Aug. 21, 1956 E. L. CLARIDGE ET AL 2,759,872

SOLVENT EXTRACTION METHOD AND APPARATUS

Filed Aug. 23, 1951 6 Sheets-Sheet 1

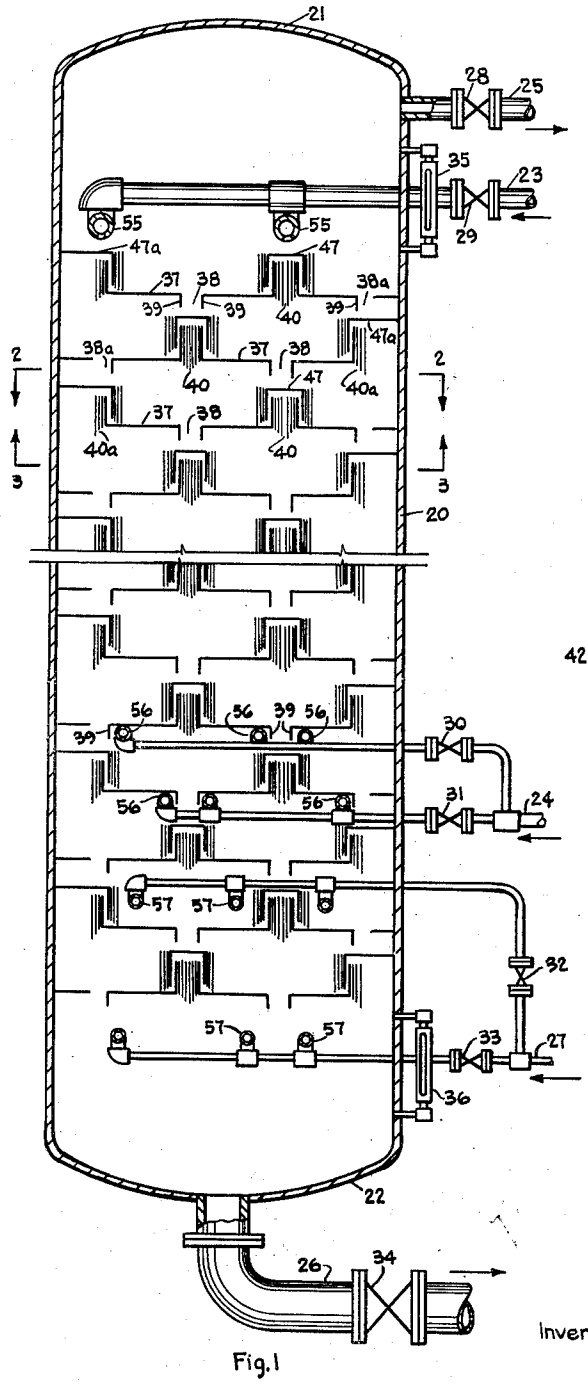


Fig. 1

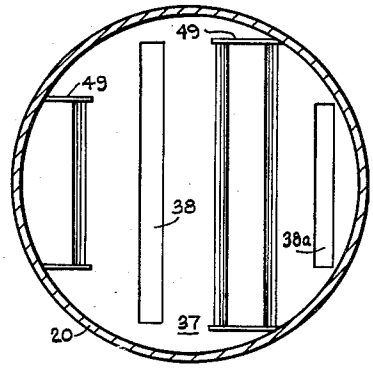


Fig. 2

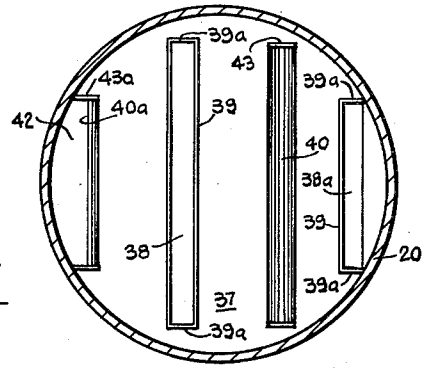


Fig. 3

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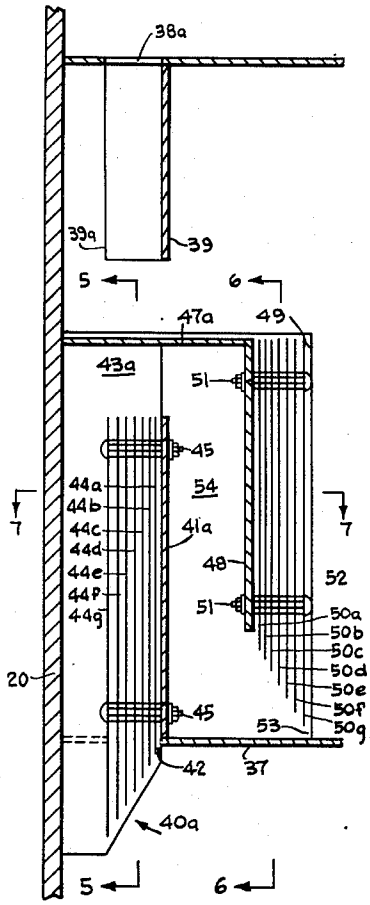


