Aug. 14, 1956 W. J. PODBIELNIAK 2,758,783

CENTRIFUGAL COUNTERCURRENT EXCHANGE DEVICE

Filed Nov. 5, 1952 3 Sheets-Sheet 1

Fig. 3

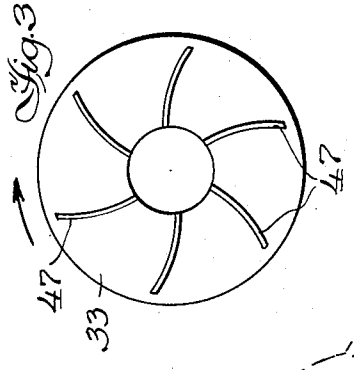
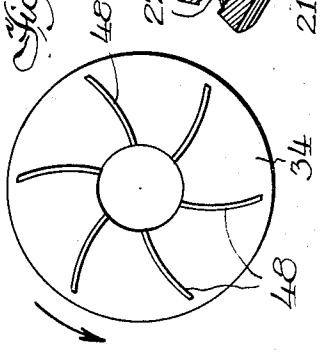


Fig. 1

Fig. 4



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CENTRIFUGAL COUNTERCURRENT EXCHANGE DEVICE

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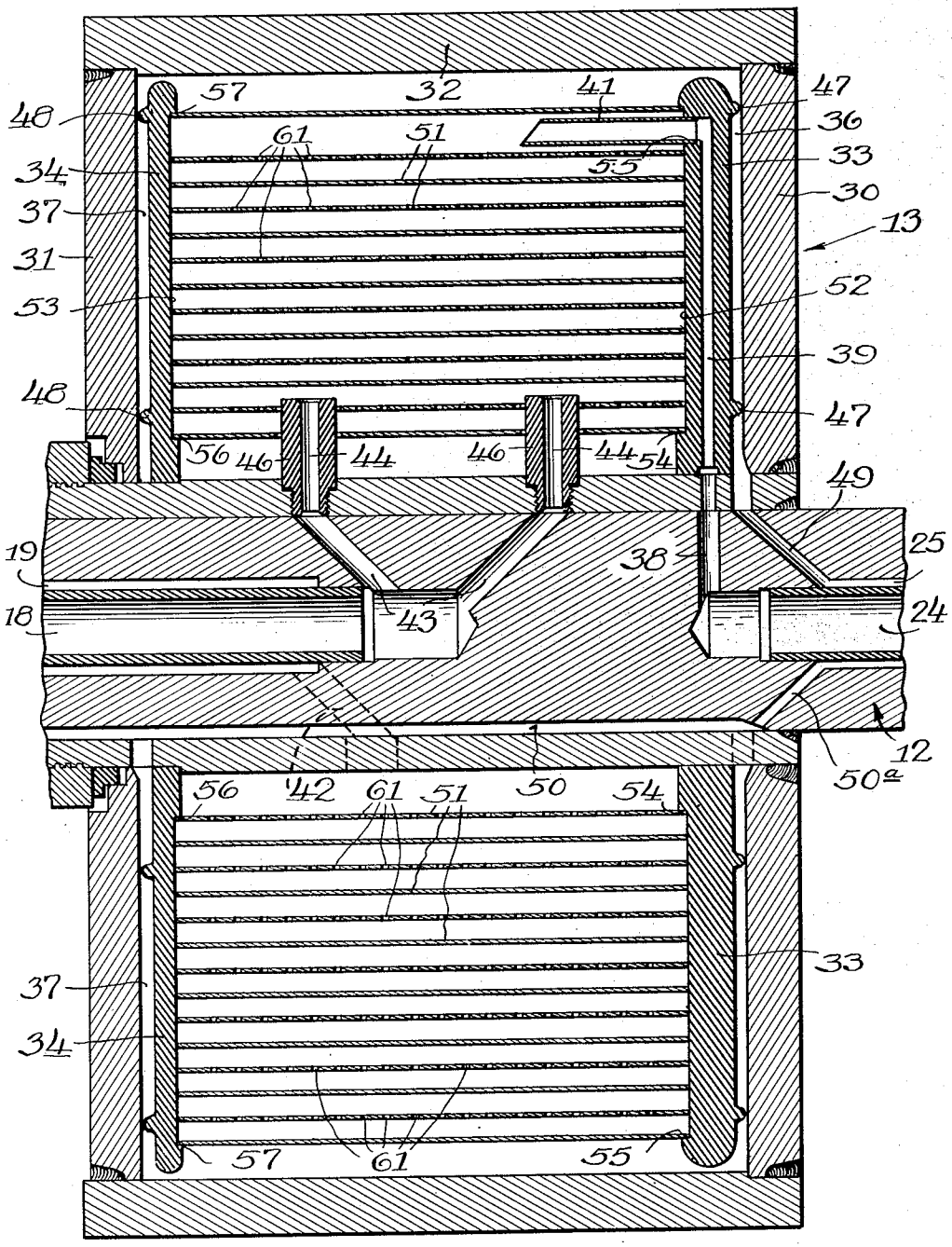


