Oct. 15, 1963 H. C. BECHTLER 3,107,194

CENTRIFUGAL FALLING FILM EVAPORATOR

Filed June 12, 1961 3 Sheets-Sheet 1

Fig. 2

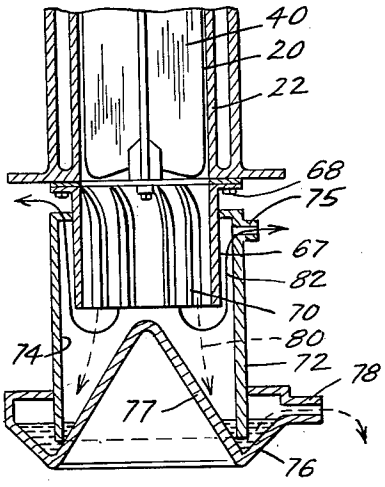


Fig. 1

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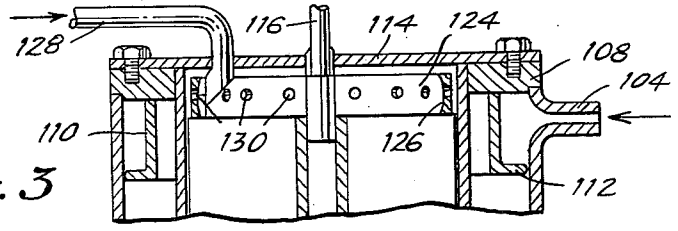


Fig. 3

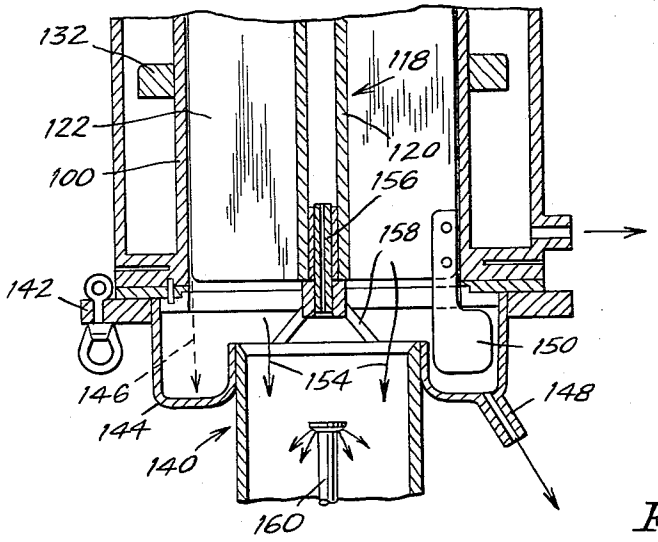


Fig. 5

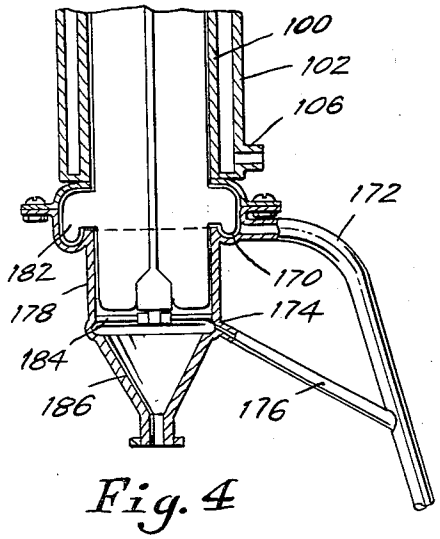
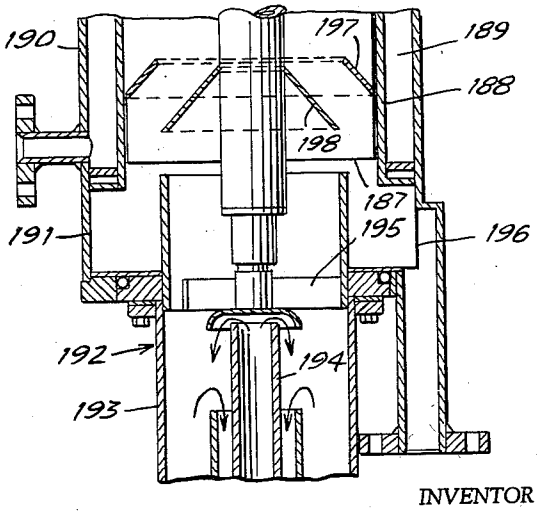


Fig. 4



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CENTRIFUGAL FALLING FILM EVAPORATOR

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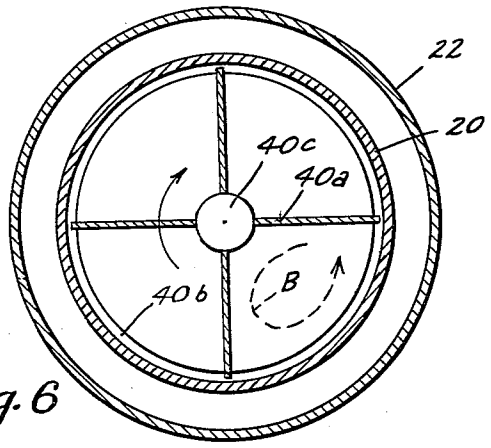


