Jan. 3, 1956 G. H. REMAN ET AL 2,729,545

CONTACT APPARATUS WITH ROTATING DISCS

Filed Sept. 13, 1951 2 Sheets-Sheet 1

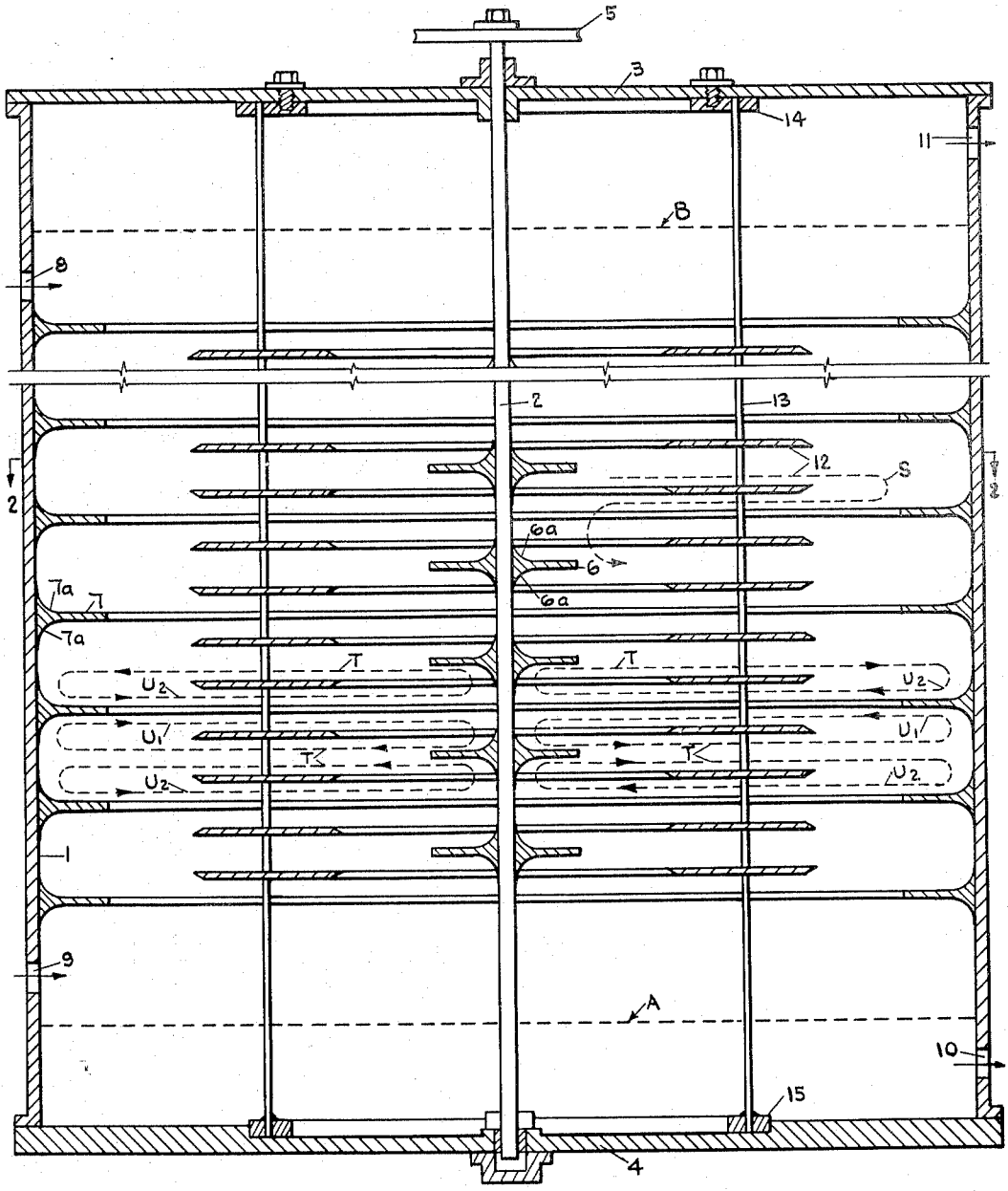


Fig.1

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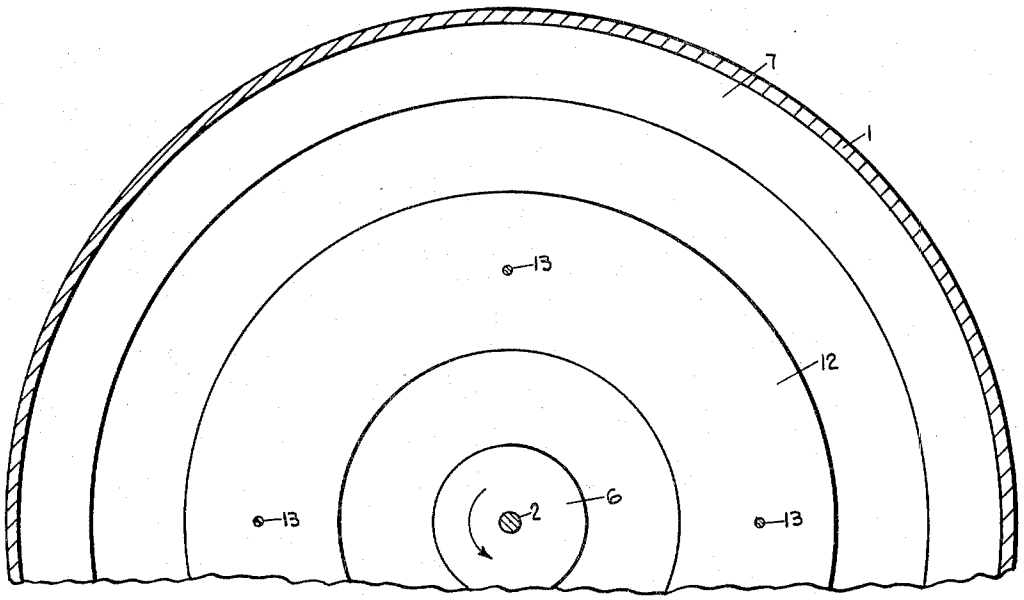


Fig. 2

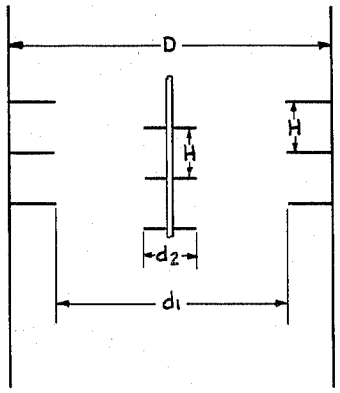


Fig. 3

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2,729,545

CONTACT APPARATUS WITH ROTATING DISCS

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Application September 13, 1951, Serial No. 246,488

Claims priority, application Netherlands September 20, 1950

8 Claims. (Cl. 23—270.5)

This invention relates to contactors for intimately contacting two or more fluent phases that are at least partially immiscible, e. g., immiscible or partially miscible, the contactor being of the type described in the U. S. Patent No. 2,601,674 to Reman, one of the joint inventors herein, to which reference may be had for further details. Such apparatus is suitable for effecting intimate contact between fluent materials conducted through the device either concurrently or countercurrently and may be applied, for example, to solvent extraction of liquid mixtures, such as mineral or fatty or essential oils, with one or more selective solvents, or for bringing reagents into intimate contact when carrying out chemical reactions, such as reactions between higher olefins and sulfuric acid. The fluent materials or phases are, as a rule, fluids, for example, a pair of liquids or a liquid and a gas; one of the phases may, however, be a solid phase, such as finely comminuted solid.

Briefly, such contacting devices comprise a stationary tube or shell which is at least partly upright, is provided with inlets and outlets for fluent materials, and is subdivided into a plurality of compartments, which may be substantially identical in size and shape, by stationary annular baffles or rings extending to the tube wall and having central openings at the tube axis; each compartment has at least one rotor disc and the several rotor discs are fixed to a common rotor shaft which is coaxial with the tube, the rotor discs being preferably located to be substantially at the centers of the respective compartments. Such a device will herein be referred to as a contactor of the character described.

When the fluent materials are admitted to the tube either at the same end or at opposite ends, and are withdrawn at ends opposite to their respective points of introduction, they flow successively through the contacting compartments and form separate phases therein. Rotation of the rotor shaft and discs thereon imparts a further movement to the phases, which is important for effecting intimate contact between them: The rotor discs cause the phases to rotate about the tube axis and the resulting centrifugal force induces the phases at the level of the discs to move radially outwardly along a somewhat spiral path toward the tube wall; upon reaching the latter the fluent material changes direction, one part moving upwards, the other downwards, and returns toward the axis as two currents within each compartment, in the neighborhood of each stationary baffle. Hence, the motion of the phases, apart from their flow through the successive compartments, is generally toroidal, forming vortex patterns.