Fig. 2

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CENTRIFUGAL COUNTERCURRENT EXCHANGE DEVICE

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Fig. 5

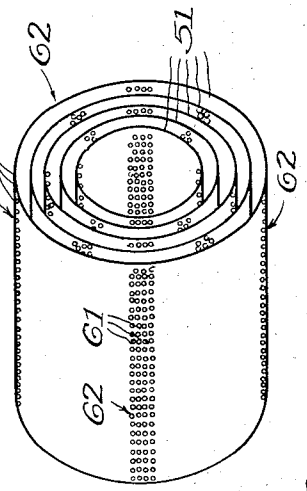


Fig. 6

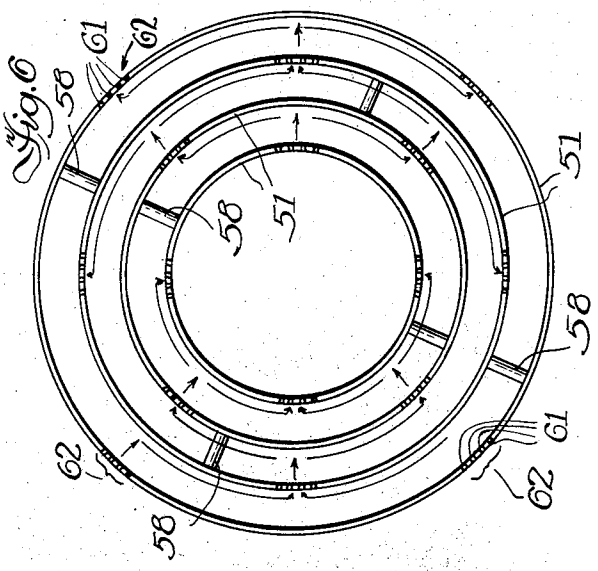


Fig. 7

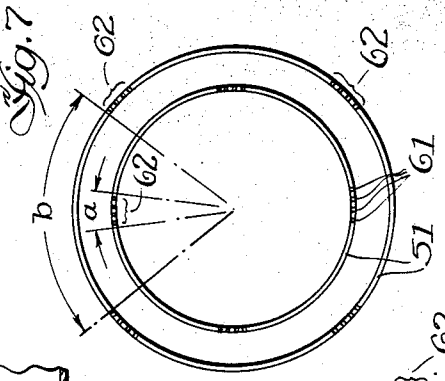


Fig. 9

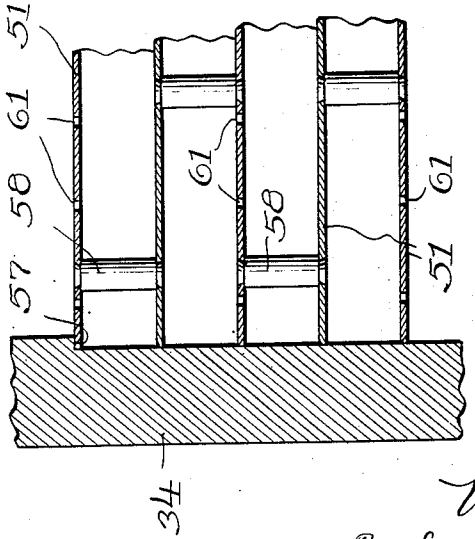
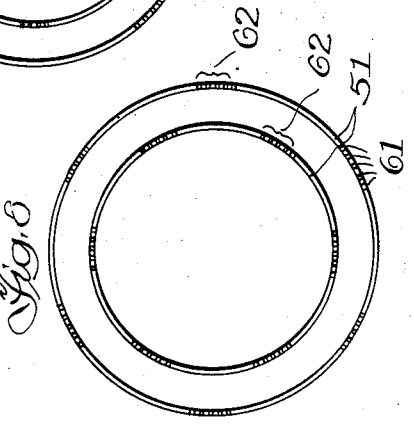


