June 24, 1952 G. H. REMAN 2,601,674

LIQUID CONTACT APPARATUS WITH ROTATING DISKS

Filed June 13, 1949 2 SHEETS—SHEET 1

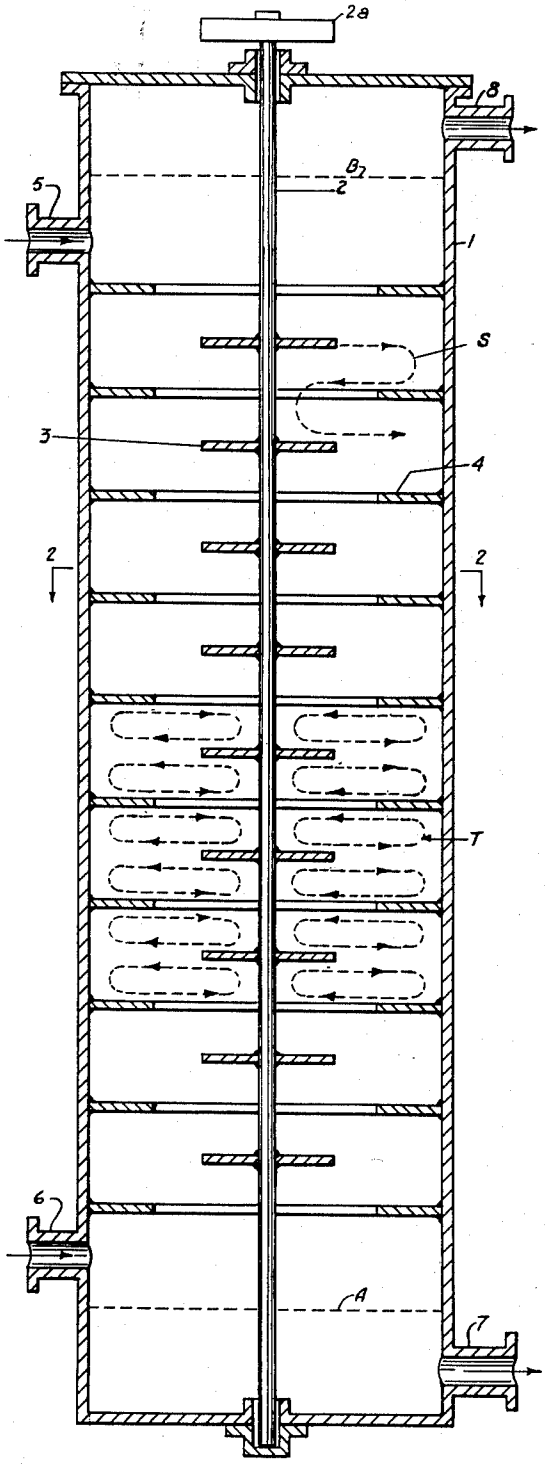


Fig. 1

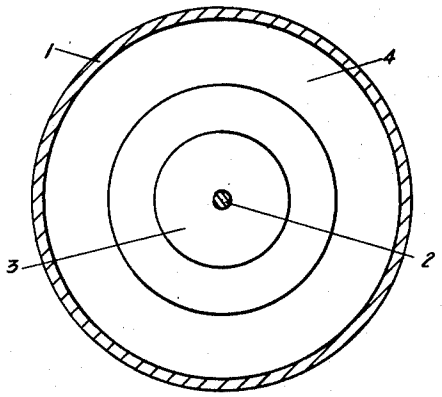


Fig. 2

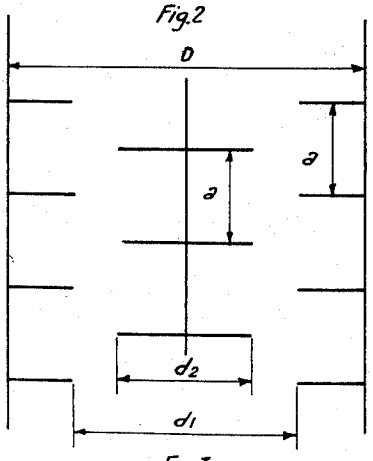


Fig. 3

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LIQUID CONTACT APPARATUS WITH ROTATING DISKS

Filed June 13, 1949 2 SHEETS—SHEET 2

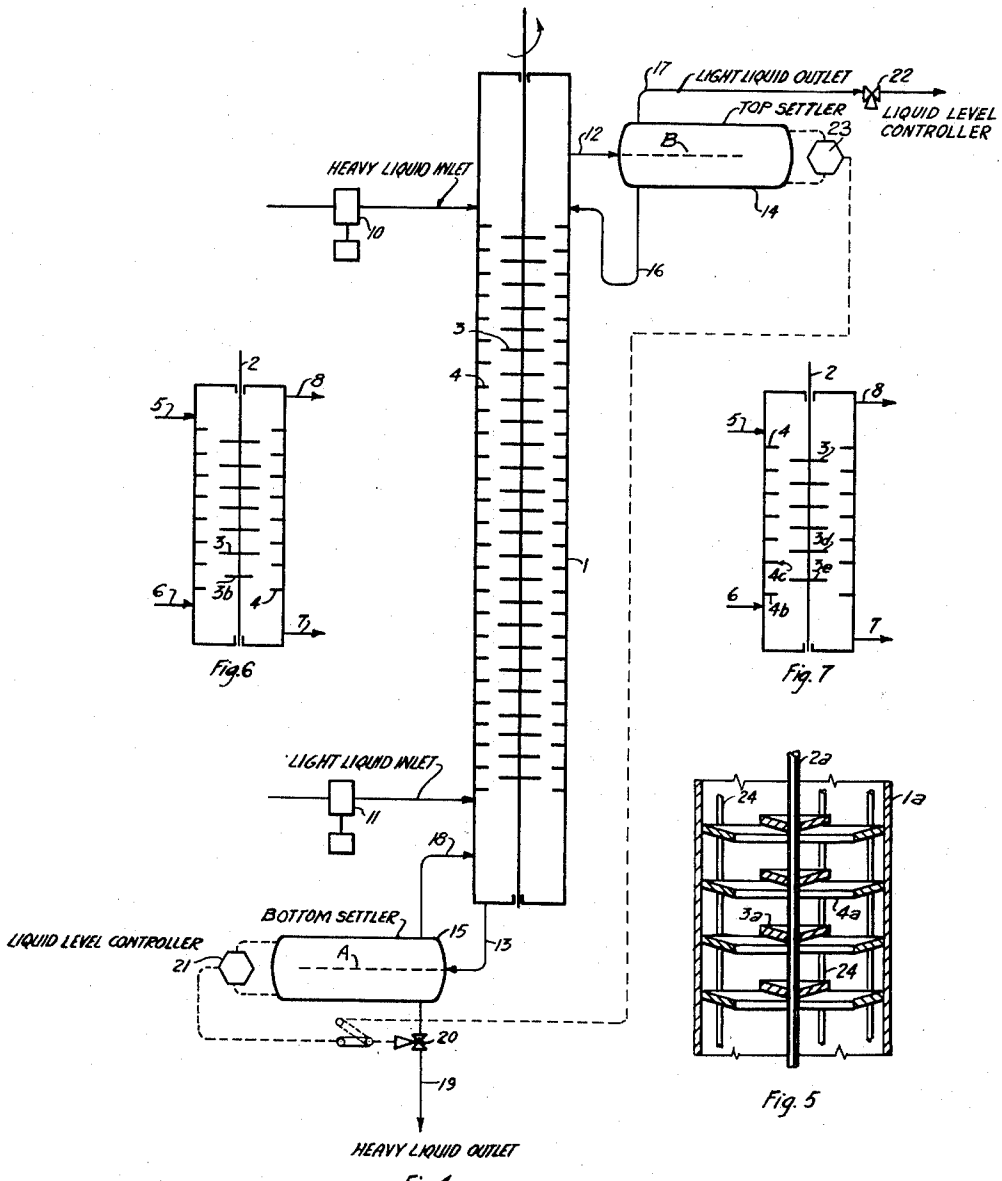


Fig. 4

Fig. 6

Fig. 7

Fig. 5

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UNITED STATES PATENT OFFICE

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LIQUID CONTACT APPARATUS WITH ROTATING DISKS

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14 Claims. (Cl. 23—270.5)

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The invention relates to a contactor for intimately contacting two or more liquids that are at least partially immiscible, e. g., immiscible or partially miscible, so as to form two liquid phases when in contact with each other, the contactor being of the type having a plurality of discs mounted on a rotating shaft within a stationary shell having fixed baffles. Such apparatus is suitable for effecting intimate contact between liquids flowing through the shell in the same direction or in countercurrent and may be applied, for example, for the solvent extraction of liquid mixtures, such as mineral or fatty or essential oils with one or more selective solvents, or for causing intimate contact between reagents when carrying out chemical reactions, such as reactions between higher olefins and sulfuric acid.

The contactor of the present invention, briefly, comprises a stationary tube or shell of which the part forming the actual contacting zone is subdivided into a plurality of compartments, preferably substantially identical in size and shape, by stationary annular baffles or rings having central openings. Further, there are rotor discs, one in each compartment, fixed on a rotor shaft coaxial with the stationary tube, the discs being located approximately halfway between the stationary baffles. The liquids to be contacted are fed into the contactor to traverse the several compartments successively, either in a common direction or in countercurrent to one another. When used for countercurrent flow of liquids, the tube is at least partly upright, e. g., vertical, and the liquids are of different densities; this results in the formation of two liquid phases of different densities which traverse the successive compartments in opposite directions. The rotation of the rotor discs imparts a further, even more important, movement to the liquid, causing intimate contacting, as will appear from the following description. The important novel features of the device according to the invention reside in the arrangement of the discs and stators. The diameter of the rotor discs is smaller than the diameter of the opening in the stator baffles. Further optional improvements reside in the relationship between the diameter of the stationary tube and the diameter of the rotor discs and the axial interval between the baffles, and also in the shapes of the stator baffles and discs, as will be described.