The aforesaid patent describes a contactor of the character described wherein the rotor discs are flat, circular discs fitted normal to the rotor shaft approximately midway between the stationary baffles or stator rings which are likewise flat, the diameters of the rotor discs being less than the diameters of the central openings in the baffles of the respective compartments. Moreover, certain preferred dimensional relations between the internal

diameter of the tube, the diameter of the central openings and the intervals between the baffles are set forth.

The present invention is particularly concerned with increasing the capacity of contactors of the character described by using tubes having diameters in excess of half a meter. When such greater tube diameters are used certain difficulties, largely of a mechanical nature, arise owing to the great length and/or the great diameter of the rotor discs when constructed according to the dimensional relations given in the aforesaid patent application. It then becomes necessary to rotate a large mass in which the centrifugal forces, forces of inertia, and vibrations (principally torsion vibrations and bending vibrations) begin to play an important part so that special provisions has to be made as regards the driving mechanism, the strength and the bearing supports for the rotor shaft. Also, the fluent materials moving from the rotor shaft to the tube wall flow over great radial distances countercurrently to the material that is returning from the tube wall toward the rotor and under some circumstances these currents interfere with one another, and/or result in intermingling of materials that cause instability in the vortex pattern.

Surprisingly, it has now been found that with tube diameters in excess of half a meter the optimum results of contactors of the character described is not always attained when the dimensioned relations are those given in the aforesaid patent. For larger columns of greater capacities the best results, for example in solvent extraction, are obtained when the individual compartments defined by the stationary annular baffles are relatively shallower, i. e., wherein the ratio of the internal diameter of the tube to the spacing of the baffles is somewhat greater. It has further proved possible to employ rotor discs having considerably smaller diameters than those specified in the earlier patent without appreciable decrease in the effectiveness of the contactor.

In summary, according to this invention, contactors of the character described having internal diameters in excess of half a meter, are constructed in accordance with any of the structural details disclosed in the said earlier patent, optionally with additional guide rings to be described herein, and again using a rotor disc having a diameter smaller than the diameter of openings in the stationary baffles, but wherein the other dimensional relations are such as to satisfy at least one and, preferably, both of the following requirements: First, the ratio of the internal diameter of the tube to the diameter of the rotor disc is greater than 5, e. g., between 5 and 10. Second, the ratio of the internal diameter of the tube to the axial interval between the baffles is at least equal to the quantity $(2+2.5D)$, but always greater than 8, and not greater than the quantity $(5+7.5D)$, wherein D is the internal diameter of the tube measured in meters. Summarizing these three relations, the preferred construction satisfies the following:

$$d2 < d_1 \tag{1}$$

$$\frac{D}{d_2} > 5 \tag{2}$$

$$\left.\begin{aligned} 2+2.5D \leq \frac{D}{H} \leq 5+7.5D \\ \frac{D}{H} > 8 \end{aligned}\right\} \tag{3}$$

wherein D is the internal diameter of the tube in meters: d_1 and d_2 are the diameters of the central opening in the stator baffles and of the rotor discs, respectively; and H is the interval between the baffles, all as indicated in Fig. 3. These relations should, preferably, apply throughout the contactor, even when the dimensions are not uniform throughout the column, except in compartments

wherein the diameter of the rotor is decreased and/or the interval H is increased to take care of peak liquid loads as explained in the aforesaid earlier patent. Thus, when the tube diameter D is not the same at all compartments, the above formulae are to be applied to each compartment.

The result of this selection of ratios is that, while the number of theoretical steps or contacting stages for an extraction is maintained, the rotor can be constructed shorter and the rotor discs kept relatively smaller despite an increase in the column diameter. It is now no longer necessary to accelerate or brake large masses; requirements may be made less exacting as regards the bearings of the rotor shaft; the centrifugal forces and forces of inertia remain small, thereby simplifying the balancing of the rotor; and vibrations, as a rule, no longer present a problem. If the rotor discs are given relatively smaller diameters in relation to the tube or shell diameter, the angular velocity of the rotor will, in general, be increased, approximately to the same degree that the rotor disc diameter is decreased, so as to maintain, about the same peripheral speed.

