of the press is shown labeled as the Dilution Section. This dilution section is used only when the press is used as one stage in a multistage washing operation. Immediately after the compressed cake leaves the device 17 of the press, the cake is contacted with dilute liquor or water admitted through pipe 22. As the cake expands, due to the resilience of the fibers, the diluting liquor is sucked into the hollows or lumens of the fibers. Thus, the dilution stream mixes almost immediately with whatever strong liquor remains in the fibers after pressing.

If the discharge end of the press were to have been so designed that air could come into contact with the cake as the fibers were being released from compression and were expanding to their natural form, air would be drawn into the fiber lumens to mix with the residual strong liquor in these lumens. Consequently, several hours of contact time between

the pulp and the dilution liquor would be needed to bring about diffusion of the strong chemical remaining in the fibers into the main body of dilution liquor.

A housing 23 is provided around the dilution section to keep the section full of pulp and dilution liquor, thus preventing this undesirable contact between the expanding fibers and air. Quill shaft 24, separately driven from outside the press, is equipped with paddle agitators 25 to insure that the pulp suspension is adequately mixed before being discharged through pipe 26 to the next stage of washing.

When a quill shaft 18 equipped with fingers is used in the discharge section, as shown in FIG. 3, mixing of the press cake with dilution liquor can be provided by agitators on shafts placed above and below the quill shaft and at right angles to the quill shaft. The agitator shafts enter and leave the housing of the discharge section through packing glands or mechanical seals, and are externally driven at an appropriate speed to thoroughly break up the cake in the dilution liquor.

When a fiber product of minimum moisture content is desired, the cake is discharged directly through the large opening, as shown at 27 in FIG. 3, without any addition of dilution liquor. In such cases it may be advisable to insert rotating devices in the discharge section to insure that the cake is broken up into small pieces for easy discharge. The housing around the discharge section, shown in FIG. 3 as being tubular with a large bottom discharge opening, may actually be quite open in design in order to provide minimum hindrance to pressed cake discharge.

It is to be understood that the invention embodies a combination of the features just described, not necessarily all included in any one embodiment. The number of features embodied in any single installation will depend on the requirements of the situation involved.

In general, the initial filtration section will be included in the complete design. This filtration section will always be equipped with rotating scrapers or "doctor blades" 11 or 11A for continuously removing fiber mat or cake from the cylindrical filtration screen 12 or 12A and pushing said cake back toward the central shaft and remixing it with the more dilute main body of the suspension. The rotating shaft to which the scrapers or doctor blades are attached will increase in diameter from the feed end to the discharge end of the filtration section. However, this increase in diameter need not necessarily constitute the total diameter increase of the spindle throughout the entire length of the apparatus. Part of the total diameter increase may take place in the press section which follows the filtration section.

If the main spindle shaft is rotating at a sufficiently high speed, say 20 to 35 r.p.m., a separately driven quill shaft 10 will not be necessary at the feed or filtration section of the press. This section of increasing diameter, with scrapers attached, may be an integral part of the main shaft, or it may be comprised of a quill shaft 10 or annular sections 37 keyed to the main shaft.

The driving force for liquid removal in this filtration section will be either hydraulic pressure applied to the suspension entering the section or vacuum applied to the outer casing 2 surrounding the cylindrical filtration screen 12 or a combination of both hydraulic pressure and vacuum. In no case will the curved scrapers 11 or 11A or doctor blades induce mechanical pressure to bring about liquid removal. They are used merely to remove fiber cake as it is formed on the cylindrical screen and remix said cake into the main body of the suspension.

This filtration section is to be used in those installations in which the fiber or pulp suspension fed to the unit is at a low consistency, in the general range of from about 1.0 percent by weight insoluble solids to about 5.0 percent by weight insoluble solids. When the suspension fed to the installation is in the range of about 8.0 percent to about 12.0 percent insoluble solids, the filtration section would serve little purpose and could be eliminated.

The screw press section will always be used to some degree in the complete apparatus. When pressing to 25 percent by weight or higher values of insoluble solids, this press section will make up a major portion of the total length of the apparatus. The number of flights on the rotating spindle, the rate of decrease in the pitch of these flights from the wet end to the dry end of the press section and the speed of rotation of the spindle are variables which are fixed by the pressing characteristics of the fibrous materials being handled, and by the degree of pressing required.