Fig. 6

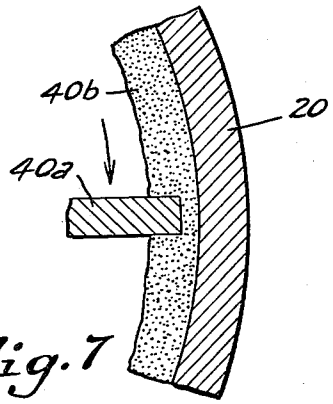


Fig. 7

Fig. 8

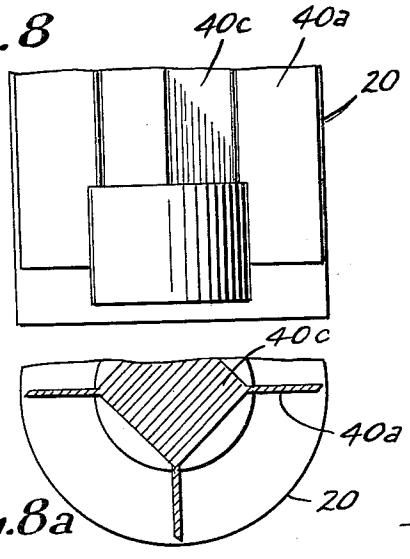


Fig. 8a

Fig. 9

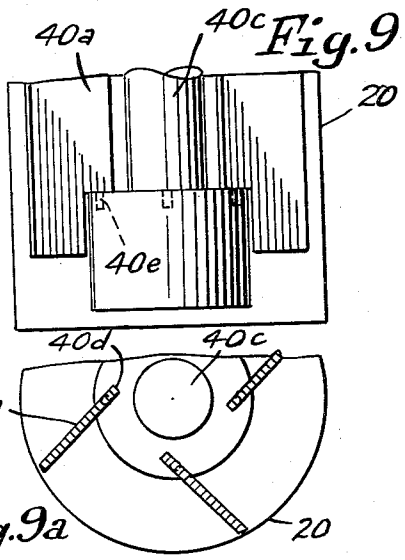


Fig. 9a

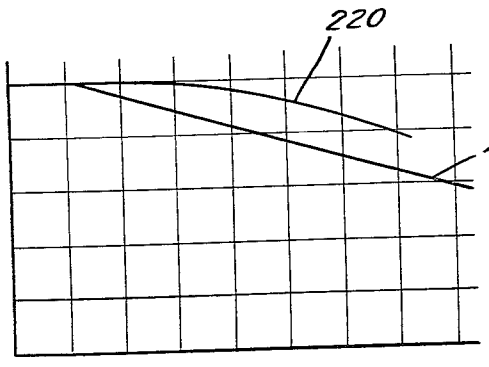


Fig. 10

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United States Patent Office 3,107,194 Patented Oct. 15, 1963

3,107,194

CENTRIFUGAL FALLING FILM EVAPORATOR

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Filed June 12, 1961, Ser. No. 116,591
6 Claims. (Cl. 159—6)

This invention relates to apparatus for concentrating liquids and more particularly concentrating apparatus of the thin film type.

In accordance with conventional practice the liquid to be evaporated is ordinarily conducted through an inlet in the top of a substantially vertical externally heated cylinder. The liquid is distributed along the inner wall of the cylinder by blades which are attached to a central rotor and extend outwardly from the rotor to a point closely adjacent to the inner surface of the cylinder. The liquid travels downwardly through the cylinder under the influence of gravity and is thrown out upon the cylinder wall in a thin film by the action of the rotor blades. At the bottom of the cylinder the concentrate is conducted to an outlet conduit.

In all commonly used designs, the foam and vapor, being of less density, is collected in the areas between the rotor blades and conducted upwardly to an outlet adjacent the top of the vertical cylinder and is withdrawn to a condenser. Thus in prior thin film evaporators the liquid is conducted from the top of the apparatus to the bottom and the resulting vapor is conducted from the bottom to the top in counterflow relation to the descending liquid. The droplets entrained by the vapor are to some extent separated from the vapor by the centrifugal action of the rotors during the upward passage of the vapor. However the efficiency of the separation of the droplets from the vapor, which is of primary importance for the successful and efficient operation of thin film evaporators, has proved undesirably low under some conditions. This low efficiency is due in part to the fact that the vapor reaches its highest speed in the region of the liquid inlet and inevitably picks up a substantial quantity of liquid from the inlet.

In order to minimize this disadvantage it has been proposed to incorporate an unheated separator section for the vapor immediately above the heated evaporating zone, the rotor blades extending upwardly into the separation zone. A construction of this type is shown for example in my U.S. Patent 2,596,086. While this arrangement is a substantial improvement over the prior art it necessitates an apparatus of large size and high initial cost.

In accordance with the present invention, contrary to prior practices, a thin film of liquid is conducted through a substantially vertical cylindrical chamber and is thrown against the walls thereof by rotor blades, as described above, and the vapor separated from the liquid is conducted through the cylindrical chamber in the same direction as the liquid and the liquid and vapor are separated by a novel construction provided at the bottom end of the evaporator.

Thus, in accordance with the present invention the vapor separated from the thin film of liquid is conducted within the evaporator in the same axial direction as the liquid to be evaporated. This materially decreases the disadvantages of conducting the liquid and the vapor, which entrains an increasing number of droplets of the liquid as it passes upwardly through the evaporating and distributing zone, in opposite directions.

Also the rotor serves not only to spread the liquid continually along the inner wall of the evaporator, thus keeping the liquid in constant motion, but also to intermix the liquid and vapor in the heating zone and then separate the vapor from all or at least the greater part of the

entrained droplets and foam ejected from the liquid being agitated by the rotor blades.

It is accordingly a primary purpose and object of the present invention to provide novel methods and apparatus for evaporating and concentrating liquids which provide improved efficiency with lower cost and decreased space requirements.