Fig. 4

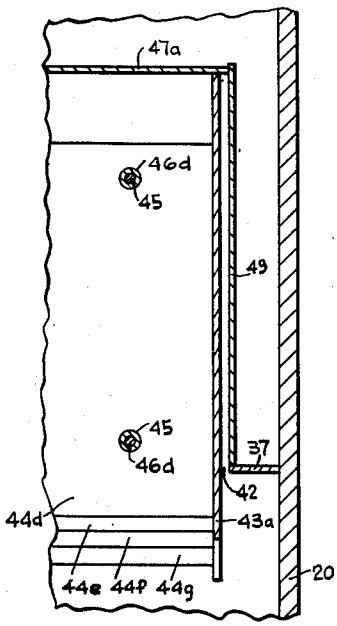


Fig. 5

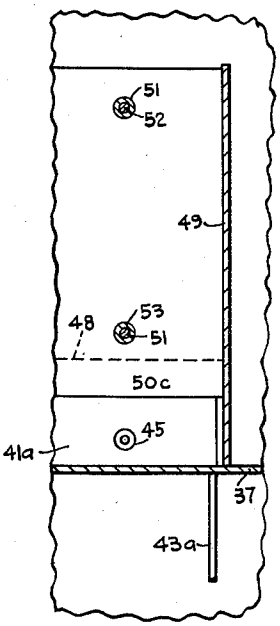


Fig. 6

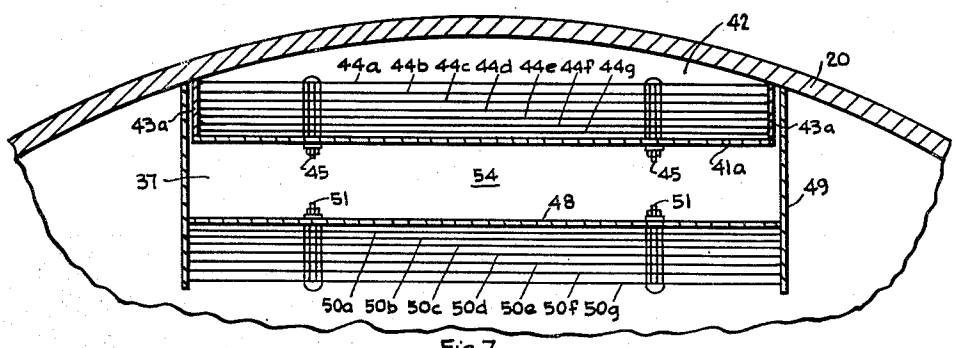


Fig. 7

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SOLVENT EXTRACTION METHOD AND APPARATUS

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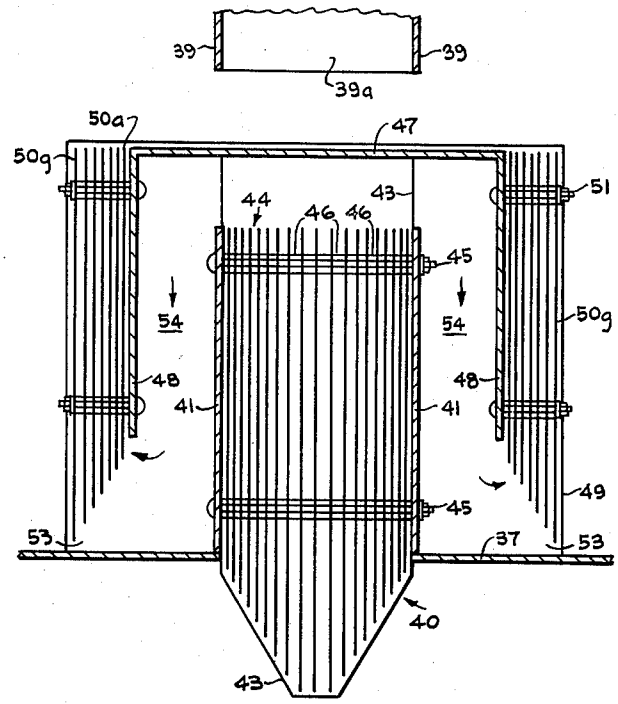


Fig. 9

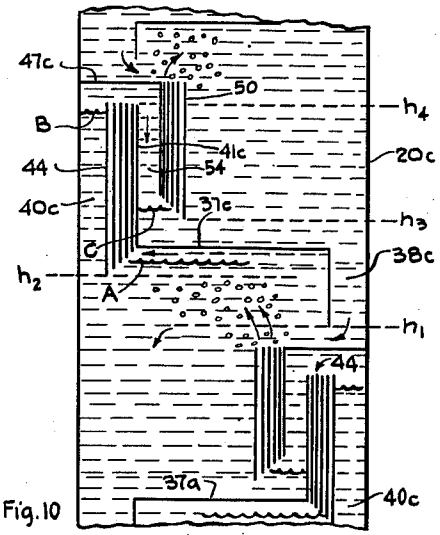


Fig. 10

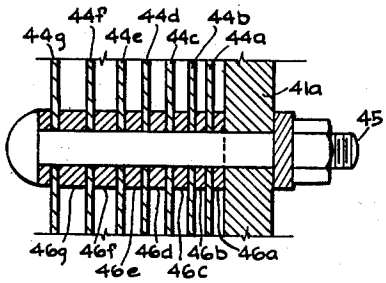


Fig. 8

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SOLVENT EXTRACTION METHOD AND APPARATUS

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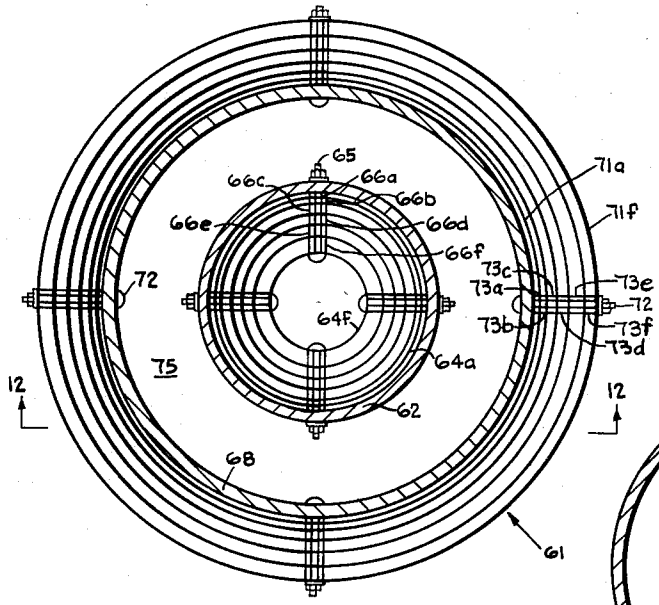