The pressing characteristics of the fibrous material to be handled should be determined experimentally before a specific press design is made. This can be done very simply in a laboratory hydraulic press. The experimental pressing section consists of a small screen cylinder, whose openings are the same size as will be used in the final design, welded concentrically inside a solid steel cylinder about 1—2 in. larger diameter than the screen cylinder. Inside the screen cylinder and concentric to it is a solid shaft. The width of the annular space between the solid shaft and the screen should be the same as the cake thickness to be formed in the commercial press. A tight-fitting plunger acts as a piston to force the pulp suspension down in the screen cylinder, pressing filtrate through the screen openings. This small press assembly, installed between the platens of a hydraulic press, can be used to obtain characteristic deliquoring curves (percent consistency v. pressing time) for the pulp to be used in the commercial press. Several curves, each for a different, constant pressing intensity, will be found to become parallel with the time axis, all at about the same pressing time. This pressing time is the retention time which must be built into the press. Thus, the overall working length of the press can be designed accurately for the type of pulp to be pressed.

In extreme cases, wherein the desired end product is still quite high in liquid content, such as from about 10 percent fibrous solids to about 16 percent fibrous solids, the press section will be quite short and the number of turns may be greatly reduced, possibly to a single turn. In this type of operation, commonly called pulp thickening, practically all of the liquid removal is brought about in the filtration section. The flighted section or press section of the unit functions mainly as a restricting valve increasing retention time to permit more filtration action or to permit the use of increased hydraulic pressure on the suspension, said hydraulic pressure being the driving force which pushes the liquid through the formed cake and the filter screen. Of course, vacuum can be applied to the outer casing of the filtration section to increase the driving force for filtration.

The unflighted section of the spindle, shown at 16 in FIG. 1, will be used when pressed fiber cakes in the range of 25 percent dry fiber or even higher are required and where maximum flexibility of operation is desired. Variation of the length of this unflighted section, along with the companion drainage section, give the desired flexibility in capacity and increased deliquoring capacity. This unflighted section may be omitted without detracting from the operation of the overall equipment.

The "fingers" or bars 41 mounted in the discharge section of the press and protruding into the pressed fiber cake may be fixed as shown at 17 in FIG. 1 in a rigid position by bolting to the discharge flange 3, or as shown in FIG. 3, may be mounted on a rotatable shaft with devices for controlling this rotation or it may be omitted entirely from the complete design if it is not necessary in view of the end product desired. In general, these fingers, whose function is to decrease or stop the rotation of the discharging cake, will be used because they increase the pressing capacity of the unit and permit higher spindle speeds than can be realized without the use of fingers. Rotatable fingers permit automatic control of the pressing capacity and consistency (percent insoluble solids) of the discharged end product.

It is possible to mount the equipment assembly in either a vertical or horizontal position.

The embodiments of the invention in which an exclusive property or privilege I claim are defined as follows:

1. An apparatus for removing liquid from a suspension of liquid and fibrous solids, comprising:

casing means defining a filter section and a press section which communicate with each other, said casing means having liquid discharge means;

cylindrical liquid pervious filter means disposed within said casing means for permitting liquid to flow from within said filter means into said casing means for discharge therefrom;

rotatable support means disposed within said cylindrical filter means in substantially concentric relation thereto;

a plurality of scrapers in said filter section, said scrapers projecting from said support means into close proximity to the interior surface of the cylindrical filter means for continuously removing a fiber mat formed on said interior surface and directing it toward the support means for remixing with the suspension;

screw flight means in the press section of said casing means, said screw flight means projecting from said support means toward said filter means for pressing liquid out of said suspension through said filter means into said casing; and

means for supplying the suspension to said filter section.

2. An apparatus according to claim 1, in which the space between said filter means and said casing means in said filter section is substantially sealed from the corresponding space in said press section, vacuum applying means coupled to said space in said filter section, said suspension supplying means including means for applying a superatmospheric pressure to the suspension inside the filter means in the filter section.