Just as it is possible to make the rotor discs relatively small in diameter, so it is also possible to keep the annular stator baffles comparatively narrow, as the latter serve principally to maintain the vortex pattern generated in the contactor by rotation of the rotor and to prevent the drops of the heavy phase from flowing down the wall of the tube or shell. There are limits, however, to the degree to which the rotor disc diameter and the width of the stator baffles can be reduced: if progressively greater dimensions are chosen for the free space between the rotor discs and the stator baffles (viz., the difference between the diameters d_1 and d_2), the vortices generated by rotation of the rotor can exercise an increasingly undesirable influence on each other, mainly through intermingling, which may cause instability in the vortex pattern. This action is especially troublesome in contactors of large diameters wherein the vortices move through relatively greater radial distances.

According to a further feature of the invention, one or more flat, annular guide rings are fitted within each compartment in the free space between the rotor discs and stator baffles. In the preferred arrangement two guide rings are provided in each compartment, one above and one beneath the rotor disc, each ring being situated approximately midway between the rotor disc and its neighboring stator baffle. The dimensions of the guide ring are advantageously such that their outer diameters are less than the diameters of the openings in the stator baffles (whereby the guide rings can be moved up and down without disturbing the stator baffles) and/or such that diameters of their openings are greater than the diameters of the rotor discs (whereby the rotor can be moved vertically through the openings). In the arrangement to be described in detail both of these conditions are satisfied, it being understood that such an arrangement is not essential. The guide rings consist, as a rule, of flat, thin sheets. They can, for instance, be attached to a number of vertical rods which may be streamlined if so desired.

While the guide rings are of especial advantage in large diameter contactors wherein small rotors and/or narrow annular stator baffles are used, it should be noted that they may also be applied in other contactors of the character described. It should be noted that the presence of the guide rings does not reduce the effective contact surface between adjacent vortices.

The invention will be further described with reference to the accompanying drawing forming a part of this specification and illustrating a preferred embodiment, wherein:

Fig. 1 is a central section on a vertical plane;

Fig. 2 is a fragmentary transverse section taken on line 2—2 of Fig. 1; and

Fig. 3 is a diagram indicating the important dimensions.

Referring to the drawings in detail, a vertical column or tube of circular cross section and cylindrical shape is indicated at 1. A coaxial rotor shaft 2 is journalled in suitable bearings mounted in the top and bottom closures 3 and 4 and has drive means, such as a pulley 5 by which it may be rotated by a belt, not shown. A plurality of circular, imperforate rotor discs 6, made of thin, flat sheet metal, are fixed to the rotor shaft for rotation therewith with their plane surfaces perpendicular to the shaft axis. The inner margins of the discs may, if desired, be curved to provide annular concave fillets 6a above and below the discs. The inner wall of the column is equipped with annular horizontal stator rings or baffles 7, likewise made of thin, flat sheet metal, but having circular openings concentric with the rotor shaft and discs. The baffles may be thickened slightly at their extreme outer margins to provide annular concave fillets 7a adjacent the column wall, both above and beneath the baffles. The stator baffles thereby subdivide the column into a vertical series of compartments, the height of which is determined by the vertical intervals between baffles. These intervals may be uniform throughout the height of the column, but also may be non-uniform, as shown in Fig. 7 of the aforesaid earlier patent. Suitable inlets and outlets for the fluent material are provided; when the column is intended for countercurrent contacting the inlets 8 and 9 are at the top and bottom, respectively, being advantageously located beyond the stator baffles but displaced somewhat in from the ends of the column, while the outlets 10 and 11 are located near the extreme ends of the column.

Considering next the dimensions, reference is made to Figure 3 to designate the symbols D, the internal column diameter, H, the vertical interval between baffles or height of compartment, d_1, the internal diameter of the stator baffles, and d_2, the diameter of the rotor discs. According to this invention, d_2 is less than d_1 and D exceeds 50 cm. In the embodiment illustrated in Figs. 1 and 2 the ratio $D:d_2$ is 6–4 and the ratio $D:H$ is 10.1. As was noted previously, it is desirable to make the former ratio greater than 5; usually ratios close to 5, e. g., 5–7, are used with columns of about 50 cm. in diameter and somewhat higher ratios may be employed with columns having greater diameters, e. g., up to 10, for columns in excess of one meter in diameter. Hence, when the column diameter is approximately 50 cm., it is desirable to use a rotor disc that is not larger than about 10 cm. in diameter; when the column diameter is, for example, 2 meters the diameter of the rotor discs would be between 20 cm. and 40 cm. The ratio $D:H$ would, in accordance with Equations 3, lie between 8 and 20 for a column having an internal diameter of 200 cm.