It is already known that extractions can be carried out in a vertical column containing a vertical rotor shaft fitted with a number of rotor discs or baffles and annular stator rings fixed to the column. (See, e. g., U. S. Patent No. 1,845,128.) According to the known constructions the diameter of the rotor baffles is appreciably greater than the inner diameter of the stator rings to bring the surfaces of the rings and rotor baffles facing each other, which has heretofore been regarded as important for creating shear between the liquids for effective contacting. This arrangement made it difficult to assemble and disassemble the apparatus because the rotor and the attached rotor baffles could not be moved through the central holes in the stator rings. Moreover, contacting efficiencies were not as great as can be realized with the contactor of the present invention.

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Also, in such prior contactors the rotor discs were provided with irregularities, such as perforations, stirrers, and radial fins or ribs for the purposes of insuring a more positive agitation of the liquids when the discs were rotated; further, the edges of the rotor and/or stator rings were flanged. These arrangements resulted in turbulence and random eddy currents, whereby a marked divergence in the sizes of the dispersed droplets of the liquid was brought about. Thus, when the liquids are subjected to the agitating action of the irregularly-shaped rotating discs and the stator, resulting in the dispersion of one liquid in the other, the particles of the dispersed liquid vary greatly in sizes; this results in an unsatisfactory extraction.

It is an object of the present invention to provide an improved rotating disc contactor which has a higher contacting efficiency than those known heretofore, and which can be more conveniently assembled and disassembled.

A further object is to provide a rotating disc contactor wherein the rotor and stator baffles are shaped to promote a greater homogeneity in the sizes of the dispersed droplets, thereby to improve the extraction.

Still another object is to provide a contactor which will operate at high efficiency over a wide range of phase ratios; and to provide a contactor which can be easily adapted to handle different liquid loads in different parts of the apparatus.

According to the invention it was found, contrary to the prior views, that a more efficient contactor results when the rotor discs have diameters smaller than the diameter of the hole in the stator baffles, so that the surfaces of the rotor and stator baffles are not opposite each other. Further, it was found to be advantageous to form these baffles with smooth, preferably plane surfaces, to avoid random turbulence, thereby, promoting homogeneity in the sizes of the dispersed droplets.

The contactor according to the present invention comprises an outer shell which should, when countercurrent extraction is to be practiced, be at least partially upright, e. g., vertical; prefer-

ably, it is circular in cross-section and has cylindrical walls, although the invention contemplates within its scope the use of shells of other shapes. The shell or column has fitted within it a series of annular, stationary, transverse stator baffles extending from the shell wall radially inwardly to a central opening thereby dividing the shell into a series of compartments in communication with one another. The stator baffles are preferably imperforate except for the central opening and are flat or substantially so, whereby each baffle has two substantially plane surfaces perpendicular to the shaft axis. The use of stator baffles of other outlines, e. g., frusto-conical surfaces of revolution, is possible. They may be permanently fixed to the shell wall or removably mounted in any desired manner, e. g., by being fixed to a removable cage or frame, and spaced axially with respect to the shell. The intervals between the baffles, i. e., the lengths of the compartments, may be uniform, but may be varied in certain cases, as to take care of peak liquid loads as will be explained. These stator baffles are provided throughout the part of the shell that is to serve as the actual contacting or extraction zone; this may but need not extend over the full length of the shell. Liquid inlet and discharge ports are provided at suitable points, e. g., at the ends of the shell; if desired, additional ports may be provided at one or more intermediate points for the admission or discharge of liquid.

A rotor shaft is rotatably mounted substantially coaxially with the shell, and is provided with suitable drive means for rotation at a high speed. It extends through the openings in the stator baffles, and carries a plurality of rotor discs or baffles arranged so that there is one rotor baffle within each compartment, approximately midway between adjacent stator baffles. While flat discs are preferred, the invention is not limited thereto, and other surfaces of revolution may be used. The diameter of each rotor baffles are less than the diameters of the central openings within the stator baffles defining the compartment containing the rotor baffle. When, as in the embodiment illustrated, a cylindrical shell is used and the stator baffles are of equal dimensions, the rotor baffles are all of lesser diameter than the diameter of the opening in the stator baffles. By this arrangement the extraction efficiency is improved, and the above-mentioned difficulties in assembling and dismantling the apparatus are avoided, it being possible to remove the rotor shaft and rotor baffles through the openings in the stators. When the stators are not all of the same size, they may be arranged with openings becoming progressively larger toward one end, thereby still permitting free movement of the shaft and rotor baffles through the openings.

The invention, further, comprises other features bringing about added and marked improvement in the contacting efficiency, such features being of utility when applied in conjunction with the contactor described above, but which may be separately applied to such a contactor. The first of these features relates to the relative dimensions of the shell and rotor baffles. It was found that best results are obtained when the ratio of the internal diameter of the shell to the diameter of the rotor baffles is from about 1.5 to and including about 3.0. According to a second feature, it was found that best results are obtained when the ratio of the internal diameter of the shell to the axial interval between the baffles is from about 2 to and including about 8. Summarizing the three optimum dimensional relations:

$$d_2 < d_1 \tag{1}$$

$$1.5 \leq \frac{D}{d_2} \leq 3.0 \tag{2}$$

$$2 \leq \frac{D}{a} \leq 8 \tag{3}$$

where D is the internal diameter of the shell; d_1 and d_2 are the diameters of the central opening in the stator baffles and the diameter of the rotor baffles, respectively; and a 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 a is increased to take care of peak liquid loads as will be explained.