Fig. 11

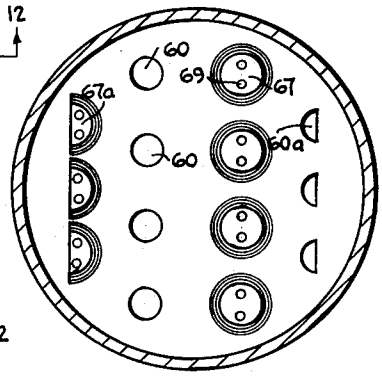


Fig. 13

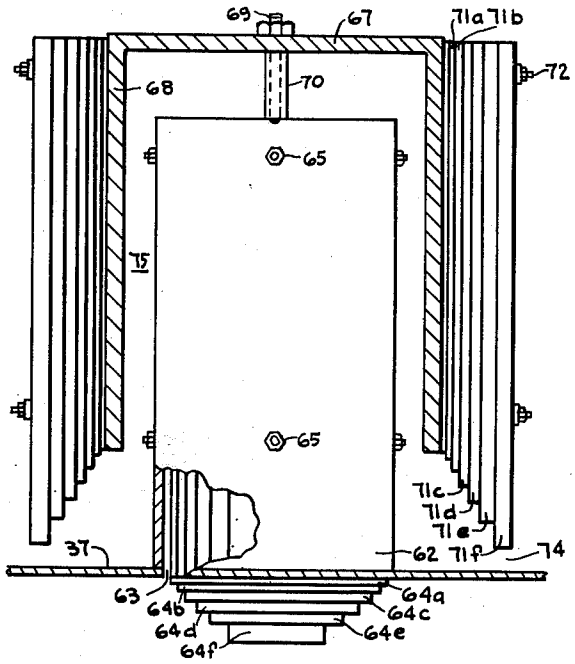


Fig. 12

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SOLVENT EXTRACTION METHOD AND APPARATUS

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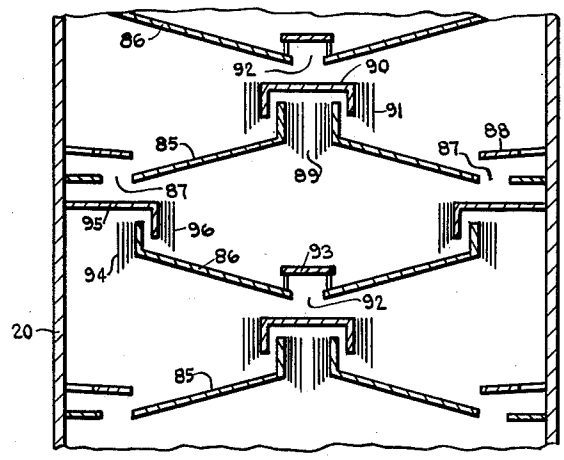


Fig. 15

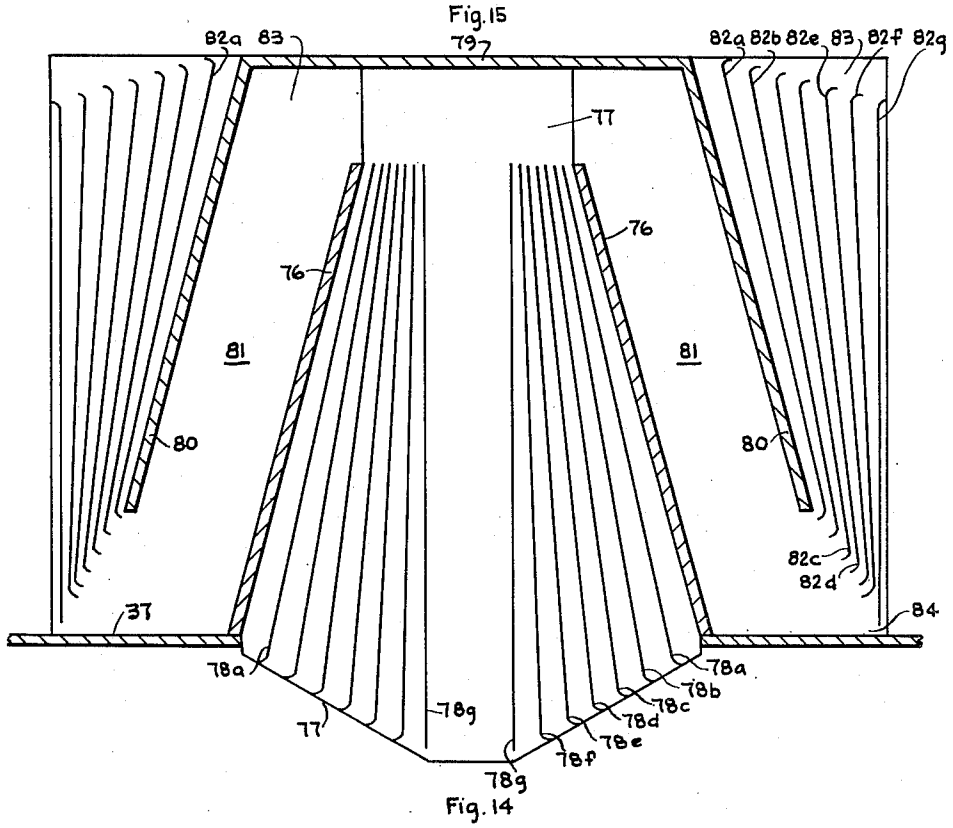


Fig. 14

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SOLVENT EXTRACTION METHOD AND APPARATUS

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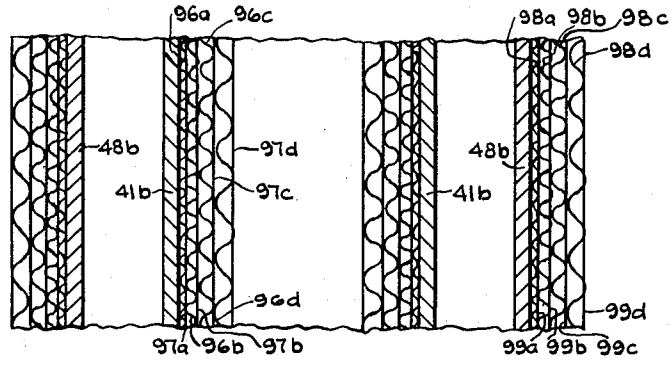