Regarding the choice of the ratio $D:H$, it may be said that for achieving optimum effectiveness in the column (measured, for example, by highest "total efficiency," which is the product of the maximum load, as hereinafter defined, and the efficiency of the extraction of each compartment) the best ratio will depend upon the nature of the fluent materials to be contacted. Since it is desired to provide the greatest number of compartments or contacting stages in a given column consistent with maintaining contacting efficiency, H will be made as small as feasible and the ratio $D:H$ as high as possible. With systems that are difficult to extract, such as the system methyl isobutyl ketone-water-acetic acid (e. g., wherein acetic acid is extracted from solution in methyl isobutyl ketone using water as a selective solvent) this ratio would be near to the value $(2+2.5D)$, but not less than 8. For systems that are easy to extract, such as the system kerosene-water-butyl amine (e. g., wherein butyl amine is extracted from solution in kerosene using water as a selective solvent) the ratio will be near to the value $(5+7.5D)$. For example, a ratio of 10 would be usual for a column 70 cm. in internal diameter intended for

extracting systems that are difficult to extract, whereas this ratio would be applied with systems that are easy to extract to columns with diameters exceeding 150 cm.

The widths ofthe annular stator baffles 7 may be selected as desired to make d_1 greater than d_2. Typically, these annular baffles extend radially in from the column wall for a distance from about 5 to 20 cm. In the embodiment illustrated, which is intended to illustrate a column with an internal diameter of 2 meters, these rings are 15 cm. in width, leaving a free radial space of about 70 cm. between the rotor discs and the inner margins of the stator baffles.

In order to prevent, under all circumstances, instability of the vortex system generated in the compartments, particularly when large free radial spaces such as noted in the foregoing paragraph are provided, a system of guide rings **12** is desirable. These rings are made of thin, flat sheet metal, supported on vertical rods **13** that are fixed to upper and lower support rings **14** and **15**, which are secured to the upper and lower closures in any suitable manner. Two guide rings are preferably mounted in each compartment, one above and one below the rotor disc thereof, the rings being centered about the rotor shaft and normal thereto and situated approximately vertically midway between the rotor disc and the neighboring stator baffle. The inner and outer diameters of the guide rings are advantageously such as to cover an annular area that includes a circle radially midway between the rotor discs and the stator baffles. It is desirable to center the rings radially between the rotor discs and stators and to cover at least a fourth of the free area, but it is not necessary that they extend over the entire free area, nor that they be located entirely within the free area. In the contactor shown, wherein the column diameter is 200 cm., the guide rings may be 30 cm. in width, as shown, the width being half the difference between the said inner and outer diameters of the rings; the width may, however, be more, for example 50–70 cm. For practical reasons, including ease in assembling and disassembling the contactor, the width should not exceed 70 cm., the width of the free space.

Operation

In operating the contactor, the fluent materials may be admitted and contacted either intermittently or continuously, either concurrently or countercurrently. In operating the contactor for countercurrent extraction heavy and light materials are introduced at the top and bottom through inlets **8** and **9**, respectively, the contactor can be operated either so that the light phase or so that the heavy phase is the continuous phase, the other phase being the dispersed phase. When the light phase is to be continuous the column is initially filled with light phase; thereafter the heavy material is introduced at the top and dispersed by the rotor discs, passing downwardly by gravity from compartment to compartment and collecting at the bottom to form a layer of settled heavy phase below the level A. By regulating the rates of feed and drawoff of the heavy phase through the outlet **10** by a suitable valve, not shown, the interface between light and heavy phase is maintained at the level A. On the other hand, when the light phase is to be dispersed the column is initially filled with heavy phase and the interface is maintained at the level B near the top of the column by similarly regulating the flow rates and the rate of discharge of heavy phase.

In man cases it is preferable to operate the contactor with the interface at the lower level A, with the heavy phase dispersed, because a higher maximum load can often be attained thereby for any given rotor speed than when the light phase is dispersed. "Load" denotes the total amount of light and heavy phases passing through a compartment in unit time, and "maximum load" denotes the load at which flooding occurs at a given rotor speed. Flooding occurs when the rotor speed is too high for given rates of introduction of materials. Thus, as the speed of the rotor is increased, the particles become more finely dispersed and tend to settle more slowly, so that there results improved contacting and decreased capacity. If the speed of the rotor is too high or the liquids are fed into the column too rapidly the phases do not settle rapidly enough and the column floods. In a contactor of the type described, wherein all compartments are of identical construction and when the phases are such that there is no substantial change in the volumes and compositions of the phases, the flooding limit is reached practically simultaneously in all compartments as the load is increased (keeping the phase ratio and the rotor speed constant).