According to still another feature, the rotor baffles and stator baffles are preferably both formed of comparatively thin, sheet material, e. g., metal or plastic, without irregularities, ribs, flanges, or the like, thereby providing each of these baffles with two substantially smooth faces. This results in an operation which differs in an important respect from that of prior devices, wherein random turbulence was effected by irregularities or perforations in these baffles, and the dispersed droplets had widely different sizes. By the preferred arrangement according to the invention a far more uniform dispersion of one liquid in the other is effected, and the extraction is materially improved. One aspect of this improvement is a better relation between degree of contacting, rate of throughput and "flooding." 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 contactor will "flood." It is evident that the flooding condition is largely determined by the presence of many small dispersed droplets, which form an emulsion incapable of settling. If the particle sizes are not uniform there will be comparatively large dispersed droplets, which are not properly contacted with the other liquid, while the contactor is already near to its flooding condition. By bringing about a greater homogeneity in particle sizes the incidence of these large droplets just prior to flooding is avoided, and the contacting efficiency is improved.

The contactor may be employed for contacting liquids, either concurrently or countercurrently. In countercurrent extractions the liquid to be separated may be passed in countercurrent to a single solvent or a solvent mixture admitted at the opposite end of the contactor; it may also be subjected to double countercurrent extraction, i. e., extracted with two partially immiscible solvents which are caused to flow countercurrently to one another by introduction at spaced points in the contactor, the liquid to be separated being introduced either with one of the solvents (usually the one with which it is most miscible) or at a point intermediate to the points of introduction of the two solvents.

The construction of the contactor according to the invention will be further illustrated with reference to the accompanying drawing forming a

part of this specification and illustrating certain preferred embodiments, wherein:

Fig. 1 is a section on a vertical plane;

Fig. 2 is a section on line 2—2 of Fig. 1;

Fig. 3 is a diagram indicating the important dimensions;

Fig. 4 is a schematic diagram illustrating the contactor in section with auxiliary equipment used therewith;

Fig. 5 is a fragmentary sectional view of a modification; and

Figs. 6 and 7 are schematic diagrams showing further modifications.

Referring to Figs. 1 and 2, the apparatus consists of a closed vertical column 1 of circular cross section and cylindrical shape having a coaxial rotor shaft 2 journalled at its ends for rotation and having a pulley 2a by which it may be rotated by a drive belt, not shown. A plurality of circular, imperforate baffles 3, 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 wall of the column is equipped with annular horizontal stator rings 4 likewise made of thin, flat sheet metal, but having circular central openings concentric with the rotor baffles and shaft; they are arranged perpendicular to the shaft axis and located so that they are approximately in the centers of the spaces between adjacent rotor baffles. The stator baffles thereby subdivide the column into a vertical series of compartments, the height of which is determined by the vertical interval between baffles. This interval may be uniform throughout the height of the column, but also may be non-uniform as will be explained. According to the invention the inner diameter d_1 of the stators is greater than d_2, the diameter of the rotor baffles, whereby it is possible to insert the rotor assembly, consisting of the rotor shaft and rotor baffles, through the openings in the stators, and, if necessary, to remove this assembly after removing the lid of the column. It will be noted that the ratio of D, the internal diameter of the column, to the diameter of the rotor baffles is, in the embodiment according to Figs. 1 and 2, 2.57, i. e., between 1.5 and 3, and that the ratio of the column diameter to the vertical interval between like baffles is 3.48, i. e., between 2 and 8.

The stators 4 are mounted only in the central part of the column, leaving settling zones at both ends. Inlet ports 5 and 6 for the admission of heavier and lighter liquid, and outlet ports 7 and 8, for the discharge of contacted heavier and lighter liquids, respectively, are provided at the ends of the column. While it is not necessary that the inlet ports be located beyond the baffles, it is desirable in this embodiment to displace the outlet ports vertically from the inlet ports toward the ends of the column, as shown, to provide settling zones or, at least, zones of reduced turbulence. Such an arrangement is, however, not essential to the invention, and other inlet and discharge arrangements may be used, as for example, external settlers as are shown in Fig. 4.

In using the contactor the liquids to be contacted may be admitted and contacted either intermittently or continuously, the latter being more generally employed. When concurrent flow is desired both liquids are introduced at one end (either top or bottom) either through the same or different ports of the column and withdrawn at the opposite end. In operating the contactor for countercurrent extraction heavy and light liquids are introduced continuously or intermittently at the top and bottom, respectively, and the contactor can be operated either so that the light liquid phase or so that the heavy liquid phase is the continuous phase. When the light liquid phase is to be continuous the column is initially filled with light liquid; thereafter the heavy liquid is introduced and dispersed by the rotor discs, passing downwardly by gravity and collecting at the bottom of the column to form a layer of heavy liquid below the level A. By regulating the rates of feed and drawoff of heavy liquid the interface between light and heavy liquids is maintained at the level A. On the other hand, when the light liquid phase is to be dispersed the column is initially filled with heavy liquid and the interface is maintained at the level B near the top of the column by regulating the rate of flow of heavy liquid.