It is also an object of the present invention to provide novel methods and apparatus for evaporating and concentrating liquids in which the liquid to be evaporated and the vapor removed from the liquid are conducted through an evaporating chamber in the same axial direction and withdrawn from the same end of the evaporating chamber.

It is also an object of the present invention to provide novel evaporating and concentrating apparatus of the thin film type in which the separator section ordinarily employed in such apparatus is substantially reduced in size.

It is a further object of the present invention to provide improved methods and apparatus for evaporating and concentrating liquids which provide improved efficiency of operation by moving the liquid and vapor in the same direction.

Another object is to provide a thin film evaporator in which the vapor accelerates the flow of liquid from the point of introduction to the point of removal.

A further object is to provide a thin film evaporator in which the vapor is intermixed with the liquid during flow through the evaporation zone.

It is a further object of the present invention to provide novel apparatus for evaporating and concentrating liquids including novel means for distributing the liquid to be evaporated uniformly around the interior of the evaporating chamber.

It is an additional object of the present invention to provide in evaporating and concentrating apparatus of the thin film type improved methods and means for collecting and withdrawing the concentrate and the vapor removed from the concentrate.

It is a further important object of the present invention to provide novel methods and apparatus for controlling the operation of a number of individual evaporating and concentrating fluids in which the movement of the vapor separated from the liquid is utilized to aid in the movement of the concentrate through and out of the apparatus.

It is also an object of the present invention to provide novel methods and apparatus for the evaporation and concentration of fluids in which hydrostatic heads and losses are eliminated thus increasing the efficiency of the evaporation and decreasing the power requirements of the apparatus.

Further objects and advantages will become apparent as the description proceeds in connection with the accompanying drawings in which:

FIGURE 1 is a vertical sectional view of a thin film evaporator constructed in accordance with the present invention;

FIGURE 2 is a fragmentary vertical sectional view of an apparatus similar to that shown in FIGURE 1 and including a modified arrangement for removing the concentrate and the vapor from the apparatus;

FIGURE 3 is a vertical section view of a modified form of thin film evaporator;

FIGURE 4 is a fragmentary sectional view of a modification of the lower portion of the apparatus of FIGURE 3;

FIGURE 5 is a fragmentary vertical section similar to FIGURE 4 illustrating a further modification of the apparatus of FIGURE 3;

FIGURE 6 is a horizontal section through the heating portion of an evaporator according to the present invention;

FIGURE 7 is an enlarged fragmentary horizontal section of the heating portion of an evaporator according to the present invention showing the relationship between the blade, the heating wall and the liquid film;

FIGURES 8 and 8*a* are respectively, a fragmentary vertical and horizontal section showing a thin film evaporator with fixed blades;

FIGURES 9 and 9*a* are respectively, vertical and horizontal sections showing a thin film evaporator with interrupted blades; and

FIGURE 10 is a graph showing the difference between full and interrupted blades in a thin film evaporator.

While the invention may be utilized for the handling of liquids and solids, for the separation of mixed fluid materials, or fluids having components with differing boiling points for the purposes of illustration the invention will be shown and described in connection with several embodiments having particular utility in the evaporation and concentration of liquids.

Referring now more particularly to FIGURE 1, the apparatus there shown is, in accordance with conventional practice of generally elongated tubular construction and is normally operated in a substantially vertical position. The principal component of the evaporator is a hollow substantially vertical cylindrical chamber **20** having an external heating jacket **22** secured to its outer surface by any suitable means. Adjacent the top of the cylinder **20** a fluid inlet **24** is provided which opens into the chamber **20** as at **26**. As shown in FIGURE 1 the heating jacket **22** terminates at a point slightly below the point **26** at which the liquid to be evaporated is introduced into the chamber to avoid over-heating in this area. Steam or other heating fluid is introduced into the heating jacket **22** through an inlet **28** and removed from the jacket through an outlet **30**. To avoid localized overheating, the wall of the chamber **20** is protected against direct impingement by the heating fluid by means of a baffle or similar means **32**.

The top of the evaporating chamber is closed by a cover assembly **34** removably secured thereto by any conventional fastening means such as the quick disconnect clamps **36** shown. A cover plate **37** supports a bearing assembly **38** in which the upper end of a rotor **40** is mounted for rotation about the axis of the chamber **20**. While the rotor assembly **40** may take any of a number of conventional forms, in its preferred form it includes at least three radially extending blades **42** preferably spaced equally about the axis of rotation of the rotor assembly. The blades are imperforate and extend outwardly to a point closely adjacent the inner surface of the evaporating chamber **20**. However, the blades may also be provided with brushes or spreaders which rotate in light contact with the inner surface of the chamber **20**.

An annular distributor ring **44** is secured to the top of the rotor blades **42** for rotation therewith at the level of the fluid inlet **26**. The rotor assembly **40** is driven through a removable coupling assembly **50** by a suitable power source such as an electric motor as shown at **52**. The rotor assembly **40** is mounted at its lower end on a bearing assembly **54** supported on a spider **56** which is secured by any suitable means to the lower end of the chamber **20**.

The lower end of the evaporator assembly is closed by a conical collector **58** having a central outlet **59**. The collector has an extension underlying a vertically extending outlet conduit section **60** formed integrally with or secured to the main evaporator chamber **20**. The collector **58** is preferably removably secured to the evaporator assembly as by disconnect clamps **62** to facilitate cleaning. The conduit section **60** is provided with suitable flange **64** for attachment to a vacuum pump and condenser.