When light and heavy partially immiscible fluent materials are introduced into the column they form light and heavy phases, consisting predominantly of the light and heavy initial materials, respectively, but one or both of these phases contains some solute dissolved out from the other material. In countercurrent extractions it is desirable that these resulting phases have a minimum density difference of 0.02 gram per cubic centimeter; however, it is easier to operate the column with phases having greater density differences, e. g., 0.08 gram per cubic centimeter.

The operation of the contactor will now be described as applied to the extraction of a light hydrocarbon oil forming the continuous phase with a heavier solvent, such as furfural or aqueous phenol, forming the dispersed extract phase. The column having been initially filled with oil, the heavier solvent is introduced continuously at the top and oil is introduced continuously at the bottom while rotating the rotor shaft and discs, resulting in a fine dispersion of the solvent in the oil, particularly at the levels of the rotating discs. The finely dispersed droplets constitute the extract or solvent phase, which is collected at the bottom and withdrawn through outlet **10** at a controlled rate to maintain the interface at A. The continuous oil phase rises through the column and dispersed extract phase settles from it at the level above the inlet **8**. The oil is then withdrawn through outlet **11**, which is preferably fully open to permit discharge of oil at the rate determined by the oil feed rate.

The mechanism of dispersion and intimate contact within the contactor compartments may be described as follows: When the contactor is in operation there is, in the first place, a countercurrent flow through the column of light and heavy phases, caused by difference in densities of the phases. The rotation of the rotor discs imparts a rotary movement to the phases in contact therewith, and thereby sets up centritugal forces which induce flow of the phases from the rotor shaft toward the column wall at the levels of the rotor discs, indicated by the dotted lines T in Fig. 1; this, in turn, displaces the phases near the column walls and causes flow in the neighborhood of the stationary baffles from the column walls inwardly toward the rotor shaft, as indicated by the dotted lines U_1 and U_2. The flow of the phases resulting from the rotation of the rotor discs causes one of the phases to be reduced to a very fine state and dispersed because of the shearing stresses accompanying this flow. The two movements of the phases described are superimposed. Hence, for the schematic picture of the flow of the phases we have a gravity settling of heavy drops in an ascending stream of light phase superimposed on a toroidal flow, which is for the greater part in a horizontal direction. This toroidal flow causes local recirculation of both liquids within each compartment (indicated schematically in Fig. 1 by the joining of the lines U_1 and U_2 with the line T) and only portions of the liquid taking part in this flow pass on to the next compartment by gravity. The path of the dispersed droplets of the heavier, extract or solvent phase which pass to the next compartments is indicated in Fig. 1 by dotted line marked S.

It is evident that the stream of dispersed solvent phase is, in each compartment, caused to move in a direction

toward the column wall where there is less turbulence; there this stream shows a tendency to become more coarsely dispersed. However, the stream is forced by the stationary baffles 7 to change its direction and is eventually—partly owing to the pumping action of the rotating discs—once again drawn to the center of the column, to be again driven to the wall by the next lower rotor disc. From the drawing it is evident that the dispersed extract phase crosses the ascending stream of oil both at the level of the rotor discs and near the stator baffles, thereby causing intensive extraction.

It will be noted that the guide rings **12** are located to separate each outward current T from the adjacent inward current U_1 above it and the adjacent inward current U_2 below it. This reduces or prevents intermingling of the streams and aids in stabilizing the toroidal vortices. Further, the fillets *6a* and *7a* assist the streams in effecting smooth changes in flow directions.

The speed of rotation of the rotor discs is preferably such that the extract phase remains dispersed throughout the column, in the less turbulent parts near the column wall as well as near the rotor discs, except, of course, in the settling zones at the ends of the column. The contactor is, therefore, not of the type having a number of successive mixing and settling stages. However, coalescence and redispersion of the dispersed droplets may occur at one or more intermediate compartments under certain conditions, and the invention is not limited to operations wherein such coalescence is avoided. It is desirable to operate the rotor at the maximum speed that can be attained without causing flooding. Typical rotor speeds are of the order of one thousand to several thousand revolutions per minute; the exact speed will depend upon the dimensions of the column and upon the properties of the fluent materials, especially the surface tension, and can be readily determined in any particular instance by operating the column at ever increasing speeds until flooding occurs, and then reducing the speed somewhat below the flooding speed.

