Oct. 15, 1963 C. M. DOYLE 3,107,218

ROTATING COLUMN CONTACT DEVICE

Filed May 9, 1960 2 Sheets-Sheet 1

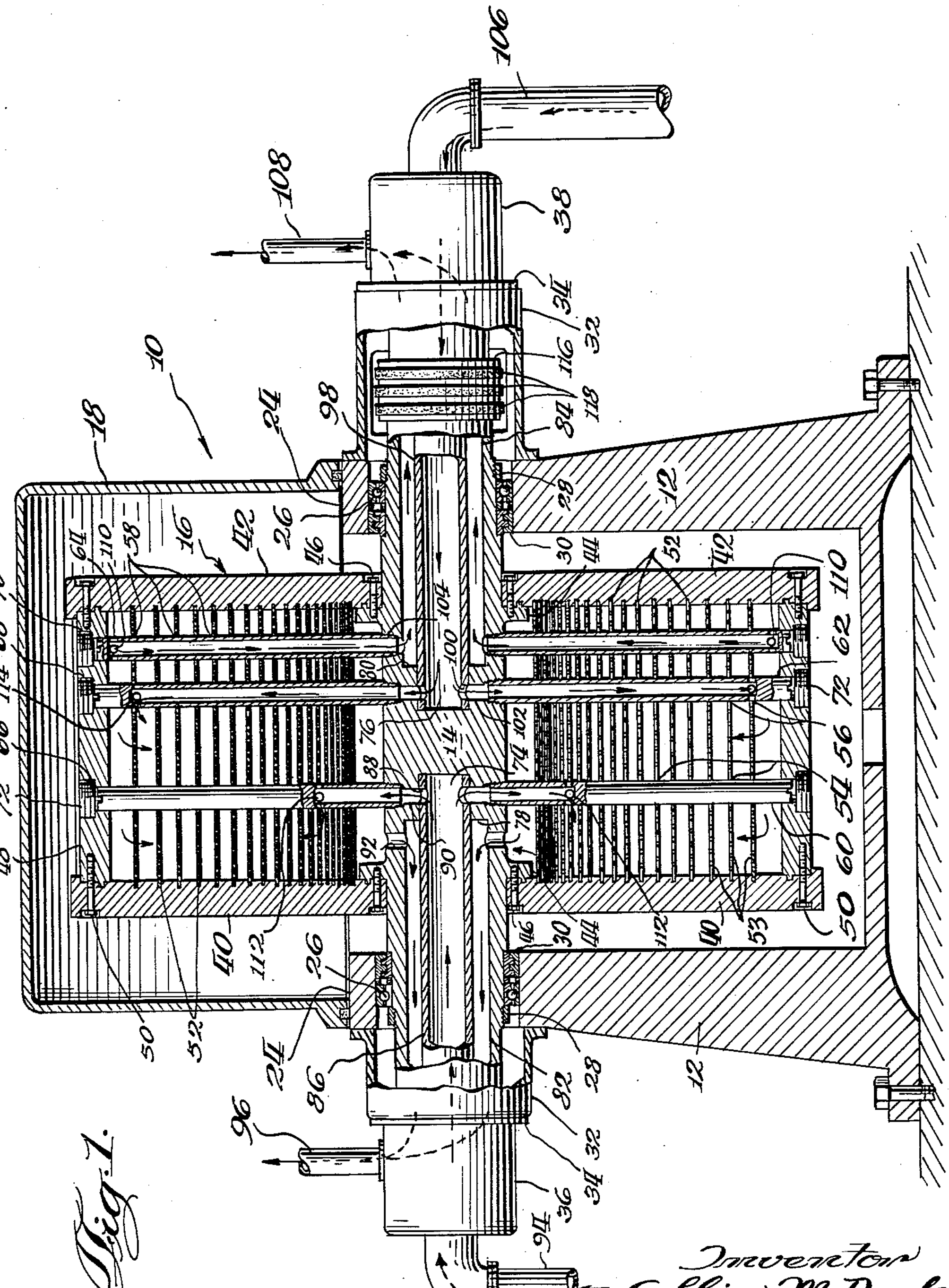

Fig. 1.