In operation the fluid inlet **24** is connected to a source of fluid under sufficient pressure to assure constant flow

and the outlets **59** and **60** are connected to any suitable vacuum producing means. The liquid introduced at **26** flows on to the distributor ring **44** and is evenly distributed by centrifugal action on to the upper unheated portion of the cylindrical wall **20**. It then begins to flow downwardly under the action of gravity and the blades **42** of the rotor assembly **40** distribute the liquid to be evaporated in a thin even film over the interior of the chamber **20**. Thus, the film of liquid is caused to flow in a downwardly directed helical path through the heated section of the apparatus.

The quantity of liquid, speed of the rotor blades and degree of heat supplied to the chamber **22**, together with the length of the chamber **20** will be selected in any particular case so that the liquid has reached the desired degree of concentration at the time it reaches the lower end of the rotor blades **42** at which time the unevaporated liquid or concentrate passes in the direction of the dotted line arrows **65** on to the conical section of the collector. The vapor extracted from the concentrate, being of less density than the concentrated liquid, is carried in the spaces between the rotor blades and because of the low pressure connection through the outlet **60**, is caused to flow downwardly between the rotor blades and out of the lower end of the cylindrical evaporating chamber **20** in the direction of the solid line arrows indicated at **66**. The vapor then passes out through the outlet **60** to be disposed of as desired, usually through a condenser not shown. Since the vapor passes substantially the full length of the rotor blades, the latter forces substantially all of the entrained liquid droplets outwardly into the liquid concentrate flowing downwardly on the wall **20** achieving a surprisingly good degree of separation which obviates the necessity for an independent separator section usually employed in thin film evaporators. Thus the rotor assembly **40** serves not only to distribute the liquid concentrate along the inner wall of the evaporator but also as a separator for liquid and vapor.

As has been pointed out above, ordinarily the resulting vapor is withdrawn at the top of the evaporating apparatus as shown in U.S. Patent No. 2,596,086. The vapor thus reaches its highest velocity with respect to the liquid to be evaporated at or near the point of introduction of the latter. Since the relative velocity between the liquid being introduced and the exiting vapor is highest at this point, and in opposite directions, entrainment of droplets of the entering liquid in the exiting vapor occurs to an objectionable degree. It is a primary feature of the present invention to eliminate this difficulty.

FIGURE 6 is a cross section of a thin film evaporator according to the present invention and FIGURE 7 is an enlargement of a portion of FIGURE 6 illustrating the relationship between the blades, the heating wall and the liquid constituting the thin film. For the purposes of description, FIGURES 6 and 7 will be described in connection with FIGURE 1 of the drawing but it is to be undertsood that the cross section of the various embodiments shown in FIGURES 2, 3, 4 and 5 would be substantially identical.

The rotor **40** carrying the radial blades **40***a* is concentric with the inner cylindrical wall **20** of the heating chamber and the outer edges of the blades **40***a* extend into the liquid film **40***b* which flows down along the wall **20**. These blades **40***a* serve not only to agitate the liquid film but also to maintain the liquid in a thin film in close and intimate contact with the heating wall **20**.

Since the outer edges of the blades **40***a* extend into the liquid layer **40***b* the quadrant between adjacent blades constitutes a closed chamber and any vapors within that closed chamber, whether or not containing entrapped liquid, is subject to centrifugal force and directed outwardly into contact with the liquid layer **40***b*. Since any entrained droplets of liquid are necessarily heavier than the gaseous vapor, the entrained droplets are forced back into the liquid layer to enhance and improve the separa-

tion between gas and liquid. As indicated by the solid arrow A the rotor, when turning in a clockwise direction, causes the vapor within each quadrant to rotate in a counterclockwise direction as indicated by the dotted arrow B. In this way both the rotary motion of the vapor in each quadrant as well as the rotary motion of the blades tends to throw entrained or entrapped droplets of liquid outwardly into the liquid layer 40*b*.

The apparatus of FIGURE 2 is substantially identical to that shown in FIGURE 1 except for the lower or outlet end. In this embodiment of the invention the conical collector 58 is replaced by an annular substantially cylindrical extension 67 of the evaporating chamber 20, the former being secured to latter by any suitable means such as bolts 68. The interior of the extension 67 may be provided with a plurality of flow straightening vanes 70 which gradually change the helical flow of the concentrate and vapor to straight axial flow. This change in direction in flow is thus accomplished without the formation of foam or froth as is ordinarily the case when a sudden change in direction is effected by centrifugal force.

An annular member 72 is positioned by any suitable means in concentric surrounding relation with the extension 67 so as to form an annular passage 74 therebetween, the upper end of which leads to an outlet 75 connected to any suitable source of low pressure or vacuum. The lower end of the cylindrical member 72 extends into a trough section 76 of the collector 77, the central conical portion of which extends upwardly within the member 72 to a point adjacent the lower end of the extension 67. The collector 77 is provided with a suitable outlet 78 which may also be attached to a vacuum. In this form of the invention the concentrate follows the path indicated by the dotted line arrows 80 and is removed through outlet 78 and the vapor is withdrawn through a path indicated by the solid line arrows 82 which may lead to a condenser or any suitable point of condensation or disposition.

While the forms of the apparatus illustrated in FIGURES 1 and 2 provide exceptionally good concentrating and separating efficiency with most liquids it has been found that they are not particularly well adapted for the concentration of liquids having an especially strong tendency to froth or foam since the streams of the concentrate and the vapor mix or cross one another after they leave the evaporator chamber.

FIGURES 3, 4 and 5 illustrate a preferred form of the invention in which this latter difficulty is substantially eliminated. The form of the invention shown in FIGURES 3 and 4 also incorporates a number of other refinements which increase the overall efficiency of the apparatus and render it suitable for use in connection with even those liquids which have a strong tendency toward frothing or foaming.