Fig. 8



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United States Patent Office 2,758,783 Patented Aug. 14, 1956

2,758,783

CENTRIFUGAL COUNTERCURRENT EXCHANGE DEVICE

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Application November 5, 1952, Serial No. 318,803

5 Claims. (Cl. 233—15)

The present invention relates to improvements in countercurrent exchange devices of the general type illustrated in Patent No. 2,286,157 and in the copending application of Walter J. Podbielniak and others, Serial No. 239,992, filed August 2, 1951. It is more particularly intended for effecting countercurrent contact between liquids of different densities that are immiscible or largely so, for example, for solvent extraction, chemical treatment or like purposes. It may likewise be employed for countercurrent contact between liquids and gases or vapors if so desired.

In the exchange device of the present invention, liquids which are immiscible or partly immiscible and of different densities are caused to travel countercurrent with respect to each other while passing through a rotor. The rotor revolves at a high rate of speed so as to exert substantial centrifugal force upon the liquids passing through the device. In general, the purpose of such countercurrent exchange is to secure solvent action of one of the liquids upon a constituent or constituents held in solution in the other. Since in such devices, highly effective countercurrent exchange and solvent action can be secured with an extremely short time of travel through the machine, the use of such machines has become very wide-spread in processes where extremely rapid and effective action is required by reason of the instability of the more valuable materials involved as, for example, in the extraction of antibiotics such as penicillin, streptomycin, aureomycin and chloromycetin.

In the past, it has been common in these countercurrent exchange devices to provide a plurality of concentric rings or cylindrical bands positioned within the rotor. In many cases, a spiral band is employed. The rings or bands are perforated so that countercurrent exchange between the two liquids treated by the machine is obtained when the liquids pass through the perforations and when the liquids contact each other in the area between the rings or bands. The efficiency of the machine is to a great extent dependent upon the manner of perforating the bands. In the present invention, the bands are perforated in a manner to secure a maximum efficiency.

The concentric bands in the present invention are perforated with rows or groups of perforations in an area generally parallel to the axis of rotation and extending transversely across the bands. The groups of perforations are spaced equiangularly around the periphery of the band with unperforated areas between the rows of perforations. The rows of perforations in one band are positioned opposite an unperforated area in the adjacent concentric bands so that the liquids passing through the rows of perforations of any band will be directed toward an unperforated area in the adjacent band or bands. This construction prevents "channeling," or operation wherein liquids passing through one band will, with little or no deviation from a straight line path of travel, pass through the perforations in an adjacent band. The present construction creates extremely efficient countercurrent contact between the two liquids and also has been found to

provide for increased throughput capacity in machines of a given size. Machines embodying the construction of the present invention have a higher stage efficiency and a greater capacity than similar machines heretofore known in the art.

The machine of the present invention also employs an improved means for passage of liquids within the rotor from its outermost portion to its innermost portion by providing an extended passageway between spill-over disks within the rotor and the side walls of the rotor. Within these passageways are a plurality of cycloidal vanes positioned to aid in the rapid removal of the heavier liquid, thus increasing the capacity of the machine.

The invention will be more fully understood from the following description thereof, illustrated by the accompanying drawings, in which:

Fig. 1 is a diagrammatic perspective view of the centrifugal exchange device of the present invention, partially broken away to schematically illustrate the operation of the rotor of the device, parts of the mounting and other stationary parts being indicated by dotted lines;

Fig. 2 is a sectional view of the rotor and a portion of the shaft through the axis thereof;

Fig. 3 is an elevational view of one side of a spill-over plate, for one side of the rotor, showing the cycloidal vanes for control of the flow of liquid;

Fig. 4 is a view similar to Fig. 3 showing the spill-over plate for the other side of the rotor;

Fig. 5 is a detail perspective view of a plurality of concentric bands as used in the rotor, showing the bands as perforated in accordance with the present invention;

Fig. 6 is a detail cross sectional view through a plurality of concentric bands;

Fig. 7 is a detail cross sectional view through two concentric bands, illustrating one arrangement of angular placement of the groups of perforations;

Fig. 8 is a view similar to Fig. 7 showing two concentric bands with a different angular placement of the groups of perforations; and

Fig. 9 is a fragmentary cross sectional view through the axis of the rotor, on an enlarged scale, showing the method of mounting the concentric bands.