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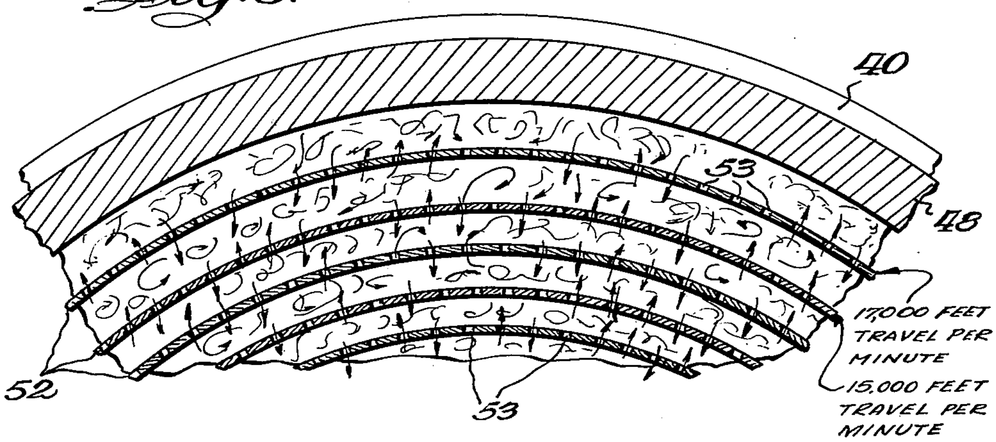
Fig. 3.



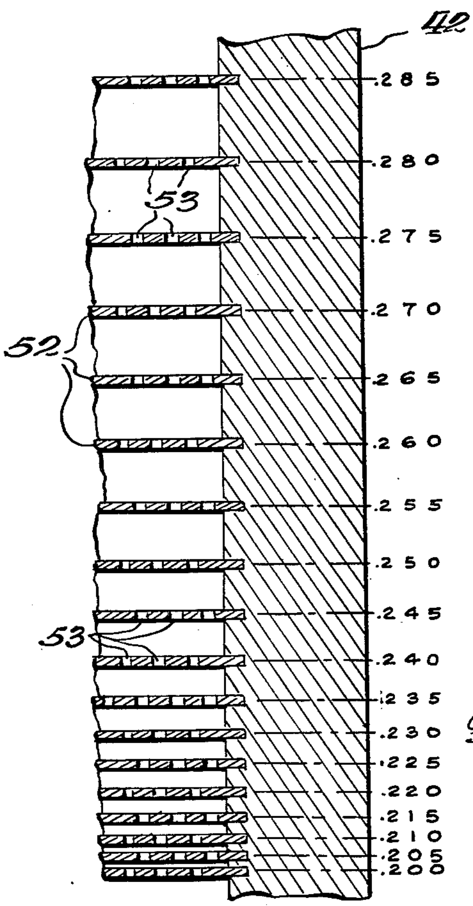
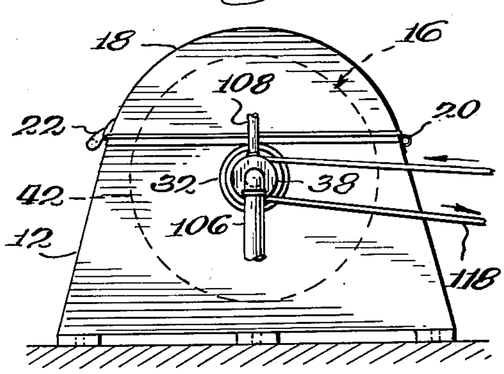


Fig. 4.

Fig. 2.



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3,107,218
ROTATING COLUMN CONTACT DEVICE

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9 Claims. (Cl. 233—15)

This invention relates generally to improvements in rotating contact devices and methods of the type typified by the devices disclosed in such patents as 2,281,796, 2,286,157, and 2,670,132.