Referring particularly to FIGURE 3 the evaporating chamber is formed by the inner wall 100 of a double wall tube, the outer wall of which encloses a heating chamber having an inlet 104 and an outlet 106. The upper end of the heating chamber formed between the walls 100 and 102 is closed by an annular ring 108 which carries a deflector plate 110 extending into the heating chamber to a point below the inlet 104 at which point it is provided with an annular outwardly extending flange 112. Thus the steam or other heating fluid entering through the inlet 104 does not impinge directly upon the wall 100 in the region of the fluid inlet and passes into the main heating chamber through the annular passage formed between the outer lip of the flange 112 and the adjacent wall 102.

Secured to the upper surface of the ring 108 is a closure plate 114 which rotatably supports the drive shaft 116 for the rotor assembly indicated generally at 118. The rotor asembly 118 comprises a central pipe or tube 120 and a plurality of radially extending vanes or blades 122 which may be of the same type as those described in connection with FIGURE 1. Mounted on the upper end of the rotor

blades 122 is a distributor ring 124 having an inner concave surface 126. An inlet pipe 128 for the fluid to be treated extends through the cover plate 114 and has an outwardly directed opening disposed closely adjacent the bottom of the concave surface 126 in substantial alignment with a plurality of small orifices 130 in the distributor ring. The fluid to be evaporated passes through the orifices 130 under the centrifugal action of the distributor ring and the fluid is thus distributed evenly around the interior of the evaporating chamber in a region not directly exposed to the heat of the incoming steam or other heating fluid.

A plurality of stiffening rings 132 are disposed in the heating chamber in surrounding relation to the inner wall 100 to provide lateral support. This obviates the necessity for constructing the walls 100 of sufficient thickness to provide structual rigidity which would unduly increase the expense and weight of the assembly and also interfere with effective heat transfer.

A collector assembly for the concentrate and for the vapor indicated generally at 140 is removably secured to the lower end of the evaporator section of the apparatus as by disconnect clamps 142. The collector for the concentrate is in the form of an annular trough-shaped member 144 disposed below and in substantial alignment with the inner wall 100 so that the concentrate as it leaves the surface of the wall 100 may pass directly in a vertical path into the trough 144 as indicated by the dotted arrows 146. The trough 144 is provided with an outlet 148 which may be connected to any suitable storage point.

If desired, one or more of the rotor blades 122 may be provided with a curved extension 150 extending into the trough 144 to agitate the concentrate so that it may flow out through the outlet 148.

Attached to the inner vertical surface of the concentrate collecting trough 144 is a cylindrical vapor outlet 152 which is preferably substantially coaxial with the wall 100 and the rotor assembly 118. If desired the lower end of the outlet 152 may be connected to a source of vacuum to assist in the withdrawal of the vapor which follows a straight vertical path as indicated by the solid arrows 154. A bearing 156 for the lower end of the rotor is supported by a spider 158 attached to the inner edge of the concentrate collecting trough 140. Since the bearing 156 is located directly above the vapor outlet, particular care need not be exercised in the lubrication of this bearing because any excess oil or grease will be carried off with the waste vapor.

If desired, a condenser, for example a spray pipe indicated at 160 may be disposed within the outlet conduit 152 to further increase the compactness of the unit and eliminate or reduce the need for a separate condenser.

The efficiency of this unit has been found to be particularly high because of the provision of a number of cooperating novel features such as the distributor ring, the thin walls of the heating chamber and principally, the arrangement of the vapor and concentrate outlets which permits straight through flow with practically no change of direction and without interference between the two streams.

FIGURE 4 illustrates a further modification of the apparatus of FIGURE 3 which provides for even better separating efficiency. In this form of the invention a two-stage concentrate collector is provided, the first stage being in the form of an annular collector trough 170 having an outlet 172, the collector trough 170 being similar to the trough 144 of FIGURE 3. The second stage is a somewhat similar collector trough 174 having an outlet pipe 176, the collector 174 being supported below the collector 170 by means of a tubular element 178 which is coaxial with and substantially the same diameter as the evaporating chamber wall 100. The rotor blades 180 extend below the lower end of the evaporating chamber wall 100 to a joint just above the collector ring 174

and are provided with laterally extending portions 182 received within the collector 170 for the purpose of pumping the concentrate out through the pipe 172. A suitable bearing support 184 for the lower end of the rotor assembly is supported from the tubular member 178. Below the collector 174 a conical vapor outlet 186 is provided which alternately may be of substantially cylindrical form and provided with a condenser as shown in FIGURE 3.

In this form of the invention the concentrate flowing off the lower end of the evaporator chamber wall 180 is forced outwardly into the first-stage collector 170 by centrifugal action and substantially all of the concentrate is removed through this first-stage collector. However, some further separation is effected by the portion of the rotor blades extending below the collector 170 and any droplets entrained in the foam are directed outwardly by the blades and are received in the second-stage concentrate collector 174 so that a remarkably small percentage of entrained liquid is finally permitted to escape from the apparatus with the vapor through the outlet 186.

FIGURE 5 illustrates a further modification of the apparatus of FIGURE 3 which has been shown to be particularly effective with strongly foaming liquids. As in the apparatus of FIGURE 3 the rotor blades 187 terminate adjacent the lower end of the evaporator wall 188 which is also substantially at the level of the lower end of the heating chamber 189 enclosed by the outer wall 190.

The collector for the concentrate is formed by an extension 191 of the outer heating jacket wall 190 and is closed at its lower surface by the vapor collector assembly indicated generally at 192 which includes the cylindrical vapor collector tube 193, a condenser assembly 194 and a bearing support 195 for the lower end of the rotor. The outlet for the concentrate is indicated at 196. The rotor blades may be provided with suitable extensions similar to the extensions 150 to facilitate the removal of the concentrate.