3. An apparatus according to claim 1, in which the rotatable support means in the filter section increases in diameter from the entrance end to the discharge end of the filter section.

4. An apparatus according to claim 1, in which the scrapers comprise arcuate blades having curved surfaces extending from adjacent the filter means toward said rotatable support means.

5. An apparatus according to claim 1, in which the filter means in said press section is of the same diameter as and constitutes an extension of the filter means in the filter section, the rotatable support means in said press section comprising a rotatable spindle;

the screw flight means, said spindle and said filter means defining an elongated zone of progressively diminishing cross-sectional area so that liquid is expressed from the suspension as it flows through said zone.

6. An apparatus for removing liquid from a suspension of liquid and fibrous solids, comprising:

casing means defining a press section, said casing means having liquid discharge means;

cylindrical liquid pervious filter means disposed within said casing means for permitting liquid to flow from within said filter means into said casing means for discharge therefrom;

a rotatable spindle disposed within said cylindrical filter means in substantially concentric relation thereto;

screw flight means mounted on said spindle and projecting therefrom toward the filter means for forwarding the suspension from the inlet end of the press section to the outlet end thereof and for expressing liquid from the suspension as it travels through the press section;

said spindle having an unflighted portion adjacent the discharge end of the press section, said unflighted portion being located within said filter means and defining therewith an annular zone whereby an annular ring of pressed fiber cake is formed around said unflighted portion adjacent the discharge end of the press section, said unflighted portion of the spindle and the portions of the filter means and casing means surrounding said unflighted portion being separable, respectively, from the remainder of the spindle, the filter means and the casing means.

7. An apparatus according to claim 6, in which finger means project into said annular zone for engaging said annular ring of press fiber cake for retarding rotation of said cake.

8. An apparatus for removing liquid from a suspension of liquid and fibrous solids, comprising:

casing means defining a press section, said casing means having liquid discharge means;

cylindrical liquid pervious filter means disposed within said casing means for permitting liquid to flow from within said filter means into said casing means for discharge therefrom;

a rotatable spindle disposed within said cylindrical filter means in substantially concentric relation thereto;

screw flight means mounted on said spindle and projecting therefrom toward the filter means for forwarding the suspension from the inlet end of the press section to the outlet end thereof and for expressing liquid from the suspension as it travels through the press section;

said spindle having an unflighted portion adjacent the discharge end of the press section, said unflighted portion being located within said filter means and defining therewith an annular zone whereby an annular ring of pressed fiber cake is formed around said unflighted portion adjacent the discharge end of the press section;

a dilution section coupled to the discharge end of the press section and being in communication therewith for receiving the pressed fiber cake therefrom, said dilution section being substantially closed to the admission of gas and having means for supplying a dilution liquid to the interior thereof, agitation means within the dilution section for breaking up the pressed fiber cake and for mixing the dilution liquid with the fibrous material so that as the fibrous material expands upon release of the pressing force applied in the press section, the dilution liquid will be sucked into the fibers; and

means for discharging the diluted fibrous material from the dilution section.

9. An apparatus for removing liquid from a suspension of liquid and fibrous solids, comprising:

casing means defining a press section, said casing means having liquid discharge means;

cylindrical liquid pervious filter means disposed within said casing means for permitting liquid to flow from within said filter means into said casing means for discharge therefrom;

a rotatable spindle disposed within said cylindrical filter means in substantially concentric relation thereto;

screw flight means mounted on said spindle and projecting therefrom toward the filter means for forwarding the suspension from the inlet end of the press section to the outlet end thereof and for expressing liquid from the suspension as it travels through the press section;

finger means mounted at the discharge end of said press section for relative movement with respect to said spindle, said finger means projecting into the space between said spindle and said filter means for retarding rotation of the pressed fiber cake in order to increase the forces which the screw flight means exert on the suspension being pressed for increasing the liquid removal effect.

10. An apparatus according to claim 9, in which said finger means are fixedly mounted on said casing means.

11. An apparatus according to claim 9, in which said finger means are mounted on a rotatable shaft which is rotatable with respect to said spindle and braking means coupled to said rotatable shaft for adjustably retarding rotation thereof.