It is preferred to operate the contactor with the interface at the lower level A, with the heavy liquid phase dispersed, because in most cases a higher maximum load can be attained for any given rotor speed than when the lighter liquid phase is dispersed. "Load" denotes the total amount of light and heavy liquid phases passing through a compartment in unit time, and "maximum load" denotes the load at which flooding occurs at a given rotor speed. With a contactor of the type described, wherein all compartments are of identical construction and when the liquids 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 liquids are introduced into the column they form light and heavy liquid phases, consisting predominantly of the light and heavy initial liquids, respectively, but one or both of these phases contains some solute dissolved out from the other liquid. In countercurrent extractions it is desirable that these resulting liquid phases have a minimum density difference of 0.02 gram per cubic centimeter to permit countercurrent flow by gravity at reasonable load; however, it is easier to operate the column with liquid phases having greater density differences, e. g., 0.03 gram per cubic centimeter, and operations with such higher density differences are more common.

Either the light or the heavy liquid may be the solvent, the other liquid being the liquid being extracted. Moreover, either the solvent or the liquid being extracted may form the continuous phase, the other forming the dispersed phase, the choice being usually made after considering the flow ratio of the feed liquids. Both liquids are usually fed into the contactor continuously, but intermittent flow is also possible. For example, when the liquid forming the continuous phase is a solvent or treating agent capable of treating a larger volume of the other liquid, the former may be introduced or replenished only intermittently, and a stream of the latter liquid may be flowed through an unchanging body of the former.

The operation of the contactor will now be described as applied to the countercurrent 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 con-

tinuously at the bottom while rotating the rotor, resulting in a fine dispersion of the solvent in the oil, particularly at the levels of the rotating baffles. The finely dispersed droplets constitute the extract or solvent phase, which is collected and coalesced at the bottom and withdrawn through the port 7 at a controlled rate to maintain the interface at the level A, suitable flow control and level-indicating means being provided, such as valve and level controller as shown in Fig. 4. The continuous oil phase rises through the column and dispersed extract phase settles from it at the level above the inlet port 5. It is then discharged through the port 8 which is preferably fully open to permit outflow of oil at a rate determined by the oil feed rate. This contacted oil is often called the raffinate phase.

The mechanism of dispersion and intimate contact within the contactor 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. This flow is caused by the difference in densities of the phases. The rotation of the rotor discs imparts a further and even more important movement to the phases which may be explained as follows, neglecting, for the moment, the countercurrent flow: The centrifugal forces caused by the rotation of the rotor discs induce flow of liquid from a rotor shaft radially outwards toward the column wall; this causes a flow of liquid from the column walls radially inwards toward the rotor shaft in the neighborhood of the stationary baffles. In addition, there is a rotation of the liquid around the rotor shaft. Thus, the motion of the liquid phase, apart from the countercurrent flow of the phases, is toroidal, as indicated by the lines T in Fig. 1. The flow of the liquid resulting from the rotation of the rotor discs causes one of the liquid phases to become reduced to a very fine state and dispersed because of the shearing stresses accompanying this flow. Both movements of the liquid described are superimposed. Hence, for the schematic picture of the flow of the phases in the extraction zone 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, 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 on to the next compartment is indicated in Fig. 1 by the line marked S.

It is evident that the stream of dispersed solvent phase S 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 stator baffles to change its direction and is eventually—partly owing to the pumping action of the rotating baffles—once again sucked to the center of the column, to be again driven to the wall of the column by the next lower rotor baffle. 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.

The speed of rotation of the rotor baffles 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 baffles, except, of course, in the settling zones at the ends of the column. The contractor 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.

A further example of the use of the contactor, involving double countercurrent extraction with two solvents is the exraction of lemon or orange oil to separate terpene hydrocarbons therefrom. In this case, pentane is fed in at the bottom as the light liquid solvent and methanol containing 10% water is the heavy solvent which is fed in at the top and dispersed in the pentane. The lemon or orange oil is introduced at an intermediate point and occurs predominantly in the continuous phase. Methanol extract phase is coalesced and drawn off at the bottom and pentane, together with the residue of the lemon or orange oil, flows off at the top. It was found that this extraction proceeded smoothly although these oils are known to give emulsion troubles.

Another common feature in the extraction of essential oils is the coagulation of proteinic bodies from the oil by the alcohols; these bodies combine at the interface in conventional equipment using successive mixing and settling zones. With the apparatus according to the invention, however, these bodies are discharged from the extraction zone with the methanol phase, which is the dispersed phase, and collect outside of the extraction zone, i. e., in the lower settler, where they do not interfere with the coalescence of the methanol drops.

The contactor may be advantageously employed together with certain auxiliary equipment, indicated diagrammatically in Fig. 4, wherein the contactor column 1, provided with rotor baffles 3 and stator baffles 4 as previously described, is provided with liquid feed pumps 10 and 11 for the heavy and light liquid. It is sometimes difficult to utilize the spaces at the ends of the column to settle out the dispersion because this necessitates taking measures to avoid too high a turbulence in these end zones, such as operating the rotor shaft at a speed lower than that desirable for effective contacting. Moreover, this necessitates the use of sight gauges and/or liquid level controllers within the column. To avoid these difficulties it is often preferable to use external settlers. Thus, as shown, the dispersion is drawn off from the top and bottom of the column via lines 12 and 13 and passed into settlers 14 and 15, respectively. Settled heavy phase is returned from the settler 14 via line 16, clear light liquid being drawn off through outlet line 17. Similarly, settled light phase is returned from the settler 15 via line 18, clear heavy liquid being drawn off through outlet line 19, controlled by valve 20 and liquid level controller 21 to maintain the interphase at the level A.