Fig. 16

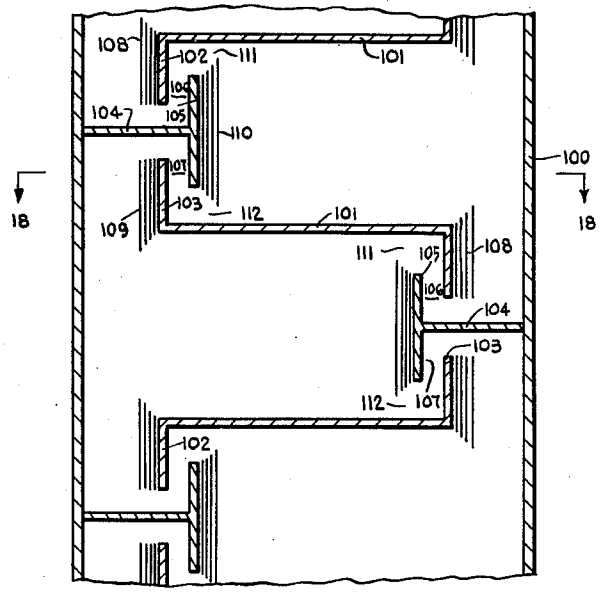


Fig. 17

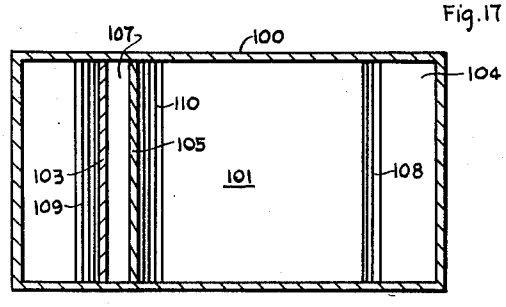


Fig. 18

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Their Attorney

United States Patent Office 2,759,872 Patented Aug. 21, 1956

2,759,872

SOLVENT EXTRACTION METHOD AND APPARATUS

Elmond L. Claridge and Horace M. Orfield, Houston, Tex., assignors to Shell Development Company, Emeryville, Calif., a corporation of Delaware

Application August 23, 1951, Serial No. 243,254

33 Claims. (Cl. 196—14.49)

This invention relates to the extraction art wherein two at least partially immiscible liquids of different densities are contacted and separated by settling. It may be applied, for example, for contacting a liquid selective solvent with hydrocarbon oil to extract aromatic, naphthenic and/or other constituents which are preferentially dissolved in the solvent to form a liquid extract phase, leaving other constituents, such as paraffinic and/or other hydrocarbons, undissolved to form a liquid raffinate phase, which may contain some solvent. More particularly, the invention is concerned with an improved method of dispersing one liquid in another and with contacting elements associated with trays adapted to effect dispersion of one liquid in the other and subsequent settling of the liquids. A single group of contacting elements together with trays defining a contact stage may be employed, or a plurality of such groups may be mounted within a column for achieving countercurrent flow of the liquids through a plurality of stages.

Extraction apparatus of this type in general comprise an upright column with conduits for the introducion of feed liquids at vertically spaced points and two or more transverse (horizontal or inclined) trays that are vertically spaced and located between said conduits for dividing the column into an upper and a lower space and one or more inter-tray spaces, said spaces communicating with one another essentially only through risers and downcomers, each tray (with the possible exception of the uppermost tray) having a riser for transporting light liquid through the tray from a lower space and each tray (with the possible exception of the lowermost tray) having a downcomer for transporting heavy liquid through the tray from a higher space, and an upper and a lower space having outlets for the discharge of settled light and heavy liquids, respectively, from the column, each inter-tray space having dispersion means such as orifices or a perforated member associated with the riser and/or downcomer for dispersing one liquid into the other liquid and each such inter-tray space, further, providing a settling zone wherein the resulting dispersion is settled to segregate the light and heavy liquids. Such apparatus will, in this specification, be designated as "apparatus of the character described."

It is known to effect countercurrent contact between liquids in apparatus of the character described. With many extraction systems, such as those involving the extraction of lubricating oil with selective solvents, such towers usually have a small number of equivalent stages far less than the actual number of trays. Much of this difficulty is due to excessive circulation of liquids within the column, resulting in entrainment of the opposite liquid and in incomplete settling. Thus, in one operation wherein a lubricating oil fraction and a solvent consisting of phenol and a minor amount of water were charged in a volumetric ratio of 1:3.77 and the oil phase was dispersed in each stage in the solvent extract phase, calculations for a selected tray indicated that if there were no entrainment, there would be 1.164 volumes of oil phase

ascending through the risers and 4.323 volumes of extract phase descending through the downcomers for every volume of oil charged to the tower. However, there was actually an upflow of 6.516 volumes and a downflow of 9.675 volumes. Such excessive flow rates indicate deleterious contamination of each stream with liquid that should occur only in the other stream and cause rates of flow through the settling spaces in excess of those that result in effective settling. The net effect is a greatly reduced stage efficiency.

Excessive circulation of liquids can be reduced by restricting the sizes of the flow passages, such as the risers, downcomers and/or the holes through which the dispersion is effected, to make the sum of the pressure drops equal to the available driving force at the desired flow rates. However, this solution is not feasible because a column designed for a specific set of operating conditions would not be suitable for liquids having other densities and viscosities or when other flow rates are used.

The object of this invention is to achieve increased tray efficiency in apparatus of the character described by providing a more efficient means of mixing, settling and segregating the phases in inter-tray spaces, and by providing means for transporting the segregated phases with a minimum of remixing and entrainment to adjacent tray spaces.

The invention further provides an improved tray structure wherein excessive circulation of liquids is avoided without restricting the flow passages, whereby the apparatus is adapted for operation under varying conditions of flow rates and types of feed stocks and solvents.

Another object is to provide an improved method for contacting at least partially immiscible light and heavy liquids wherein the liquid to be dispersed is injected into a current of the other liquid transversely thereto and in a variable number of narrow channels in accordance with the quantitative rates of flow, whereby the degree of dispersion is controlled.

Still another object is to provide an improved method of operating an extraction apparatus of the character described forming a dispersion that flows from the mixing zone into the settling zone in a manner to promote settling and avoid turbulence; wherein excess potential energy of the liquid to be dispersed is converted into heat by friction loss against walls instead of by contact with the liquid forming the continuous phase; wherein the settled liquid from one stage, which is to be dispersed in an adjoining stage, is transported in a variable number of narrow channels, substantially segregated from the dispersion; and wherein excessive circulation of the liquids around the trays is prevented by flowing the liquid to be dispersed through a riser assembly and through a liquid seal deep enough to balance the hydrostatic forces tending to cause circulation of the other liquid.