Referring to the drawings, and particularly Figs. 1 and 2, the numeral **11** indicates a supporting framework which carries a rotatable shaft **12** upon which is mounted the rotor **13**. The rotor may be provided with a suitable stationary casing **14** (shown in dotted lines in Fig. 1) which preferably comprises upper and lower portions **15** and **16**, the upper and lower portions being suitably hinged at the rear (the hinges not being shown) to permit access to the rotor. The rotor **13** is rotated by a driving belt (not shown) through a drive pulley **17** attached to shaft **12**.

In the device as illustrated in the drawings, the countercurrent or solvent exchange takes place within the rotor **13**, which is rotated at a high rate of speed, for example from 2000 to 5000 R. P. M. or even higher, thus developing substantial centrifugal forces within the rotor. The heavier liquid is introduced at an inner point in the rotor and travels outwardly under the action of the centrifugal force, leaving at or near the outermost portion of the interior of the rotor. The lighter liquid is introduced under pressure at an outer point in the rotor and is forced inwardly through the rotor, against the outwardly traveling heavier liquid, to effect the desired countercurrent exchange or solvent action. The lighter liquid, after this process has been conducted, is withdrawn from an inner point within the rotor. In the ensuing description of the apparatus, it will be assumed that the heavier liquid is the liquid initially containing the valuable material to be extracted and it will be assumed that the lighter liquid is the solvent which is being employed to extract the valu-

able material from the heavier liquid, although, of course, the role of the two liquids could be reversed.

From the preceding description, it will be apparent that it is necessary to supply the heavier liquid and to withdraw the lighter liquid at points near the axis of the rotor; and that it will be necessary to supply the lighter liquid and remove the heavier liquid at points near the periphery of the rotor. For this purpose, shaft **12** is provided with two sets of internally concentric conduits, as illustrated in Figs. 1 and 2 of the drawings. As shown, the shaft **12** is provided internally at the left with concentric conduits, the inner one being designated **18** and the annular conduit surrounding it being designated by the number **19**. A stationary cap **20** is provided at the extreme left end of the shaft as shown in Fig. 1. A pipe **21** connected to cap **20** communicates with annular conduit **19**. Inner conduit **18** communicates with an opening through the end of the cap **20** as indicated at **22**, suitable sealing means **23** being provided to prevent intermixture between the light and heavy liquids. The opening **22** in the end of cap **20** may be threaded or otherwise arranged to permit the connection of a pipe (not shown) for the supply of heavy liquid. The heavy liquid enters the rotor through the cap **22** and passes into conduit **18**. Light liquid which has already passed through the rotor leaves the rotor through annular conduit **19**, passing out of pipe **21**.

Similar conduits are provided in the opposite end of the shaft for supply of light liquid to the rotor and the removal of the heavy liquid from the rotor. Thus, as shown in Figs. 1 and 2, at the right, shaft **12** is provided with an internal conduit **24** surrounded by an annular conduit **25**. The inner conduit **24** extends through the shaft and communicates with the opening **26** in stationary cap **27** into which the end of the shaft **12** fits. The opening **26** is threaded or otherwise arranged to permit the connection of a pipe (not shown) for the supply of light liquid to the rotor. The annular conduit **25** connects with pipe **28** (Fig. 1) and through this pipe the heavy liquid, after treatment, is discharged from the rotor. A seal **29**, similar to the seal **23** at the opposite end of the shaft, is provided between the end of the shaft **12** and the cap **27**.

The rotor, as best illustrated in Fig. 2, is formed as a cylindrical casing made up of two side plates or disks **30** and **31** and a peripheral cylindrical member **32** rigidly secured to each other and to the shaft to form a closed chamber. Within the side members or disks **30** and **31** of the rotor, and spaced therefrom to provide a small clearance of say about 1/16 to 1/8 inch, are spill-over plates **33** and **34**. The plates **33** and **34** are of less radius than the internal surface of the cylindrical wall member **32** to provide an annular discharge passageway extending entirely around the edges of the spill-over plates **33** and **34**. The space **36** between disk **30** and spill-over plate **33** and the space **37** between disk **31** and spill-over plate **34** form inter-disk or inter-plate passageways which serve for the discharge of heavy liquid leaving the rotor.