In the extraction according to the foregoing paragraph the heavy phase was the dispersed phase, and the valve 22 in the light liquid outlet line was fully open. When the light liquid phase is to be dispersed the interface is maintained at the upper level B by regulating the rate of flow of heavy liquid by the valve 20 and liquid level

controller 23, the controller 21 being in this case unnecessary.

As was indicated above, the baffles need not in every case be flat, but may be surfaces of revolution. A modified embodiment using frusto-conical baffles is shown in Fig. 5, wherein the column 1a has a shaft 2a with frusto-conical baffles 3a, and the stator baffles 4a are also frusto-conical. It is evident that the flat baffles of Fig. 1 form a special (and preferred) case of baffles which are surfaces of revolution, the generatrix in this case being perpendicular to the axis of revolution. While Fig. 5 shows both the rotor and stator baffles to be frusto-conical, it is evident that either one could be flat. A further modification shown in Fig. 5 is in the manner of mounting the stator rings in the column. Instead of being permanently fixed to the column, the stators 4a are fixed to vertical rods 24, forming a frame-work which can be removed from the top of the column.

The efficiency of the contactor according to the present invention will be apparent from the data in the following examples.

EXAMPLE I

The experiments were carried out with a vertical column having a diameter of 79 mm., containing flat horizontal stator rings with central circular holes having diameters of 50 mm., and spaced vertically at 22 mm. Four different rotors, having flat rotor baffles of diameters indicated in the table, and all operated at 1500 revolutions per minute, were used in successive runs to extract acetic acid from a mixture of acetic acid and methyl isobutyl ketone, using water as a solvent. The methyl isobutyl ketone formed the lighter, continuous phase, and water formed the heavier, dispersed extract phase.

In each run the column was loaded to the maximum without inducing flooding, and the total efficiency was determined. By "total efficiency" is meant herein the product of the maximum load (as previously defined) in liters/hour and the efficiency of the extraction expressed as a percentage. (An efficiency of 100% denotes that the extractive action of a compartment of the column is equal to that of a theoretical step or stage; for a definition of the theoretical stage, see Perry's Chemical Engineer's Handbook, 2d edition, 1941, page 1215.) The results of the runs are tabulated in Table I:

Table I

Run	Diameter of rotor baffles in mm.	$\frac{D}{d_i}$	Total Efficiency
1	25	3.16	2,875
2	30	2.63	4,305
3	39	2.02	4,130
4	49	1.61	3,150
5	60	1.32	2,170

The data clearly show that the best results are obtained when the ratio of the column diameter to the rotor baffle diameter is from about 1.5 to 3.0. The curve of total efficiency for this series of runs has a maximum in the vicinity of a ratio 2.63, and the total efficiency decreases as the ratio is increased or decreased. In the case of known constructions of rotating disc contactors, in which the diameter of the rotor baffles exceeds the inner diameter of the stator rings, the diameter of the rotor baffles would be greater than 50 mm., and a lower ratio with even lower total efficiencies than those of run 4 would result, showing the known constructions to be less favorable than that according to the invention.

As to the width of the stator rings it can be remarked that with decreasing width the maximum load of the column increases and the efficiency decreases. Especially in the case of columns with a small diameter the width of the stator rings can be small, even very small, since the pumping action caused by the rotor baffles is so powerful that the presence of the stator rings is not or hardly required for reversing the radially outward liquid stream as indicated at S in Fig. 1.

As regards the distance a between the stator baffles it can be remarked that the maximum load as a function of this distance at first increases about proportionately to the distance of the baffles and—as soon as the distance between the baffles becomes equal to the diameter of the tube—remains practically constant; that when the distance between the baffles is increased the efficiency per compartment (hence for each baffles) first rises slightly to become practically constant immediately after; and that the efficiency of a column of a certain length decreases accordingly, as there are fewer compartments (stator baffles). In view of these considerations the ratio of the diameter of the column to the distance between the rotor baffles is preferably chosen between 2 and 8.

EXAMPLE II

In order to determine the most favorable value of the speed of rotation of the rotor baffles the above extraction experiments were repeated with different speeds of rotation and various loads of the column. The diameter of the rotor baffles was 30 mm.; the inner diameter of the stator rings was 50 mm.; and the distance between the baffles was 22 mm.

The results are listed in Table II.

Table II

Speed of rotation R. P. M.	Efficiency in Per Cent at a load in l./h. of—				Efficiency at the maximum load	Maximum permissible load l./h.	Total Efficiency
	40	60	80	100			
875	15	15	16	18	24	143	3,430
1,225	21	22	24	26	31	122	3,780
1,400	24	25	27	30	33	114	3,760
1,575	27	28	30	34	35	104	3,640
1,850	32	33	35	-----	37	90	3,330

The above table shows that in the column used the best extraction was obtained with a speed of rotation of 1200–1600 R. P. M.