More particularly, the invention relates to a new and improved contact device of the character described but which is constructed and functions in a manner which is radically different from that of the said patented devices.

The basic application of the subject devices is in operations where it is necessary or desirable to bring into intimate contact two fluids, as for example two liquids for the purpose of extracting or separating a component from one of said liquids. The method, construction and operation of the device is based upon certain physical laws and properties of the reactants such as the total or partial immiscibility and varying densities of any two given reactants, and the devices are most advantageously utilized in operations such as purification, chemical treatment, and solvent extraction.

Generally, the prior devices comprised a sealed cylindrical rotor in which were positioned a plurality of spaced concentric cylindrical bands. The bands were formed with a plurality of perforations or openings. The heavier liquid or other reactant was admitted into the rotor at the center thereof and the lighter liquid was admitted into the rotor under pressure at the periphery thereof. When the rotor was operated at high speeds, the centrifugal force created thereby cause the heavier liquid to travel through the maze of perforations outwardly toward the periphery of the rotor. Simultaneously, the pressurized lighter liquid was forced to travel inwardly toward the center of the rotor. During the described movements of the two liquids, the same were brought into intimate contact so that the function of the process could be accomplished, and means were then provided for removing the lighter liquid from the center of the rotor and the heavier liquid from the periphery of the rotor.

While the prior devices unquestionably represented a great advance over such earlier contact devices as the static column, the rotating disc column and the mix tank-centrifugal separator, exhaustive experimentation has proven that the theories which dictated the construction of said prior devices are actually erroneous. Thus, it has been determined that while the described prior devices functioned with a reasonable modicum of efficiency, the erroneous principles which governed their construction and operation greatly limited their efficiency.

Referring specifically to said Patent No. 2,670,132, it will be noted that the essential consideration in that device appears to be the supposition that the primary contacting effect between the two liquids is effected by a "jet action" of the liquids through the relatively small openings formed in the concentric separator bands. Thus, the patented device is based upon the premise that the mixing occurs when the two liquids pass simultaneously through a single small opening. Any surface contact of the liquids in the spaces between the separator bands is described as being an unimportant and even undesirable

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factor. As a matter of fact, the patented device is actually provided with means for reducing or preventing any such surface contact. Thus, in keeping with the described basic supposition, the patented device employs relatively small openings (0.007 to 0.080 inch) and depends upon relatively high speeds of rotation (4,000 r.p.m.) to create the said "jet action."

Contrary to the basic supposition of the said patent, I have determined experimentally and in accordance with the basic laws of physics (as will subsequently be more fully described), that substantially all of the intimate contacting of the liquids occurs as a result of their surface contact in the areas between the separator bands. This being the case, it has been found that the distinctive structure of the said prior device which is based upon the erroneous supposition of "jet action" is actually a handicapping limitation upon the efficiency of that device.

It is therefore an important object of this invention to provide a rotating column contact device, the construction and operation of which is based upon and advantageously utilizes the fact that the primary contacting effect occurs as a result of the surface contact of the liquids in the areas between the separator bands. Thus, the invention is truly a rotating column which utilizes centrifugal forces as a source of mixing energy.

In further keeping with the "jet action" supposition, the said patent claimed that it was important that the spacing between the separators bands decrease as the radii of the bands increase. Thus, this varied spacing was allegedly an inverse function of the radius, so that the spacing decreased outwardly from the center of the rotor. Although the mathematical description of the spacing is not too clear, any spacing which decreases outwardly tends to defeat the very functions which such devices are intended to perform. This is true because the greatest amount of centrifugal force and hence mixing energy is present at the point in the rotor which has the greatest linear velocity. This point is, of course, at the periphery of the rotor. Thus, to obtain the greatest possible amount of actual mixing and consequently the greatest amount of liquid separation or extraction, the volumes of the liquids should be greatest at the periphery. Obviously, then, the spacing between the separator bands should be greatest near the periphery of the rotor, or at least not less than at any other point.

It is therefore another important object of this invention to provide a rotating column contact device of the character described in which the spacing between the separator bands increases as the radii of the bands increase, or in the alternative, the spacing is at least uniform.