The operation of this unit is substantially the same as that disclosed in FIGURE 3. Under some circumstances, separation of the vapor from the droplets entrained therein may be enhanced by providing the rotor with additional means for deflecting the droplets outwardly toward the evaporator wall 188. This additional separating means preferably takes the form of two conical deflectors 197 and 198, the latter being secured directly to the rotor shaft and extending a substantial distance outwardly toward the evaporator wall 188. A distance of approximately two-thirds is sufficient. The conical ring 197 is attached to the rotor blades and extends inwardly from the outer edges thereof to a point substantially in alignment with the outer edge of the conical ring 198. It will be understood that the rings 197 and 198 are preferably segmental and extend between the rotor blades and may be perforated to provide free passage for the vapor. Preferably the rings are of the same conicity, the rings being disposed at an angle of about 45° with respect to the axis of the rotor.

It has been found that the advantages of the above described evaporators and concentrators can be most fully utilized if the units are relatively small. For example, with an evaporation capacity between 250 and 300 pounds per hour. It is desirable to handle any production capacity beyond this limit by grouping the small units so that any needed capacity can be provided with one type of unit. This permits standardization of production which alone would provide sufficient saving to justify its adoption.

In thin film evaporators the vapors travel at high velocities so that it would normally be anticipated that when the vapors and unevaporated liquid flow in the same direction, the entrainment of droplets or foam in the vapor would be substantial and carry-over losses may be excessive, making the equipment uneconomic. Even where the liquid and vapor flow in opposite directions,

as in thin film evaporators of the more general type, it is frequently necessary or desirable to provide entrainment separators for removing droplets from the liquid as shown in Mueller Patent No. 2,596,086.

However, by extensive experiment and testing it has been found that where the liquid and vapor flow in the same direction, as described above, with the advantages of improved velocity and fluidity which such concurrent operation provides, excellent separation between liquid and vapor may be obtained substantially equal to, or perhaps even superior to, the separation obtained by previously known countercurrent separators.

In order to obtain sharp separation between liquid and vapor and to prevent entrapment of liquid droplets or foam in the moving vapor, it is necessary to provide a rotor and evaporator section meeting specific design requirements and to control the rotor speed within predetermined limits.

In a cocurrent evaporator of the type herein described, the separating action is a resultant of two individual effects. The first effect involves the flow of an entrapped droplet of liquid downwardly in a helical path through the heating chamber between adjacent blades or vanes of the rotor. The blades or vanes have a higher angular velocity than the liquid droplets so that the rotating vanes will contact the downwardly moving droplets during the passage of the droplets through the heating section. Once a liquid droplet is caught or touched by a blade of the rotor, the droplet adheres to the vane and is forced outwardly by centrifugal force toward the inner cylindrical wall of the evaporating section into the liquid layer on this inner wall.

In addition to the above-mentioned effect which is more or less mechanical, there is a second effect which contributes to an important extent to the successful operation of the system and is due to the design of the rotor and heating section and to the speed of rotation of the rotor and blades.

Between adjacent vanes of the rotor there is a secondary vortex formed as illustrated by the dotted arrow B in FIGURE 6. This secondary vortex causes any entrained droplets or foam to move radially of the vortex where the droplets or foam will contact either the blades or the liquid layer on the inner wall of the heating section. When the droplets or foam contact the blades or vanes, they are forced out into the liquid layer as described above and where they contact the liquid layer directly, they are also removed from the moving stream of vapor.

In order to accomplish this separation, certain conditions are essential: First of all the blade or vane must extend uninterruptedly from the rotor shaft to a position sufficiently closely adjacent the inner wall of the heating section that the outer tip of the blade is always immersed in the liquid flowing down the inner wall of the chamber. This means that the chamber formed by adjacent blades and the inner wall of the chamber is a substantially vapor-tight conduit from the top to the bottom of the apparatus. If the blades are interrupted, that is, if they are spaced from the rotor shaft or if their outer ends are not immersed in the liquid serious losses can occur. For example, FIGURES 8 and 8*a* illustrate the system of the present invention where the blades 40*a* are full and continuous from the rotor or rotor shaft 40*c* outward into close proximity with the inner wall of the heating section. FIGURE 7 shows how the outer blade tips are immersed in the liquid layer 40*b* to form a vapor-tight seal.

FIGURES 9 and 9*a* illustrate an evaporator employing interrupted blades, that is, blades where there is a space between the inner end of the blade indicated at 40*d* and the rotor shaft 40*c*. FIGURES 9 and 9*a* show blades pivoted to the rotor at 40*e* but the effect would be substantially the same if the blade were inter-

rupted but rigid as in U.S. Patent No. 2,068,091 rather than pivoted.

FIGURE 10 is a graph showing the comparison of performance characteristics between a full blade evaporator such as illustrated in FIGURES 8 and 8*a* and an interrupted blade evaporator as shown in FIGURES 9 and 9*a*.

In the graph of FIGURE 10, the separation efficiency is plotted against the evaporation capacity in kilograms per hour. The upper curve indicated at 200 represents the performance characteristics of the uninterrupted blades (FIGURES 8 and 8*a*) and the curve 221, the characteristics of the interrupted blade (FIGURES 9 and 9*a*). For the purposes of this application the separation efficiency is as follows:

$$\text{Separation efficiency} = \left(1 - \frac{f_B B}{f_B B + f_K K}\right) \cdot 100$$

where

B=vapor
K=concentrate
f_B=concentration of vapor
f_K=concentration of concentrate

It will be noted that at relatively low capacity (low evaporation rates) there is no appreciable difference between evaporator using full blades as in FIGURE 8 and 8*a* and interrupted blades as in FIGURE 9 and 9*a*. As the evaporation capacity increases, the separation efficiency for interrupted blades decreases more rapidly than the separation efficiency of the full blade.