12. An apparatus according to claim 9, including rotatable support means mounted for relative rotation with respect to said spindle, said finger means being attached to said support means for rotation therewith relative to said spindle and adjustable force applying means coupled to said support means for adjusting the rate of rotation thereof.

13. An apparatus for removing liquid from a suspension of liquid and fibrous solids, comprising:

casing means defining a press section, said casing means having liquid discharge means;

cylindrical liquid pervious filter means disposed within said casing means for permitting liquid to flow from within said filter means into said casing means for discharge therefrom;

a rotatable spindle disposed within said cylindrical filter means in substantially concentric relation thereto;

screw flight means mounted on said spindle and projecting therefrom toward the filter means for forwarding the suspension from the inlet end of the press section to the outlet end thereof and for expressing liquid from the suspension as it travels through the press section;

a dilution section attached to the press section for receiving the pressed fiber cake therefrom, said dilution section being closed to the admission of gas and having means for supplying a dilution liquid to the interior of the dilution section, agitation means within the interior of the dilution section for mixing the dilution liquid with the pressed fiber cake so that as the fibrous material expands upon release of the pressing force applied in the press section, the diluting liquid will be sucked into the fibers; and

means for discharging the diluted fibrous mass from the dilution section.

14. An apparatus according to claim 13, including finger means mounted at the discharge end of the press section, said finger means projecting into the space between said spindle and said filter means for retarding rotation of the pressed fiber cake in order to increase the forces which the screw flight means exert on the suspension being pressed for increasing the liquid removal effect.

15. An apparatus for removing liquid from a suspension of liquid and fibrous solids, comprising:

a cylindrical filtration screen barrel backed by an apertured strengthening member and whose overall length is designed to provide a retention time appropriate to the deliquoring characteristics in the particular fibrous solids to be processed, the liquid flowing out through the openings in the barrel and the forward-moving fibrous material being retained in the barrel;

a solid filtration casing enclosing the filtration screen barrel; a rotating spindle inside the filtration screen barrel and concentric to it;

the filtration screen barrel defining a filtration section into which the fibrous suspension is pumped under hydraulic pressure, the diameter of the spindle increasing from the point of entrance of the suspension to the discharge end of the filtration section, the spindle in the filtration section being equipped with a plurality of rotatable scrapers for continuously removing the fiber mat as it is formed on the cylindrical screen and to force said cake toward the spindle and cause mixing of said cake with the main body of the suspension, the filtration casing being isolated from the remainder of the apparatus by means of flanges and means for applying a vacuum to said filtration casing, the pulp entering the filtration section being at a low consistency in the range from about 2.0 percent fibrous solids to about 5.0 percent fibrous solids, the suspension leaving the filtration section being in the range of from about 8.0 percent to about 12.0 percent solids;

a pressing section consisting of a cylindrical press screen barrel of the same diameter as the filtration screen barrel for receiving the thickened suspension leaving the filtration section, the press screen barrel in the pressing section being surrounded by a solid metal press casing to receive the pressed-out liquid, the rotating spindle extending inside the press screen barrel in the pressing section and being concentric to it, continuous screw flight means attached to the spindle in the pressing section, said flight means being of decreasing pitch from the entering end to near the discharge end of the pressing section, said screw flight means bringing forces to bear on the suspension and forcing liquid out of the suspension through the

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cylindrical press screen barrel and out into the solid press casing from which the liquid is discharged, said spindle having a short unflighted portion at the discharge end of the pressing section and inside the cylindrical press screen barrel, the pressed cake from the pressing section being discharged as an annular ring of pressed cake at a dry solids content in the range of from about 15 percent to about 60 percent;

a plurality of bars having pointed edges extending into the ring of pressed pulp, said bars retarding the rotation of the pressed pulp and thereby increasing the forces which

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the screw flight means exert against the suspension being pressed and increasing the liquid removal effect;
a closed dilution section for receiving the pressed cake and having mechanical agitation means for mixing the cake with a dilution liquid while excluding gas therefrom so that, as the fibrous material expands upon release from the pressing forces of the press section, the diluting liquor will be sucked into the fibers, sufficient additional liquid being added in the dilution section so that the diluted fibrous mass can be discharged from this dilution section.

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