These objects can be best accomplished by a combination of features which bring about the following coexisting conditions, it being understood that the invention is not limited to devices that achieve all of them:

1. Avoiding dispersion of one phase in the other in the course of mixing to such an extent that large quantities of droplets too small to settle at the prevailing flow rates are produced.

2. Insuring contact of all portions of each liquid phase with appropriate portions of the other liquid phase.

3. Providing a quiet settling space.

4. Balancing the hydrostatic forces ordinarily tending to cause excessive circulation rates around the trays by means other than the use of frictional flow resistances.

5. Transport of settled liquid phases by means which keep them segregated so that remixing does not occur.

6. Providing means for converting excess potential energy of the liquid phases, during transport from the

settling zone to the mixing zone, into heat by friction with surfaces other than the interfacial surface between liquid phases, in order to avoid the production of excess interfacial surface.

In summary, according to the invention each inter-tray space constituting a contacting stage wherein light liquid is to be dispersed in heavy liquid is provided with: a heavy liquid inlet, such as a downcomer from the space above, for supplying heavy liquid at a feed zone spaced horizontally from the outlets of the space; a riser through the lower tray defining the inter-tray space that extends a substantial distance above the said lower tray; a seal cap over and in spaced relation to the riser having a skirt spaced laterally from the riser and extending a substantial distance beneath the top of the riser but terminating short of the said lower plate to provide a downward channel of appreciable vertical extent constraining light liquid debouching from the riser to reverse direction and descend; one or more baffles on the outside of the skirt defining one or more narrow discharge channels communicating at the bottom with the downward channel and open at the top to discharge light liquid upwardly at a mixing zone into the stream of heavy liquid that flows from the feed zone to the outlets, the mixing zone being displaced by a substantial horizontal distance from the outlets, whereby an intermediate quiescent settling zone is provided; and a by-pass inter-connecting the bottom of the downward channel with the lower part of the inter-tray space. When the inner-tray space is used to disperse heavy liquid in light liquid the contacting elements are inverted from the positions specified, that is, the space is provided with a light liquid inlet, such as a riser supplying light liquid at a feed zone, a downcomer for heavy liquid extending beneath the upper tray of the space, and a seal cap under and in spaced relation to the downcomer, the skirt on the seal cap extending upwardly a substantial distance above the lower end of the downcomer to provide an upward channel and the baffle being arranged to discharge heavy liquid downwardly through one or more narrow discharge channels, while the by-pass passageway interconnects the top of the upward channel with the upper part of the inter-tray space. The details of such an inverted arrangement of the contacting elements being identical with the arrangement used for dispersing light liquid in heavy liquid and being completely indicated upon inverting the drawings of this specification, no further details regarding such arrangement need be given; the operation, similarly, will be described only with reference to the arrangement for dispersing light liquid. Both arrangements are, however, to be regarded as falling within the scope of the invention.

By thus arranging the riser, seal cap and by-pass passageway the hydrostatic pressure tending to cause excessive circulation is balanced, thereby insuring that only light liquid or substantially only light liquid is transported through the riser. This effect of preventing all or objectionable amounts of entrainment of heavy liquid and consequent excess circulation of liquid around the tray is dependent upon the height of the said downward channel, which must be made tall enough to balance the hydrostatic head; the least height that may be employed will depend upon the tray spacing, the densities, viscosities, and interfacial tension of the liquids, and the degree of entrainment of each liquid in the risers and downcomers, but particularly upon the phase concentration gradients between trays and through risers and downcomers, expressed as fractional volume occupied by either phase, as will be explained hereinafter. Greater heights for this channel are not detrimental. The provision of the narrow discharge channels results in absorbing the excess potential energy driving the light liquid upwards, thereby insuring that the light liquid is discharged into the heavy liquid with a moderately low exit velocity, preventing an excessively severe dispersion in the heavy liquid such as would otherwise cause settling difficulties. This improved settling, in turn, decreases the degree of entrainment and influences the sealing action for preventing excessive circulation as was described earlier in this paragraph. The narrow discharge channels, in conjunction with the by-pass passageway, further minimize the tendency for entrained heavy liquid to be carried up and dispersed in the heavy liquid.

To attain the full advantages of the invention and to achieve the six desirable conditions listed above, it is preferred to employ the following features, all of which need not, however, be employed simultaneously: (1) The risers are assemblies having a plurality of vertical partitions defining between them narrow riser channels extending to progressively greater distances beneath the lower tray of the respective space, the riser channel of least downward extending being at the outer margin of the riser assembly so as to be the first traversed by light liquid flowing along the under side of the tray. The partitions are preferably but not necessarily imperforate; thus, walls with small holes may be used. (2) The riser channels have progressively greater widths, starting with the channel of least downward extent. (3) A plurality of baffles is employed on the outside of the skirt, to provide a plurality of narrow discharge channels, the baffles terminating at progressively lower levels beneath the bottom of the skirt. (4) The discharge channels have progressively greater widths, starting with the channel nearest to the skirt. (5) The seal cap of the riser is positioned directly beneath and in spaced relation to the heavy liquid inlet or downcomer, whereby the seal cap acts to deflect the heavy liquid and the feed zone is located directly above the seal cap. (6) The mixing zone is located at a level that is only a small distance beneath that of the interface in the settling zone; this is preferably accomplished by using a tubular downcomer that projects downwardly to below the interface level and/or by inclining upper tray of the respective space to be below the said interface level in the region of the feed zone. (7) The mixing zone is located in the upper third of the inter-tray space. (8) The baffles are shaped to provide thin discharge channels the upper outlets of which are directed to have an upward component, i. e., are either vertical or inclined upwards to avoid any directional velocity for the dispersion leaving the mixing zone that is downward from the horizontal. (9) The heavy liquid inlet is arranged so that the heavy liquid traverses the mixing zone essentially horizontally or slightly upwards, thereby further avoiding the directional velocity component mentioned under (8).