A second essential is that the tip speed of the rotor blades must be at least eight meters per second and the blades or vanes must be of sufficient number so that each point on the inner surface of the evaporating section is swept by a blade or vane fifteen to thirty times per second. The tip speed of the vane may be increased over the eight meters per second minimum limit but increases in the tip speed of the blades require very substantial increases in power and increase the demands for bearings, rotor shaft stiffness, balancing etc. Consequently it is normally desirable to design the apparatus for a blade tip speed not much in excess of eight meters per second.

The clearance between the outer tip of the rotor blade and inner wall of the evaporator chamber is dependent to some extent on the material to be treated. It is important that the blade tip be immersed in the liquid but the thickness of the liquid film, as illustrated at 49*a* in FIGURE 7, is dependent upon the physical characteristics of the liquid to be treated. Ordinarily the clearance between the outer tip of the rotor blade and the inner surface of the evaporator wall is between 1 and 3 millimeters.

The rotor speed and number of blades may be readily determined by the following equations where the evaporating section is assumed to have an inside diameter of 600 millimeters.

$$\text{Tip speed } u = \frac{\pi \times NR}{30} = (8+16)\,\text{m./sec.}$$

N=r.p.m. of rotor
R=radius of rotor

$$N = \frac{(8+16)30}{\pi \times 0.3} = 255+510 \text{ r.p.m.}$$

$$\text{Blade passage frequency } f = \frac{N}{60} Z$$

Z=number of blades

$$Z = \frac{60f}{N} = \frac{60(15+20)}{255+510} = \frac{2100}{765} = 2.74$$

Z=3 (approximately)

In all cases, whether the evaporators are used individually or in series or parallel groups, the liquid and the vapor are conducted in the same direction therethrough and the speed of the vapor in the evaporator increases in the same direction as the concentration of the liquid. Consequently, the vapor exerts a mechanical influence helping to move the concentrate which is gradually becoming more viscous through and out of the evaporator. Also, in contradistinction to the principle of counterflow of liquid and vapor utilized in prior evaporators, the vapor arising in the zone of the most violent evaporation, that is, the highest foam production, has the longest path to the outlet so that a high degree of separation is achieved in the evaporator, thus eliminating the necessity in most cases for an auxiliary separator. Further, by conducting the vapor to the condenser unit in a straight line as for example as in FIGURES 3 and 4 hydrostatic heads and losses from other causes are eliminated and consequently a higher vacuum may be maintained within the evaporator itself by means of condenser unit of given capacity.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

This application is a continuation-in-part of application Serial No. 335,487, filed February 6, 1953, and now abandoned.

What is claimed and desired to be secured by United States Letters Patent is:

1. Apparatus for evaporating and concentrating liquid comprising, a substantially vertical cylindrical chamber; a rotor mounted for rotation in said chamber; a distributor ring mounted adjacent the upper end of said rotor within said chamber for rotation with said rotor, said distributor ring having an inner concave surface and radially directed openings therein, means for introducing the liquid to be concentrated at a point inwardly of and closely adjacent said openings whereby said liquid will pass through said openings by the action of centrifugal force and be distributed uniformly around the interior of said cylindrical chamber; blades extending out from said rotor below said distributor ring to spread the liquid in a thin film on the chamber; means for heating said chamber; and means providing separate outlets adjacent the bottom of said chamber for the concentrated liquid and the vapor removed therefrom.

2. Apparatus for evaporating and concentrating liquids comprising a chamber having a substantially vertical cylindrical wall upon which the liquid to be concentrated flows downwardly, closure means at the top of said chamber, means adjacent the closure means for introducing liquid to be concentrated, means for heating the vertical wall of said chamber, a rotor rotatably mounted within said chamber coaxially with said wall, imperforate vanes being continuously connected along one edge to said rotor and extending substantially continuously radially and longitudinally throughout the heated region of said cylinder, means for rotating the rotor whereby liquid is spread in a thin film on the wall of the chamber for downward flow, the tips of the vanes projecting into the liquid flowing down the cylindrical wall, thereby forming vapor-tight compartments in the transverse sense as defined by adjacent vanes, the rotor and the liquid flowing down the cylindrical wall, collecting means secured to the lower end of the chamber, said collecting means having an open compartment for receiving the concentrated liquid and the vapor, a portion of the compartment being laterally offset from the chamber, an outlet connected to the collecting compartment for exhausting concentrated liquid therefrom, and a separate outlet con-

nected to the collecting compartment in the laterally offset portion for exhausting the vapor removed from the liquid, whereby the liquid and vapor flow in the same helical direction downwardly through the heated region of the chamber thereby increasing the velocity of the liquid concentrate, the liquid and a portion of the vapor being mixed to a turbulent thin film while passing downwardly over the chamber wall thereby increasing the fluidity of the liquid concentrate, the vanes and the vapor contained within the vapor-tight compartments forcing all the entrained liquid droplets outwardly into the liquid concentrate flowing downwardly on the chamber wall and whereby the direction of flow of the vapor is changed by the collecting compartment to a direction transverse of the chamber toward said vapor outlet in the offset portion of the collecting compartment.