A further object is to afford a rotating column contact device of the character described in which the openings in the separator bands are substantially larger than heretofore, thus taking full advantage of the gravitational forces set up in the rotating column to insure the greatest amount of surface contact of the liquids between the bands.

As already indicated, it was heretofore necessary to operate the said prior devices at a fixed relatively high speed of approximately 4,000 r.p.m. in order to achieve the desired "jet action." It is well known that in certain applications, such high speeds are not only unnecessary, but are actually undesirable. Thus, for example, in the removal of caffein from coffee with trichlorethylene, these two liquids must be mixed very gently in order to avoid emulsification. Similarly, in the removal of penicillin from fermented liquor with chloroform, such high speeds result in an undesirable stable emulsion. To combat these problems it was often found necessary to employ certain "wetting" agents, which in turn created new problems by affecting the surface tensions and densities of the liquids.

A related problem resulting from the use of a fixed speed of rotation is related to the fact that the mixing energy required to thoroughly mix any two liquids is directly proportional to the volumetric ratios of the liquids. Thus, for example, a much greater amount of mixing energy is required to mix two liquids which are in the volumetric ratio of 1 to 500 than is required to mix two liquids which are in the ratio of 1 to 1. Obviously, then, with a fixed speed of rotation, the device is often operating at a speed far in excess of that actually required. To compensate for this great loss of efficiency, it was often necessary to operate the prior devices at maximum throughput at all times.

Still another object therefore, is to provide a rotating column contact device of the character described which may be operated at variable speeds so that the greatest control over the mixing of the liquids is maintained at all times. A related object is to provide a device of the character described in which the speed of rotation may be varied to compensate for variations in throughput so that maximum efficiency is always achieved.

Still a further object is to afford a rotating column contact device of the character described which may be operated at the slowest speed consistent with maximum efficiency, thereby prolonging the life of the device. A related object is to afford a device of the character described having greater diameter (i.e., volume capacity) and number of mixing stages than heretofore possible, and still maintain the operational stresses well within the stress limits of ordinary construction materials.

Depending upon the physical characteristics of the liquids used, it is known that varying areas of settling or clarification are required for efficient separation of the two liquids after mixing. Thus, while the output position of the two liquids is always constant, it is often desirable to vary their input positions to provide a greater or smaller area of clarification.

Yet another object therefore, is to provide a rotating column contact device of the character described in which the input positions of the liquids may be varied as required, thereby varying the area of settling or clarification.

Yet a further object is to afford a rotating column contact device of the character described having removable means for gaining access to the rotor for purposes of cleaning, repair and the like.

With the foregoing and other objects in view which will appear as the description proceeds, the invention consists of certain novel features of construction, arrangement and a combination of parts hereinafter fully described, illustrated in the accompanying drawings, and particularly pointed out in the appended claims, it being understood that various changes in the form, proportion, size and minor details of the structure may be made without departing from the spirit or sacrificing any of the advantages of the invention.

For the purpose of facilitating an understanding of my invention, I have illustrated in the accompanying drawings a preferred embodiment thereof, from an inspection of which, when considered in connection with the following description, my invention, its mode of construction, assembly and operation, and many of its advantages should be readily understood and appreciated.

Referring to the drawings in which the same characters of reference are employed to indicate corresponding or similar parts throughout the several figures of the drawings:

FIG. 1 is a vertical sectional view of a device embodying the invention, with portions thereof being shown in elevation;

FIG. 2 is an end elevational view of the device;

FIG. 3 is an enlarged fragmentary detail sectional view of the outermost separator bands illustrating the manner in which the liquids flow therethrough and are mixed therebetween; and

FIG. 4 is an enlarged fragmentary detail sectional view showing a somewhat exaggerated arrangement of the separator bands wherein the spacing therebetween increases as their radii increase.