The improved method, therefore, includes the improvement of dispersing light liquid by flowing a current of heavy liquid at an elevated part of a contacting stage substantially horizontally through a mixing zone, supplying light liquid to a lower part of the stage beneath the mixing zone and beneath the interface in the settling zone and in direct communication with the settled heavy liquid in that stage, and transporting the light liquid from said lower part upwards to the mixing zone through one or more narrow discharge channels for dissipating the excess potential energy of the light liquid, and thereafter discharging the light liquid from the top of the narrow channel or channels into the current of heavy liquid at a low velocity. Further features of the method include the progressive increase in the number of narrow discharge channels used in the described manner as the total rate of flow of light liquid is increased, whereby more light liquid may be dispersed without materially increasing the exit velocity thereof into the heavy liquid stream; the method of transporting the light liquid from an inferior contacting stage through partitioned risers, in segregation from heavy liquid, wherein the number of narrow riser channels in operation is progressively increased as the total flow rate of light liquid is increased; and the provision of a hydraulic seal to balance the pressure tending to cause excessive circulation.

Having thus indicated the general nature of the inven-

tion, reference is made to the accompanying drawings forming a part of this specification and showing certain preferred embodiments thereof, wherein:

Fig. 1 is a vertical central sectional view of a contacting tower wherein the invention is applied;

Figs. 2 and 3 are horizontal sectional views taken on correspondingly numbered lines on Fig. 1;

Fig. 4 is an enlarged vertical sectional view of a riser assembly and seal cap at the margin of a tray;

Figs. 5, 6 and 7 are fragmentary sectional views taken on correspondingly numbered lines on Fig. 4;

Fig. 8 is a further enlarged detail of a portion of Fig. 4;

Fig. 9 is a vertical sectional view of a symmetrical riser assembly and seal cap at an inner part of the tray, illustrating a modified arrangement of the partition walls;

Fig. 10 is a diagrammatic fragmentary vertical sectional view indicating certain dimensions;

Figs. 11 and 12 are respectively a horizontal sectional view and a vertical sectional view taken on the correspondingly numbered lines in the opposite views, showing a modified form of riser assembly and seal cap;

Fig. 13 is a horizontal sectional view through a contacting tower, on a reduced scale, showing a tray provided with risers of a type shown in Figs. 11 and 12;

Fig. 14 is a vertical sectional view showing further modified construction of a symmetrical riser assembly and seal cap;

Fig. 15 is a vertical sectional view through a portion of a contacting column showing the invention applied to inclined trays;

Fig. 16 is a sectional view through a modified riser and seal cap taken on a horizontal section plane at intermediate level and showing a modified construction of the partition walls and the baffles;

Fig. 17 is a vertical sectional view of a further modification wherein the column is adapted for dispersing either the light or the heavy liquid; and

Fig. 18 is a horizontal sectional view taken on line 18—18 on Fig. 17.

Referring to Figures 1 to 8 in detail, **20** indicates a vertical column having top and bottom closures **21** and **22**, vertically spaced conduits **23** and **24** at the top and at a lower level for the introduction of raw heavy and light liquids, respectively, and outlet conduits **25** and **26** at the top and bottom for the discharge of contacted light and heavy liquids, respectively. Conduit **27** is provided at the bottom for the introduction of an auxiliary solvent or anti-solvent. Each of the above conduits and/or the branches thereof are provided with a valve, shown at **28** to **34** inclusive. Level gauges **35** and **36** at the top and bottom, respectively, permit the level of the inter-phase to be observed at either of these levels depending upon the operating conditions.

The column contains a plurality of vertically spaced horizontal trays **37** extending entirely across the column area and dividing the column into a plurality of inter-tray spaces that are isolated from one another and communicate only through risers and downcomers. Each tray has two downcomers **38** and **38***a* extending substantially across the tray at their respective locations, the former being symmetrical and near the center of the tray and the latter being somewhat smaller than the former and near the margin; as seen in Figs. 2 and 3, the downcomers are elongated horizontally to several times the widths thereof. They extend downwardly into the inferior space to a level intermediate the top and bottom thereof; the lower extremities of the downcomers are defined by the bottoms of flat vertical plates **39** that form side walls. The downcomers **38** near the centers of the trays have such plates at both sides whilst the marginal downcomers **38***a* may have only one such plate at the downcomer margins toward the center of the column. End plates **39***a* (Fig. 3) are juxtaposed to the ends of the plates **39** to close the ends of the downcomers; the end plates of the downcomers **38***a* extend to the wall of the column. The plates **39** and **39***a* extend beneath the inter-face level in the quiescent settling zone immediately beneath the respective trays, as will be described hereinafter. Typically, these plates extend from four to twelve inches beneath the trays.

Each tray is additionally provided with a riser assembly positioned directly beneath each downcomer of the next higher tray and having like outlines in plan; thus complete or symmetrical riser assemblies **40** are provided beneath downcomers **38** and half riser assemblies **40***a* are provided at the margins of the trays beneath downcomers **38***a*. As shown more particularly in Figs. 4 to 8, each half riser **40***a* has an upright riser wall **41***a* resting on the tray **37** at the edge of an opening **42** therein with the ends thereof sealed to vertical end plates **43***a* that extend from above the top of the wall **41***a* downwardly through the opening **42** and horizontally to the column **20**; and a plurality of vertical partition walls **44***a* to **44***g*, inclusive, supported by any suitable means. One specific support arrangement (Fig. 8) includes bolts **45** extending through holes in the wall **41***a* and the partitions **44***a* to **44***g* and a plurality of spacers **46***a* to **46***g* which maintain the partition walls in spaced relation. The partitions extend the full horizontal length of the riser assembly with their ends in abutment with end plates **43***a*. According to a preferred arrangement the partition walls are flat parallel plates providing between them narrow riser channels that are horizontally elongated and extend downwardly beneath the tray **37** for progressively greater distances, the riser channel of least downward extent (between wall **41***a* and partition **44***a*) being at the outer margin of the riser assembly so as to be first traversed by light liquid flowing horizontally along the under side of the tray toward the riser. The partition wall **44***g* that has the greatest downward extent typically extends from two to ten inches beneath the tray. It will be noted that the spacings increase progressively, the tallest channel being the widest: this is an advantageous, although not an essential arrangement, it having been found that equally spaced plates can be used. The last riser channel, between the wall of the column **20** and the partition wall **44***g*, is much wider, e. g., as wide as the combined widths of the other channels.