Light liquid enters the rotor through inner conduit **24** and then passes through conduit **38** and into conduit **39** drilled into spill-over plate **33**. The light liquid enters the rotor through the tube **41** which is spaced a sufficient distance inwardly from peripheral cylindrical member **32** to provide a clarifying or demulsifying area for the heavy liquid leaving the rotor. It is manifest that a plurality of conduits **38** and **39** and tubes **41** may be provided equiangularly about spill-over plate **33** so that the light liquid may enter the rotor at various points about the periphery. After the light liquid has travelled inwardly toward the axis of the rotor, it leaves the rotor through conduit **42** (shown in dotted lines in Fig. 2) and annular conduit **19**, and discharges through pipe **21**.

Heavy liquid entering the rotor through inner conduit **18** passes into the rotor through conduits **43** and through openings **44** in plugs **46**. Plugs **46** extend upwardly a sufficient distance to provide an adequate clarifying or demulsifying area for the light liquid being removed. A plurality of conduits **43** and plugs **46** may be provided about the periphery of the axis of the rotor, if desired.

As shown in Figs. 3 and 4, spill-over plate **33** is provided with a plurality of vanes **47** of generally radial arrangement, suitably cycloidal, and spill-over plate **34** is provided with a plurality of similar vanes **48**. Cycloidal vanes **47** are mirror images of cycloidal vanes **48**. The vanes **47** and **48** are of a thickness approximately equal to the inter-disk passageways **36** and **37** (Fig. 2).

Vanes **47** and **48** aid in breaking up circumferential swirl or agitation in the liquid passing through inter-disk spaces **36** and **37** and keep the mixed solids and liquid agitated and in turbulent uniform flow and thereby help to prevent the building up of excessive pressure drops which occur when a continuous disk-like passageway for liquid is provided.

The heavier liquid leaves the rotor at the right side (Fig. 2) by passing through inter-disk passageway **36** and thence through conduit **49** into annular conduit **25**; at the left side, it passes through inter-disk passageway **37**, and then through conduit **50** (milled parallel to the axis of the shaft) and conduit **50***a* into annular conduit **25**. It is then discharged through pipe **28**. As is apparent, other means for removing the heavy liquid from the rotor chamber may be provided, as disclosed, for example, in my prior application Serial No. 111,218, filed August 19, 1949, now Patent No. 2,670,132, granted February 23, 1954.

Annular passageways of progressively increasing radius are provided in the rotor. These passageways are preferably formed by concentric rings or bands **51**. Recessed portions **52** and **53** are provided in spill-over plates **33** and **34**, forming annular shoulders **54** and **55** in plate **33** and **56** and **57** in plate **34**. Concentric bands **51** are spaced from one another by means of lugs **58** (Figs. 6 and 9), the entire set of bands being fitted as a whole in recesses **52** and **53**, with the innermost band resting on shoulders **54** and **56**, and the outermost band being held by shoulders **55** and **57**. Bands **51** are thus securely held in place between the spill-over plates. The distance between bands may vary considerably from about 0.15 inch to 3 inches depending upon the physical properties of the two liquids to be contacted. The distance between the bands is determined to a great extent by the physical properties of the two liquids introduced. The distance between bands together with the area, size and spacing of the perforations may be varied depending upon a desired balancing of mixing between the perforations and the partial clarification obtained between the bands. If desired, the distance between bands may be varied, for example, by making the distance between bands a function of the radial distance from the axis of rotation, as shown in the aforesaid prior application of Walter J. Podbielniak, Serial No. 111,218, now Patent No. 2,670,132.

Concentric bands **51** are perforated with perforations **61**, preferably arranged in a plurality of rows **62** (Figs. 5 to 8) about the periphery of each band, parallel to the axis of rotation of the band. The perforations need not be arranged precisely in rows, as long as they are clustered in groups of relatively fixed width which run substantially the length of each band between spill-over plates **33** and **34**, parallel to the axis of rotation.