If the diameter of the column is greater it can be expected that the optimum speed of rotation of the baffles will decrease.

The apparatus according to the invention has also the advantage that the phase ratio has only little or no influence on the efficiency of the extraction, such in contrast to the known extraction apparatus which generally shows a considerable reduction of the efficiency if the phase ratio becomes greater than 3.

EXAMPLE III

The above advantage is apparent from the results of experiments listed in Table III. These experiments were carried out with the aforementioned column, in which the diameter of the rotor baffles was 30 mm., the inner diameter of the stator rings 50 mm., and the distance between the rotor baffles 22 mm. The load amounted to

60–80 liters/hour. The phase ratio is the ratio of the quantity of extracting agent (water) to the quantity of the mixture to be treated (methyl isobutyl ketone+acetic acid).

Table III

Speed of rotation R. P. M.	Efficiency in per cent at a phase ratio of—		
	0.2	1.0	5.0
875	14	16	18
1,225	19	21	23
1,575	27	29	30
1,850	34	37	40

Theoretically speaking it may be assumed that the maximum load of the column will be approximately proportionate to the diameter of the column and that the efficiency will not vary with the diameter of the tube, at least not to an appreciable extent.

EXAMPLE IV

A spindle oil with a viscosity of 50 centistokes at the extraction temperature was extracted in countercurrent with furfural (1 part by volume of oil to 2.6 parts by volume of furfural) in an extraction column according to the invention. The diameter of the column was 79 mm., the diameter of the rotor baffles 30 mm., the inner diameter of the stator rings 40 mm., the distance between the rotor baffles 22 mm., and the number of revolutions per minute 1200.

At a total throughput of 36 liters/hour (10 liters of oil and 26 liters of furfural) the efficiency per compartment of the column was found to be approximately 32%.

When comparing the present apparatus with a similar apparatus of the same capacity (150 liters/hour), which, however, had no stator rings and in which the rotor consisted of a rotating cylinder without baffles, it appeared that in the latter apparatus the volume for a theoretical step is 1½–2 times as large, in other words the efficiency of this apparatus is 1½–2 times less than that of the device according to the invention.

It is well known in the extraction art that, under certain operating conditions, greater liquid loads occur at certain points of a countercurrent extraction zone than at other points of the zone. Such load differences may be due to volume changes or to the shuttling of solute between the liquid phases, fluid being "trapped" so to speak; such peaks in the liquid load may be caused by the use of temperature gradients. Further, loading peaks may result from introduction of solvent or of a liquid mixture to be extracted at an intermediate point in the column. A commonly encountered load peak occurs near the point of introduction of the liquid to be extracted, particularly in the case where a double countercurrent extraction is used, i. e., an extraction wherein two at least partially immiscible solvents are flowed countercurrently through the contactor and the mixture to be extracted is introduced into the counterflowing solvent system, as in the extraction of lemon or orange oil, as previously described. In such situations it may occur that if all compartments are of identical construction most of them will be under-loaded when the compartment carrying the peak load is near the flooding condition.

The contactor according to the present invention can be easily adapted to increase the permissible maximum liquid load at whatever compartment or compartments loading peak occurs. Either of two, or both expedients in conjunction, can be employed: (*a*) The diameter d_2 of the rotor baffle can be decreased somewhat under the diameter of the rotors in the other compartments. (*b*) The spacing *a* between baffles can be increased somewhat above that in the other compartments. The former results in a slight drop in stage efficiency in the modified compartment, while the latter reduces the stages per length of column. These expedients, however, result in an increase in the over-all total efficiency of the contactor in situations wherein peak loadings occur.

The modification of the rotor baffle diameter and/or compartment length may in some cases result in using ratios for D/d_2 and D/a which fall outside of the preferred ranges. Thus, the former ratio may have values from about 3 to 5, while the latter ratio may be as low as 1 or less.

The first of these expedients is shown in Fig. 6 wherein the lowermost rotor baffle **3***b*, near the inlet port **6** through which the liquid to be treated is introduced, has a smaller diameter than the other rotor baffles **3**.

The second expedient is shown in Fig. 7, wherein the vertical distance between the two lowermost stationary baffles **4***b* and **4***c* (and also the distance between the two lowermost rotor baffles **3***d* and **3***e*), near the inlet port **6** for the liquid to be extracted, is greater than that between the baffles higher up in the column.

It is evident that the number of compartments may be selected as desired, considering the stage efficiency and the number of theoretical stages required. For example, contactors having from about 15 to 100 compartments are typical.

I claim as my 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 a central opening and dividing said shell into a series of compartments; a rotor shaft extending axially with respect to said shell through said openings; a plurality of disc-like rotor baffles fixed to said shaft, each rotor baffle being wholly within one of said compartments and displaced a substantial distance axially from the stationary baffles thereof and extending outwardly toward the wall of said shell, each of said rotor baffles being smaller than the openings in the stationary baffles toward one end of the shell from the respective rotor baffle, whereby said shaft and rotor baffles can be moved through said openings toward the said end of the shell; means for introducing and discharging fluid at axially displaced points in said shell; and means for rotating said rotor shaft and rotor baffles.