Referring now to FIG. 1 of the drawings, the reference numeral **10** indicates generally the rotating column contact device. The device **10** may comprise a pair of standards **12**, **12** through which is journaled a rotating shaft **14**. Connected to the shaft **14** is a cylindrical rotating column indicated generally by the reference numeral **16**. A semi-cylindrical housing such as **18** may be mounted on the standards **12** for encasing the rotating column **16**. The housing **18** may be hingedly connected as at **20** (see FIG. 2) and have a handle such as **22** so that ready access may be had to the column **16** for purposes of servicing, maintenance, cleaning and the like.

The shaft **14** may be journaled in any suitable manner. Thus, the standards **12** may include a pair of aligned split rings **24**, **24**. Seated in each of the split rings **24** may be the outer race of an annular ball bearing **26**. Suitable means such as a threaded lock ring **28** and a keying member **30** may be employed for locking the shaft **14** in operational position. Annular cap members **32**, **32** may be connected to the standards **12** for encasing the ends of the shaft **14**. Each of the cap members **32** may be provided with suitable connecting means such as **34**, for connecting to the cap members a pair of conduit sections **36** and **38** whose function will be subsequently described.

The column **16** comprises a pair of circular plates **40** and **42** which may be integrally formed with or connected to the shaft **14** in any suitable manner. Thus, in the embodiment illustrated, the shaft **14** is formed with a pair of annular flanges **44**, and the plates **40** and **42** are secured thereto by means of the bolts **46**. The plates **40** and **42** are connected together adjacent their periphery by a cylindrical shell **48**, said shell being secured to said plates by a plurality of bolts such as **50**. A plurality of concentric perforated separator bands **52** are fixedly positioned between the plates **40** and **42**. Each band is formed with a plurality of perforations such as **53** therethrough. It is important to note, as illustrated, that the bands **52** are arranged so that the spacing between any pair thereof increases as their radii increase, for reasons which will become apparent as the description proceeds.

Formed through the separator bands **52** are a plurality of groups of aligned holes such as **54**, **56** and **58**. Removably positioned through said groups of holes **54**, **56** and **58** are rods such as **60**, **62** and **64** respectively. Each of the rods **60**, **62** and **64** is threaded at its inner end for connection to the shaft **14** in a manner which will be subsequently described. The shell **48** is also formed with a plurality of threaded openings such as **66**, **68** and **70**, each of said threaded openings being aligned respectively with one of said groups of aligned holes **54**, **56** and **58**. A threaded plug such as **72** is removably positioned in each of said openings **66**, **68** and **70**. It will thus be apparent that when desired, the plugs **72** may be removed for purposes of servicing or cleaning the interior of the column **16**. Similarly, the rods **60** or **62** may be removed and replaced by similar rods to perform an important function which will be subsequently described.

As already indicated above, the heavier liquid is generally introduced and the lighter liquid withdrawn from near the center of the column, while the lighter liquid is introduced and the heavier liquid withdrawn from near the periphery of the column. With these objects in mind, the following means may be provided. The shaft 14 is centrally bored at both ends thereof to provide a pair of axial openings 74 and 76 which terminate at points near the middle of the shaft, but are spaced apart as shown in FIG. 1 of the drawings. The axial openings 74 and 76 are formed with annular shoulders 78 and 80 respectively to afford enlarged diameter opening portions 82 and 84.

Positioned in the opening 74 is a tube 86 which is provided with a plurality of holes 88 formed in the wall of said tube adjacent the inner end thereof. A plurality of bores 90 is drilled radially in the shaft 14 with each of said bores being aligned with a respective hole 88. Each of the bores 90 is complementarily threaded to removably receive the inner end of one of the rods 60. It will thus be apparent that each of the bores communicates with the opening 74 and a rod 60. A plurality of openings such as 92 is also drilled in the shaft 14 so that the enlarged portion 82 of the axial opening 74 communicates with the center of the interior of the column 16. The conduit section 36 is provided with suitable conduits (not shown) which are aligned respectively with the tube 86 and the enlarged diameter opening 82. Attached to said conduit section 36 and communicating with said conduits is a heavy liquid inlet pipe 94 and a light liquid outlet pipe 96.