For further examples of the application of the contactor and modifications to take care of greater liquid loads in certain compartments, reference is made to the aforesaid earlier patent.

A contactor of the character described provided with the fillets *6a* and *7a* is the subject of a patent application Ser. No. 245,507, filed September 7, 1951, by Pieters, one of the joint inventors herein.

We claim as our invention:

1. A rotating disc contactor comprising a tubular shell; a plurality of annular, stationary baffles fixed within said shell extending from the shell wall to central openings and dividing said shell into a series of communicating compartments; a rotor shaft extending axially with respect to said shell through said openings; a plurality of rotor discs fixed to said shaft, each disc being wholly within one of said compartments and displaced axially a substantial distance from the stationary baffles thereof and extending radially outwards toward but terminating short of the wall of said shell; at least one flat guide ring in a compartment, said ring having an outer periphery materially smaller than the internal size of the shell and an inner opening materially greater than the size of the shaft and being spaced axially from and situated between the rotor disc and a stationary baffle of the compartment; means for introducing and discharging fluent materials at axially displaced points in said shell; and means for rotating said rotor shaft and rotor discs.

2. A contactor according to claim 1 wherein there are two guide rings in the compartment on opposite sides of the rotor therein.

3. A contactor according to claim 1 wherein the rotor disc in each compartment is smaller than the opening in the guide ring and the opening in the stationary baffles of the respective compartment and of all compartments toward one end of the shell, whereby said shaft and rotor discs can be moved axially through said openings toward said end of the shell.

4. A contactor according to claim 1 wherein the guide rings are connected together by support means interconnecting adjoining guide rings and the guide rings in each compartment are smaller than the openings in the stationary baffles of the respective compartment and of all compartments toward one end of the shell, whereby said guide rings can be moved as a unit through said openings in the stationary baffles toward said end of the shell.

5. A contactor according to claim 1 wherein the stationary baffles, rotor discs and guide rings are substantially flat and lie in planes substantially perpendicular to the axis of the rotor shaft, each rotor disc being substantially midway between neighboring stationary baffles and each guide ring being substantially midway between a rotor disc and a neighboring stationary baffle.

6. A rotating disc contactor for countercurrently contacting at least partially immiscible fluent materials comprising an at least partially upright, circular, cylindrical column with an internal diameter greater than half a meter; a plurality of substantially flat annular, stationary baffles fixed within said column perpendicular to the axis of the column and extending from the column wall to central circular openings and dividing said shell into a series of intercommunicating compartments; a rotor shaft extending coaxially with said column and through said openings; a plurality of circular, substantially flat rotor discs fixed to said shaft perpendicularly to the shaft axis, each of said discs being located approximately in the center of a compartment between the stationary baffles thereof, said rotor discs having diameters less than the diameters of the openings in the stationary baffles so as to leave an intervening free area; a pair of circular, thin, substantially flat guide rings within each compartment on opposite sides of the rotor disc therein, each guide ring having an external diameter materially smaller than the internal diameter of the column and a central opening with a diameter materially greater than the diameter of the rotor shaft and covering at least a fourth of the said free area, each guide ring being situated axially midway between a rotor disc and a neighboring stationary baffle; inlet means for introducing fluent material at different levels into the column; outlet means for discharging fluent material at different levels; and means for rotating said rotor shaft and rotor discs.

7. A contactor according to claim 6 wherein the ratio of the internal diameter of the column to the distance between the stationary baffiles defining a compartment is at least equal to the quantity $(2+2.5D)$ and greater than 8 but not greater than the quantity $(5+7.5D)$, wherein D is the internal diameter of the column measured in meters.

8. A contactor according to claim 6 wherein the ratio of the internal diameter of the column to the diameter of the rotor disc in at least the majority of the compartments is greater than 5.

References Cited in the file of this patent

UNITED STATES PATENTS

1,208,534	Foret	Dec. 12, 1916
2,091,645	McConnell	Aug. 31, 1937
2,273,660	Poole	Feb. 17, 1942
2,601,674	Reman	June 24, 1952