3. Apparatus for evaporating and concentrating liquids comprising a chamber having a substantially vertical cylindrical wall upon which the liquid to be concentrated flows downwardly, closure means at the top of said chamber, means adjacent the closure means for introducing liquid to be concentrated, means for heating the vertical wall of said chamber, a rotor rotatably mounted within said chamber coaxially with said wall, imperforate vanes mounted on said rotor, extending substantially continuously radially and longitudinally throughout the heated region of said cylinder, means for rotating the rotor whereby liquid is spread in a thin film on the wall of the chamber for downward flow, the tips of the vanes projecting into the liquid flowing down the cylindrical wall, thereby forming vapor-tight compartments defined by adjacent vanes, the rotor and the liquid flowing down the cylindrical wall, collecting means secured to the lower end of the chamber, said collecting means having a compartment for receiving the concentrated liquid and the vapor, an outlet connected to the collecting compartment for exhausting concentrated liquid therefrom, and a separate outlet connected to the collecting compartment for exhausting the vapor removed from the liquid, whereby the liquid and vapor flow in the same helical direction downwardly through the heated region of the chamber thereby increasing the velocity of the liquid concentrate, the liquid and a portion of the vapor being mixed in a turbulent thin film while passing downwardly over the chamber wall thereby increasing the fluidity of the liquid concentrate, the vanes and the vapor contained within the vapor-tight compartments forcing all the entrained liquid droplets outwardly into the liquid concentrate flowing downwardly on the chamber wall, wherein the collecting means includes a cylindrical extension having one end secured to the lower end of the chamber and the opposite end extending into the collecting compartment, said extension having a plurality of flow straightening vanes for changing the helical flow of the cencentrate and vapor to axial flow.

4. The invention according to claim 3 wherein distributor means is provided within the chamber above the vanes and independent of the liquid introducing means for spreading the liquid substantially uniformly around the chamber wall above the vanes.

5. Apparatus for evaporating and concentrating liquids comprising a chamber having a substantially vertical cylindrical wall upon which the liquid to be concentrated flows downwardly, closure means at the top of said chamber, means adjacent the closure means for introducing liquid to be concentrated, means for heating the vertical wall of said chamber, a rotor rotatably mounted within said chamber coaxially with said wall, imperforate vanes being continuously connected along one edge to said rotor extending longitudinally thereof, said vanes extending substantially continuously radially and longitudinally throughout the heated region of said cylinder, said vanes being of sufficient number to sweep each portion of the cylindrical wall 15 to 30 times per second, the vane tips projecting outwardly into close proximity to the wall of the chamber, the clearance between the blade tip and the inner surface of the cylindrical wall being between 1 to 3 millimeters, means for rotating said rotor so that the outer tips of the vanes move at a speed not less than 8 meters per second, whereby liquid is spread in a thin film on the wall of the chamber for downward flow, said vane tips projecting into the liquid flowing down the cylindrical wall, thereby forming vapor-tight compartments in the transverse sense as defined by adjacent vanes, the rotor and the liquid flowing down the cylindrical wall, collecting means, said collecting means having an open compartment for receiving the concentrated liquid and the vapor, a portion of the compartment being laterally offset from the chamber, an outlet connected to the collecting compartment for exhausting concentrated liquid therefrom, and a separate vapor outlet connected to the collecting compartment in the laterally offset portion for exhausting the vapor removed from the liquid, whereby the liquid and vapor flow in the same helical direction downwardly through the heated region of the chamber, the liquid and a portion of the vapor being mixed in a turbulent thin film while passing downwardly over the chamber wall thereby increasing the fluidity of the liquid concentrate, the vanes and the vapor contained within the vapor-tight compartments forcing all of the entrained liquid droplets outwardly into the liquid concentrate flowing downwardly on the chamber wall thereby increasing the velocity of the liquid concentrate, and whereby the direction of flow of the vapor is changed by the collecting compartment means to a direction transverse of the chamber toward said vapor outlet in the offset portion of the collecting compartment means.

6. Apparatus for evaporating and concentrating liquids comprising a chamber having a substantially vertical cylindrical wall upon which the liquid to be concentrated flows downwardly, closure means at the top of said chamber, means adjacent the closure means for introducing liquid to be concentrated, means for heating the vertical wall of said chamber, a rotor rotatably mounted within said chamber coaxially with said wall, imperforate vanes mounted on said rotor extending longitudinally thereof, said vanes extending substantially continuously radially and longitudinally throughout the heated region of said cylinder, said vanes being of sufficient number to sweep each portion of the cylindrical wall 15 to 30 times per second, the vane tips projecting outwardly into close proximity to the wall of the chamber, the clearance between the blade tip and the inner surface of the cylindrical wall being between 1 to 3 millimeters, means for rotating said rotor so that the outer tips of the vanes move at a speed not less than 8 meters per second, whereby liquid is spread in a thin film on the wall of the chamber for downward flow, said vane tips projecting into the liquid flowing down the cylindrical wall, thereby forming vapor-tight compartments defined by adjacent vanes, the rotor and the liquid flowing down the cylindrical wall, and a collecting means connected to the lower end of the chamber, including an outlet for concentrated liquid and a separate outlet for the vapor removed from the liquid, whereby the liquid and vapor flow in the same helical direction downwardly through the heated region of the chamber, the liquid and a portion of the vapor being mixed in a turbulent thin film while passing downwardly over the chamber wall thereby increasing the fluidity of the liquid concentrate, the vanes and the vapor contained within the vapor-tight compartments forcing all of the entrained liquid droplets outwardly into the liquid concentrate flowing downwardly on the chamber wall thereby increasing the velocity of the liquid concentrate, wherein the collecting means includes a cylindrical extension having one end secured to the lower end of the chamber and the opposite end extending into the collecting compartment, said extension having a plurality of flow straighten-

ing vanes for changing the helical flow of the compartments and vapor to axial flow.

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