In a similar manner a tube 98 having a plurality of holes 100 adjacent the inner end thereof is positioned in the opening 76. A plurality of bores 102 is drilled in the shaft 14 with each of said bores being aligned with a respective hole 100. Each of the bores 102 is complementarily threaded to removably receive one of the rods 62. A plurality of openings such as 104 is also drilled in the shaft 14, and each of said openings 104 is complementarily threaded to removably receive one of the rods 64. The conduit section 38 is similar to the conduit section 36 and has connected thereto a light liquid inlet pipe 106 and a heavy liquid outlet pipe 108.

Referring to the rods 60, 62 and 64, it will be seen that the same are of varying construction, one from the other. Thus, each of the rods 64 is hollow throughout substantially its entire length, and has an opening 110 formed therein beyond the outermost separator band 52, or adjacent the periphery of the column 16. As indicated by the flow arrows, the heavy liquid is withdrawn from the column 16 by flowing through the openings 110 into the rod 64 and out of the heavy liquid outlet pipe 108 along the course already described. Since it is contemplated that the positioning of the openings 110 is always the same, it is apparent that the outlet position of the heavy liquid within the column 16 is always adjacent the periphery of said column. Similarly, as indicated by the flow arrows, the light liquid is withdrawn from the center area of the column 16 by flowing directly through the openings 92 and out of the light liquid outlet pipe 96 along the course previously described. Since the radial positioning of the openings 92 is constant, it is thus apparent that the outlet position of the light liquid within the column 16 is also constant.

It is important to note, however, that the rods 60 and 62 illustrated are hollow for only a portion of their respective lengths. Thus the rod 60 has an opening 112 intermediate its length but nearer to the inner end thereof, while the rod 62 has an opening 114 intermediate its length but near the outer end thereof. It is contemplated that the rods 60 and 62 may be interchanged with rods which are similar but have their openings 112 and 114 formed in varying positions along the lengths thereof. Since the openings 112 and 114 comprise the inlet openings into the column 16 for the heavy liquid and light liquid respectively, it will thus be apparent that the inlet position of both liquids may be varied at will.

The described adjustability of the input positions of the liquids renders my device adaptable for virtually any operation of the type under consideration irrespective of the physical characteristics of the liquids involved. It is well known that the area required for any two liquids to clarify or settle after the same have been mixed varies with the physical characteristics and volumetric ratios of the liquids used. It thus becomes necessary to vary the clarification area, or area where no mixing occurs, to suit the characteristics of the particular liquids being used. It should thus be apparent, that by providing for the adjustment of the position of the input openings 112 and 114 as described, I have provided a simple means for varying the clarification area.

To rotate the shaft 14 and column 16, one side of the shaft (the right side as viewed in FIG. 1) is provided with a sheave 116 upon which are mounted a plurality of drive belts 118 (see FIG. 2). Each of the drive belts 118 may be connected to a motor of different operational speed (not shown), so that the speed of rotation of the column 16 may be correspondingly controlled for purposes which will be more fully described hereinafter. It is contemplated that the operational speed ranges will be between 300 r.p.m. and 1,000 r.p.m. It should be understood, of course, that instead of the multiple motors and drive belts described, a single drive belt and motor with variable speed control gear box may be employed with equally satisfactory results.

The operation of the device may now be described as follows. The inlet openings 112 and 114 are pre-set according to the number of mixing stages and area of clarification required by the particular operation. The heavy liquid and light liquid respectively are introduced into the column 16 through said openings 112 and 114 in the manner described. The shaft 14 and column 16 are rotated at the exact pre-determined speed suitable for the particular operation. When the column 16 is thus rotated, the heavy liquid is forced outwardly by centrifugal force through the perforated bands 52. Simultaneously, the pressurized light liquid is forced inwardly through the perforated bands 52. As either liquid passes through a band 52, the same is broken up into droplets because of the plurality of perforations 53 in the band. A violent and intimate mixing of both droplet-dispersed liquids then takes place in the areas between each pair of bands 52. After both liquids have passed through all of the mixing stages, the same continue on through the pre-set non-mixing or clarification areas. The light liquid is then withdrawn from the center of the column 16 and the heavy liquid from the periphery thereof in the manner already described.