The rows or groups of perforations **62**, which extend transversely across the band, are spaced equiangularly about the periphery of bands **51**, the number of groups being varied, depending upon the size of the machine, the throughput capacity desired, and the nature of the liquids that are introduced. It is preferred to employ from between 2 to 8 groups for each band. With larger machines up to 8 groups, or even more, may be used; with smaller machines a lesser number of groups is employed, say between 2 and 4. For an average sized machine, 4 groups are customarily used (as shown in Figs. 5, 6 and 7). Fig. 8 shows two concentric bands **51** hav-

ing 6 groups of perforations. The size and relative spacing of the perforations may vary as desired and depending upon the liquids introduced into the machine, but the perforations are preferably between about 3/32–3/16" in diameter and spaced between about 5/8–1" from one another. The width of each group may also be varied, but it is preferred to have not less than two, or more than about 8, perforations in side-by-side relationship to make up the width of the group. If desired, the number of perforations may vary from band to band, for example, the number of perforations may decrease with increase in radius of the bands.

The concentric bands **51** are positioned so that a group of perforations **62** is always opposite an unperforated area in the bands immediately adjacent thereto. Each group of perforations **62** is preferably positioned midway between two similar groups in the adjacent bands of smaller and larger radii. As shown in Fig. 7, the width of each row or group of perforations is such that the radial angle "*a*," subtended by the width of a group of perforations **62**, except for the innermost bands, is less than the radial angle "*b*," subtended by the width of opposite unperforated areas in the adjacent bands, and preferably from 1/8 to 1/2 the radial angles of the opposite unperforated areas of the adjacent bands, for an extended area of contact for the two liquids.

It is manifest that the heavier liquid, passing outwardly from near the axis of the rotor, and the lighter liquid, moving inwardly towards the axis, will mix with one another, as they pass through the perforations and in the relatively wide unperforated areas, before traveling to the next band through the perforations. Fig. 6 at the right diagrammatically illustrates the path of travel of the heavier liquid as it moves outwardly from the axis and the path of the light liquid is indicated by the arrows at the left of the figure, the centrifugal force forcing the heavier liquid outwardly and the pressure forcing the light liquid inwardly transcending the rotary effect and the force of gravity. Between the bands, owing to the fact that there is a substantial imperforate area of each band opposite the perforations in the bands on each side of it, and because of the rotary movement or swirl imparted to the liquid by the rotation of the rotor, there is much turbulent intermixture, although some degree of separation and demulsification may take place. Although the precise nature of the interaction between bands has not been determined, the present arrangement has been found to give unusually high efficiency and at the same time, great flexibility and high throughput capacity. "Channeling," with resulting inefficiency of contact appears to be greatly reduced.

As hereinbefore indicated, clarification or demulsification areas are provided at the outermost portion of the rotor for the heavy liquid and at the innermost portion of the rotor for the light liquid. By varying the position of the pipe **41** for admission of the light liquid inwardly or outwardly, the extent of the demulsification area for the heavy liquid may be varied; and by varying the length of the inlet plugs **46** for the heavy liquid, the extent of the demulsification area for the light liquid may be varied.

The apparatus of the present invention has been successfully employed in many different applications for the extraction of active principles, for example, the separation of antibiotics, such as penicillin, aureomycin, chloromycetin and the like from the aqueous solutions resulting from the fermentive processes from which they are produced. The apparatus has been found particularly useful in the extraction of penicillin since the very high contacting efficiency and solvent extraction effect is secured with exceedingly rapid traverse of the liquid through the equipment, the actual time involved in the operation being very small. This is of great importance, since, under the conditions under which the solvent extraction of the penicillin must be effected, a progressive destruction of the penicillin with time takes place and

it is extremely important that this be reduced to a minimum. Thus, with a machine having four groups of perforations per band and a rotor diameter of about 26 inches wherein the length of the bands between the spill-over plates is approximately 10 inches, over 98% of the penicillin has been recovered from penicillin broth, using amyl acetate as a solvent. The machine has a capacity of between 25 to 35 gallons of penicillin broth per minute and a retention time as low as 7 or 8 seconds.

While concentric bands have been referred to in describing the structure of the present invention, it is readily apparent that, by using spiral bands, substantially concentric bands may be secured, as described, for example, in the prior application of Walter J. Podbielniak and others, Serial No. 239,992, above referred to.

Although the present invention has been described in connection with a specific embodiment of the invention, it is to be understood that many details may be modified without departing from the scope of the invention and that the invention is not to be limited to specific details, except insofar as included in the appended claims.