2. A rotating disc contactor according to claim 1 wherein in at least the majority of the compartments the ratio of the internal diameter of the tubular shell at said compartment to the diameter of the rotor baffle in said compartment is at least about 1.5 and not greater than about 3.

3. A rotating disc contactor according to claim 1 wherein in at least the majority of the compartments the ratio of the internal diameter of the tubular shell at said compartment to the distance between the stationary baffles of said compartment is at least about 2 and not greater than about 8.

4. A rotating disc contactor according to claim 1 wherein said tubular shell is cylindrical and circular in cross section and all stationary

baffles have circular openings with diameters greater than the diameters of the rotor baffles.

5. A contactor according to claim 1 wherein the stationary baffles and the rotor baffles have smooth surfaces of revolution, substantially free from surface irregularities.

6. A contactor according to claim 5 wherein the stationary baffles and the rotor baffles have plane surfaces disposed perpendicular to the axis of the shaft.

7. A rotating disc contactor for countercurrently contacting at least partially immiscible liquids comprising an at least partially upright column; a plurality of annular, stationary baffles fixed within said column extending from the column wall to a central opening and dividing said shell into a series of compartments; a rotor shaft extending axially with respect to said column through said openings; a plurality of disc-like rotor baffles fixed to said shaft and extending outwardly toward the wall of said column, each of said rotor baffles being located approximately in the center of a compartment between the stationary baffles thereof, said rotor baffles having diameters less than the diameters of the openings in the stationary baffles of the respective compartments; inlet means for introducing liquids at different levels into the column; outlet means for discharging liquids at different levels from the column; and means for rotating said rotor shaft and rotor baffles.

8. A rotating disc contactor according to claim 7 wherein the rotor baffles are formed of flat sheet material disposed perpendicular to the shaft axis.

9. A rotating disc contactor according to claim 7 wherein the stationary baffles are formed of flat sheet material disposed perpendicular to the shaft axis.

10. A rotating disc contactor according to claim 7 wherein the column is cylindrical, the stationary baffles are of substantially the same size throughout the column, and the diameter of the rotor baffles near the inlet means for the liquid to be treated is smaller than the diameter of the rotor baffles in other parts of the column.

11. A rotating disc contactor according to claim 7 wherein the distance between stationary baffles near the inlet means for the liquid to be treated is greater than the distance between stationary baffles at other parts of the calumn.

12. A rotating disc contactor for countercurrently contacting at least partially immiscible liquids comprising an at least partially upright column; a plurality of annular, stationary baffles fixed within said column extending from the column wall to a central opening and dividing said shell into a series of compartments; a rotor shaft extending axially with respect to said column through said openings; a plurality of disc-like rotor baffles fixed to said shaft and extending outwardly toward the wall of said column, each of said rotor baffles being located approximately in the center of a compartment between the stationary baffles thereof, the ratio of the internal diameter of the tubular shell to the diameter of the rotor baffles being, in at least the majority of the compartments, at least about 1.5 and not greater than about 3; inlet means for introducing liquids at different levels into the column; outlet means for discharging liquids at different levels from the column; and means for rotating said rotor and rotor baffles.

13. A rotating disc contactor for countercurrently contacting at least partially immiscible liquids comprising an at least partially upright column; a plurality of annular, stationary baffles fixed within said column extending from the column wall to a central opening and dividing said shell into a series of compartments, the ratio of the internal diameter of the tubular shell to the distance between the stationary baffles being, in at least the majority of the compartments, at least about 2 and not greater than about 8; a rotor shaft extending axially with respect to said column through said openings; a plurality of disc-like rotor baffles fixed to said shaft and extending outwardly toward the wall of said column, each of said rotor baffles being located approximately in the center of a compartment between the stationary baffles thereof; inlet means for introducing liquids at different levels into the column; outlet means for discharging liquids at different levels from the column; and means for rotating said rotor and rotor baffles.

14. A rotating disc extraction column for countercurrently contacting at least partially immiscible liquids of different densities comprising: a vertical, cylindrical column of substantially circular cross section having an internal diameter D; an outlet opening at each end of the column for the discharge of contacted liquids; an inlet opening near each end of the column for the introduction of liquids to be contacted, said inlet openings being spaced vertically from the outlet openings away from the ends of the column to provide a settling zone between the inlet and outlet openings at each end of the column; a series of annular, stationary baffles of thin, flat sheets with plane upper and lower surfaces disposed horizontally within the column, each baffle extending from the column wall radially inwardly to a central circular opening of diameter d_1, said baffles being imperforate except for said circular opening and being spaced at substantially uniform vertical intervals a and located between said inlet openings; a rotor shaft substantially coaxial with the column mounted for rotation and extending through said openings in the baffles; and a plurality of circular, imperforate rotor baffles with diameters d_2 of thin, flat sheets with plane upper and lower surfaces fixed to the shaft for rotation therewith with their surfaces perpendicular to the shaft, said rotor baffles being spaced along the rotor shaft at substantially uniform vertical intervals a and located to cause one rotor baffle to lie substantially at the center of each space between adjacent stationary baffles; the relations between the dimensions stated in at least the majority of said compartments being such that:

$$1.5 \leq \frac{D}{d_2} \leq 3.0,\ 2 \leq \frac{D}{a} \leq 8, \text{ and } d_2 < d_1$$

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