The precise manner in which the above described violent mixing of the liquids in the areas between the bands 52 occurs will now be explained. In a typical embodiment of the invention, the diameter of the column 16 might be 72 inches, so that the diameter of the outermost band 52 might be 64 inches. In such a device, the innermost band 52 would have a diameter of about 24 inches. Assuming a speed of rotation of 1,000 r.p.m., we can determine by simple well known calculations that the linear speed of a point on the outermost band 52 will be approximately 17,000 feet per minute. By the same arithmetic calculation, the linear speed of a point on the innermost band 52 will be approximately only 6,300 feet per minute. It is thus apparent that a light liquid which is introduced at the periphery of the column 16 must decelerate some 11,000 feet per minute in its passage through the column. Similarly, a heavy liquid which is introduced at the center of the column must accelerate some 11,000 feet per minute.

Generally, both liquids travel co-currently or in the same direction as they pass through the column 16. This direction of travel is of course the same as the direction of rotation of the column itself. However, it should now be apparent that as a liquid passes from one band to the next, this liquid is either accelerated or decelerated as above described. Since the passage of a liquid from one band 52 to the next takes but a short moment of time, the described acceleration or deceleration thus imparts a violent or jolting action to that liquid. In the case of the decelerating lighter liquid, the jolting action is in a direction opposed to the general direction of the liquid's travel. On the other hand, the jolting action of the accelerating heavy liquid is in the same direction as the general direction of the liquid's travel. There thus occurs a violent cross-collision between the two liquids in the area between any two bands 52.

Referring now specifically to FIG. 3 of the drawings, the reasons for increasing the spacing between the bands 52 in direct proportion to the increase in the length of their radii, rather than decreasing the same as heretofore, will now become apparent. As indicated, the outermost band 52 has a linear velocity of approximately 17,000 feet per minute. Assuming that the next band 52 is spaced about 2 inches from the outermost band (i.e., a diameter of about 60 inches), the linear velocity of a point on that band is approximately 15,000 feet per minute. It should be apparent that the greatest amount of acceleration or deceleration will occur between the two bands which are spaced farthest apart. Thus, for example, the acceleration or deceleration between the two innermost bands which may be only about .200 inch apart (see FIG. 4) is virtually negligible. Actually, in the case of the two innermost bands, the change of velocity would be about 100 feet per minute as compared to the described change of about 2,000 feet per minute between the two outermost bands. Obviously then, the most violent cross-collision and mixing will occur between the bands which are spaced farthest apart.

An additional reason for spacing the bands in the manner here described is the known fact that the centrifugal force or mixing energy imparted to the liquids is the greatest where the linear velocity is the greatest. Since the most efficient mixing of the liquids thus occurs near the periphery of the column 16, it will be apparent that the greatest possible volume of the liquids should desirably be brought into contact near the periphery of the column. In this regard, it is obvious that a much larger volume of the liquids will collide in the 2 inch space between the two outermost bands than in the .200 inch space between the two innermost bands.

As previously indicated, my device actually comprises a rotating column in which centrifugal force is used to impart mixing energy to the liquids. This being the case, I have found it desirable to utilize the gravitational forces set up in the rotating column. In this regard, the perforations in the bands 52 are considerably larger than heretofore, the same ranging in diameter or size from 3/32 (.094) inch to ½ (.500) inch. It has also been determined that for most efficient utilization of the gravitational forces, the area of the perforations in the bands should be approximately 5 to 11 times the area of the admission openings of the liquids. Thus, the innermost band may have a perforation area of about 5 times the area of the liquid admission openings, while the perforations of the outermost band may be about 11 times the area of the liquid admission openings.