Referring to Fig. 9, each complete riser assembly **40** at an intermediate part of the tray comprises a pair of parallel upright horizontally elongated riser walls **41** at the margins of a rectangular opening in the tray, vertical end plates **43** extending from above the top of walls **41** downwardly through the said openings and sealed to the ends of the walls **41**, and a plurality of vertical partitioned walls collectively indicated by number **44** which are threaded on bolts **45** and separated by spacers **46** at progressively increasing intervals, the intervals being the greatest at the center. The risers **40** differ from risers **40***a* in being symmetrical about a vertical plane, whereby there are within each riser two narrowest marginal riser channels of least downward extent for receiving liquid from both the sides of the riser. Fig. 9 illustrates a modified arrangement differing from that shown on Figs. 1 to 8 in that the series of partitions **44** is continued fully across the width of the riser and no riser channel of width equal to the combined widths of the others is provided. It should be understood that this variant is optional and may be applied if desired, to the marginal riser of Figs. 4 to 8 or may be omitted from Fig. 9 by omitting several of the partition walls near the center.

Each riser has a seal cap **47** or **47***a* resting on plates **43** or **43***a*, spaced vertically from the top of the riser wall **41** or **41***a* and having a dependent skirt **48** extending well beneath the top of the plate **41** or **41***a* and suitably sealed at the ends, as by end plates **49** which extend horizontally outwardly beyond the skirt **48** and downwardly to the tray to prevent escape of liquid at a level above the bottom of the skirt. A bundle of

baffles 50*a* to 50*g* is mounted on the outside of each skirt in closely spaced relation by any suitable means, such as bolts 51 and spacers 52 which may be similar to the parts shown in Fig. 8. The ends of the baffles abut end plates 49. The lower edges of the baffles extend beneath the lower edge of the skirt 48 for progressively greater distances, the baffle nearest the skirt having the least downward extent and the tallest baffle 50*g* being spaced from the tray 37 to provide a passageway 53 inter-connecting the downward channel 54 between plate 41 and skirt 48 with the lower part of the inter-tray space. It will be noted that the baffles define between them a plurality of lower, horizontally elongated vertical discharge channels that are open at the top substantially at the level of the seal cap 47 or 47*a* and have their intake openings at progressively lower levels. Typically, the bottom of the skirt 48 is from two to twelve inches above the tray 37 and the bottom of the baffle 50*g* is from one-half to two inches above the tray. The latter baffle may however be in engagement with the tray and the passageway 53 may be an opening through the baffle or end wall 49. It is advantageous to make the dicharge channels of progressively greater widths, starting with the channel nearest the skirt as shown, although this is an optional arrangement.

The widths of the narrow riser channels and discharge channels will be selected in accordance with the properties of the liquid to be passed through them, particularly the viscosity, the hydrostatic pressure to be balanced by friction between the plates (dependent upon the density difference between the liquid phases, the vertical dimensions of the apparatus and the flow rates) and the exit velocity desired for the light liquid emerging from the upper ends of the discharge channels (dependent upon the degree of dispersion that can be tolerated while achieving settling of the dispersion, influenced largely by the interfacial tension of the liquid phases). The versatility of the apparatus is increased by making the channels of progressively greater widths as described above. By way of illustration, the narrowest riser channels and discharge channels may be between about 1 and 8 millimeters in width, and successive channels may have progressively wider widths following an arithmetic progression with a difference of from one-eighth to one-half of the width of the narrowest channel. It is preferred to have the axes of the outlets of these channels directed above the horizontal, i. e., either vertical as shown in Figs. 1, 4 and 9, or inclined, as shown in Fig. 14.

Referring again to Fig. 1, the supply conduits 23, 24 and 27 are provided with suitable distributing devices, such as horizontal perforated pipes 55, 56 and 57, respectively. The heavy-liquid distributing pipes 55 preferably extend above the tops of the uppermost seal caps 47 and 47*a*; the light liquid distributing pipes 56 preferably extend along the outer sides of the downcomers, adjacent the plates 39 thereof; and the pipes 57 are disposed to bring the second solvent or anti-solvent into contact with the descending heavy phase, as shown.

The operation will be described with reference to the extraction of lubricating oil, which is the light liquid supplied through 24, with a selective solvent consisting essentially of phenol, which is the heavy liquid supplied through 23. The column is initially filled with solvent. While solvent is admitted continuously oil is introduced continuously at any one or more selected trays by opening valve 30 or 31 or both. The oil emerging from the pipes 56 forms a layer of light liquid oil or raffinate phase that floats on the solvent phase. The interface between light and heavy liquid phases will be above the bottom of the downcomer plate 39; the light phase cannot, therefore, ascend through the downcomers, but moves toward the risers in three separate slowly-moving currents, one toward the marginal half-riser 40*a* and the other two toward the two sides of the symmetrical riser 40. Each current thus approaches the horizontally elongated riser channels from a direction perpendicular thereto and traverses first the riser channel at the outer margin of the riser, between the riser plate 41 or 41*a* and the first partition wall 44*a* and ascends through the riser channel as a transport stream. Should the depth of the light layer be such as not to exceed the distance by which the partition 44*a* protrudes beneath the tray, only the first, outer riser channel comes into operation; however, when the depth of this layer is greater a part of the current underflows the first partition, and successively more riser channels come into operation. Thus, the number of riser channels that are in operation is self-adjusting in accordance with the depth of the layer of light liquid or, stated in another way, in accordance with the level of the interface. It may be noted that the riser channels that are not in operation are filled for the greater part with heavy liquid phase, the upper portions usually containing a more or less quiescent body of light phase.