I claim:

1. In apparatus for countercurrent exchange between at least partially immiscible liquids of different densities, a rotor provided internally with a rotor chamber, means for supplying heavier liquid to and removing lighter liquid from the inner portion of said rotor chamber, means for supplying lighter liquid to and removing heavier liquid from the outer portion of said rotor chamber, spaced concentric bands within said rotor, each of said bands being provided with a plurality of groups of perforations spaced equiangularly about the periphery of said band and arranged parallel to the axis of rotation of the rotor, unperforated areas in each of said bands between said groups of perforations, each of said groups of perforations extending over substantially the entire length of the band in a direction parallel to said axis of rotation of the rotor and each of said groups of perforations being positioned opposite an unperforated area in each adjacent band, whereby heavier and lighter liquids passing through said rotor chamber are forced to travel circumferentially in each space between bands before passing to the adjacent space between bands, and channeling is avoided.

2. In apparatus for countercurrent exchange between at least partially immiscible liquids of different densities, a rotor provided internally with a rotor chamber, means for supplying heavier liquid to and removing lighter liquid from the inner portion of said rotor chamber, means for supplying lighter liquid to and removing heavier liquid from the outer portion of said rotor chamber, spaced concentric bands within said rotor, each of said bands being provided with at least two groups of perforations spaced equiangularly about the periphery of said band and arranged parallel to the axis of rotation of the rotor, unperforated areas in each of said bands between said groups of perforations, each of said groups of perforations extending over substantially the entire length of the band in a direction parallel to said axis of rotation of the rotor and each of said groups of perforations being positioned opposite an unperforated area in each adjacent band, whereby heavier and lighter liquids passing through said rotor chamber are forced to travel circumferentially in each space between bands before passing to the adjacent space between bands, and channeling is avoided.

3. In apparatus for countercurrent exchange between at least partially immiscible liquids of different densities, a rotor provided internally with a rotor chamber, means for supplying heavier liquid to and removing lighter liquid from the inner portion of said rotor chamber, means for supplying lighter liquid to and removing heavier liquid from the outer portion of said rotor chamber, spaced concentric bands within said rotor, each of said bands being provided with a plurality of groups of perforations spaced equiangularly about the periphery of said band and arranged parallel to the axis of rotation of the rotor,

unperforated areas in each of said bands between said groups of perforations, each of said groups of perforations extending over substantially the entire length of the band in a direction parallel to said axis of rotation of the rotor and each of said groups of perforations being positioned opposite an unperforated area in each adjacent band, the angle subtended by a group of perforations being less than the angle subtended by the opposite unperforated area in the adjacent outer band, whereby heavier and lighter liquids passing through said rotor chamber are forced to travel circumferentially in each space between bands before passing to the adjacent space between bands, and channeling is avoided.

4. In apparatus for countercurrent exchange between at least partially immiscible liquids of different densities, a rotor having two side plates and a peripheral cylindrical member making up a rotor chamber, means for supplying heavier liquid to and removing lighter liquid from the inner portion of said rotor chamber and means for supplying lighter liquid to and removing heavier liquid from the outer portion of said rotor chamber, said means for removing heavier liquids comprising a spill-over plate spaced from and parallel to each of said rotor side plates to form inter-plate spaces between said side plates and said spill-over plates for the discharge of the heavier liquid from the rotor chamber, and a plurality of cycloidal vanes on each of said spill-over plates in said inter-plate spaces, the cycloidal vanes on one of said spill-over plates being mirror images of the cycloidal vanes on the other of said spill-over plates.

5. In apparatus for countercurrent exchange between

at least partially immiscible liquids of different densities, a rotor having side plates and a peripheral cylindrical member making up a rotor chamber, means for supplying heavier liquid to and removing lighter liquid from the inner portion of said rotor chamber, means for supplying lighter liquid to and removing heavier liquid from the outer portion of said rotor chamber, spaced concentric bands within said rotor and each of said bands being provided with a plurality of groups of perforations spaced equiangularly about the periphery of said band and arranged parallel to the axis of rotation of the rotor, unperforated areas in each of said bands between said groups of perforations, each of said groups of perforations extending over substantially the entire length of the band in a direction parallel to said axis of rotation of the rotor and each of said groups of perforations being positioned opposite an unperforated area in each adjacent band, said means for removing heavier liquids comprising a spill-over plate spaced from and parallel to each of said rotor side plates to form inter-plate spaces between said side plates and said spill-over plates for the discharge of heavier liquid from the rotor chamber, and a plurality of generally radial vanes on each of said spill-over plates in said inter-plate spaces.

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