From the foregoing description and drawings, it should be apparent that I have provided a novel rotating column contact device. The device is designed to most efficiently utilize the known applicable physical laws. Thus, for example, the space between the separator bands increases as their radii increase. The input positions of the two liquids may be readily varied to provide any desired area of clarification. The device employs variable speed drive means so that complete control over the mixing of the liquid may be maintained at all times. The variable speed also permits compensation for less than maximum throughput, so that maximum efficiency is always maintained. Since the device need never be operated at a speed in excess of that required, the stresses on the materials of construction are greatly reduced. Thus columns of greater diameter and volume than heretofore practicable may be safely and efficiently employed. Similarly, a longer life for the rotating members themselves is thereby assured.

It is believed that my invention, its mode of construction and assembly, and many of its advantages should be readily understood from the foregoing without further description, and it should also be manifest that while a preferred embodiment of the invention has been shown and described for illustrative purposes, the structural details are nevertheless capable of wide variation within the purview of my invention as defined in the appended claims.

What I claim and desire to secure by Letters Patent of the United States is:

1. A rotating column contact device for effecting intimate contact between relatively immiscible liquids of different densities comprising; a rotor, means for supplying heavier liquid to and means for removing lighter liquid from the interior of said rotor adjacent the axis thereof, means for forcing lighter liquid into and means for discharging heavier liquid from the interior of said rotor adjacent the periphery thereof, a plurality of spaced concentric separator bands positioned in said rotor, each of said bands being formed with a plurality of openings therethrough, the spacing between adjacent bands increasing as their radii increase.

2. The device of claim 1 in which the size of said openings are from .094 to .500 inch in diameter.

3. The device of claim 1 in which said first means includes a heavier liquid inlet hole and said third means includes a lighter liquid inlet hole, and the total area of the openings in each of said bands is from 5 to 11 times the total area of said inlet holes.

4. The device of claim 3 in which the total area of the openings in the innermost of said bands is 5 times the total area of said inlet holes and the total area of the openings in the outermost of said bands is 11 times the total area of said inlet holes.

5. The device of claim 1 in which said first means and third means include a heavier liquid inlet hole and lighter liquid inlet hole respectively, and means for readily changing the position of said inlet holes relative to the axis and periphery of said rotor.

6. The device of claim 5 in which said last-mentioned means includes portions of said separator bands having a plurality of groups of aligned holes formed therein and portions of the periphereal shell of said rotor having a plurality of service openings formed therein one in alignment with each of said groups of aligned holes, a service plug removably closing each of said service openings, and a plurality of rods each of which is removably positionable in one of said groups of aligned holes, said inlet holes being formed in said rods at varying positions relative their length.

7. In a rotating column contact device for effecting intimate contact between immiscible or partially immiscible liquids of different densities including a rotor and means for introducing a heavier and lighter liquid into and removing said liquids from the interior of said rotor; said heavier liquid being introduced and said lighter liquid being removed in the proximity of the rotor axis and said lighter liquid being introduced and said heavier liquid being removed in the proximity of the periphery of the rotor; a plurality of spaced concentric bands positioned in said rotor, each of said bands being formed with a plurality of openings therethrough, the spacing between adjacent bands increasing as their radii increase.

8. The device of claim 7 in which said openings have a dimension of from .094 to .500 inch.

9. A rotating column contact device for effecting intimate contact between immiscible or partially immiscible liquids of different densities comprising, a cylindrical rotor including a central shaft, means including a heavier liquid inlet hole for supplying heavier liquid into said ro-

tor adjacent the axis thereof, means including a lighter liquid inlet hole for forcing lighter liquid into said rotor adjacent the periphery thereof, means for readily adjusting the positions of said inlet holes relative to said axis and periphery respectively, means for removing said lighter liquid from said rotor adjacent the axis thereof, means for discharging said heavier liquid from said rotor adjacent the periphery thereof, a plurality of spaced concentric separator bands positioned in said rotor, the spacing between adjacent bands increasing as their radii increase, each of said bands being formed with a plurality of openings through which, on rotation of the rotor, the liquids pass and are dispersed into droplets, said openings having a dimension of from .094 to .500 inch, and variable speed drive means connected to said shaft for ro-

tating said rotor, said drive means adapted to operate at speeds of from 300 to 1,000 revolutions per minute.

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