After emerging from the tops of the narrow riser channels at a distant level upwardly beyond the lower extremity of the adjoining higher stage, the light phase enters the downward transport channels 54 and descends through them at least to the lower margins of the skirts 48. Solvent phase initially present in the channel 54 is thereby forced out, mainly through the passageway 53, to form an interface between light and heavy liquid phases below the bottom of the skirt. Light liquid phase is thereby supplied to each stage to a point at a level near the bottom thereof, beneath the level of the interface level in the settling zone thereof and in direct communication (through passageway 53) with the settled heavy liquid phase in the settling zone, and the space at the bottom of the downward channel may be regarded as a feed compartment for the light liquid. The light phase thus supplied then enters one or more of the upwardly elongated narrow discharge channels formed by the skirt 48 and the baffles 50*a*—50*g*, the number of discharge channels in operation being controlled automatically by the level of the interface at the bottom of the channel 54, by the mechanism described above with respect to the riser channels. Thus the baffles that extend beneath the interface level in the seal cap form inverted dams preventing escape of the light liquid from the feed compartment through the passageway 53. In ascending through the narrow discharge channels a part of the potential energy of the ascending phase is dissipated as friction, resulting in discharge at the top with a low or moderately low exit velocity. As the total rate of flow of light liquid is increased, progressively more discharge channels are placed in operation, whereby the exit velocity of the light liquid from the channels previously in operation is not appreciably changed, and the discharge velocity from the additional wider channels is not significantly higher than that from the channels previously in operation.

Heavy solvent phase descending through the downcomers 38 and 38*a* or introduced from the pipes 55 is deflected upon reaching the tops of the seal caps 47 and 47*a* and flows thence as a current moving horizontally in directions normal to the elongation of the downcomers, moving towards the center of the tray from the seal caps 47*a* of the half risers and in two opposite directions from the seal caps 47 of the symmetrical risers. Thus, the spaces above the seal caps may be regarded as feed zones, from which flow currents of heavy liquids that have widths in the horizontal direction transverse to the direction of flow equal to several times the depth thereof. From the feed zones the heavy phase passes over the upper ends of the discharge channels and the light phase, which is discharged from the latter as one or more narrow laminar streams, is injected upwardly into the heavy phase and dispersed therein. There the laminar streams are disrupted into drops and entrained by the heavy phase to leave the tops of the baffles at an initial direction that is inclined upwardly with respect to the horizontal. The space immediately above the baffles 50*a*—50*g* of each seal cap is, therefore, a mixing zone. The space between

each mixing zone and the nearest riser in the same inner-tray space is a quiescent settling zone through which the liquids flow slowly.

The dispersed droplets of light phase settle upwards as the dispersion flows through the settling zone and coalesce, forming a supernatant, continuous layer of light phase in contact with the under side of the upper tray defining the space. Immediately beneath this layer is a dispersion of light phase in continuous heavy phase from which the light phase is settling, this dispersion becoming progressively purer in heavy phase towards the bottom of the zone. The substantially horizontal interface between settled light phase and dispersion is above the bottom of the downcomer plates **39** and above the level of the mixing zone, whereby no downward movement of heavy phase through the interface need take place. The separated light and heavy phases leave the settling zone through the riser and downcomer, respectively.

When equilibrium conditions have been established the above-described action takes place in each of the inter-tray spaces in the column. Final light phase is withdrawn at the top through conduit **25** and final heavy or solvent extract phase at the bottom through conduit **26**. The rate of withdrawal of the latter is controlled by valve **34** to maintain an interface level above the uppermost tray as indicated, for example, by the gauge **35**. In this operation the gauge **36** is not used; it is used to maintain the interface level at the bottom when the heavy phase is dispersed in the light phase, the trays being in each case inverted from the positions shown.

In the inter-tray spaces beneath the level of the column at which oil is admitted the descending extract phase is contacted with an auxiliary solvent admitted through the conduit **27** or with a light phase generated within the column. Thus, in the latter case, an anti-solvent, such as phenolic water, is admitted through the conduit **27**, which reduces the solvent power of the selective solvent and causes a part of oil dissolved therein to be sprung from solution to form a light liquid phase. The latter ascends through the risers as was described above.

To prevent excessive circulation of liquids around the trays it is important to provide an effective hydraulic seal by making the downward channel **54** sufficiently tall to counteract the unbalanced forces tending to produce circulation. Prior extraction apparatus of the character described have failed to achieve such a seal. This requirement is best explained with reference to Fig. 10, which shows a column **20***c* wherein each tray **37***c* has one downcomer **38***c* and one riser **40***c* at opposite margins, these being constructed as previously described with riser walls **41***c*, seal caps **47***c* provided with skirts, partition walls **44** and baffles **50**. Three interface levels A, B and C are indicated by wavy lines in the settling zone, riser and downward channel **54**, respectively. Four reference levels are indicated by broken lines: h_1 at the bottom of the downcomer; h_2 at the lowest extremity of the partitions **44**; h_3 at the lowest extremity of the baffles **50**; and h_4 at the top of the riser wall **41***c*. Heavy phase, often containing some dispersed light phase, occurs in the part of the riser not in operation for transporting light phase, up to the interface level B, and it is desired to make the distance h_4-h_3 great enough to maintain this interface level below the top of the riser wall **41***c*. During operation only a small pressure drop occurs in the downcomer, and it is advantageous to design the riser to provide a seal without allowance for the pressure drop due to flow.

When the interface B is at level h_3, hydrostatic balance occurs when the pressure at level h_1 due to the columns of the liquid within the riser up to the level h_3 and beneath the riser down to level h_1 is equal to the pressure at h_1 due to the columns of liquid within the downward channel **54** inside the seal cap and within the downcomer and immediately above it. If d_1 is the density of the liquid within the part of the riser that contains heavy phase (i. e., the part communicating with the settling space below the interface A), d_2 the density of the liquid immediately beneath the riser down to the level h_1, d_3 the density of the liquid in the downward channel and d_4 the density of the liquid in the downcomer and immediately above the downcomer, the following equation defines the hydrostatic balance:

$$d_1(h_4-h_2)+d_2(h_2-h_1)=d_3(h_4-h_3)+d_4(h_3-h_1) \quad (1)$$

The positions of levels h_1, h_2 and h_3 may be selected with a view toward making the column as short as possible while providing sufficient height to permit effective settling and graduated lengths for the partition walls and baffles. Thus, in a typical design the distance from h_1 to h_2 may be 5 inches and that from h_2 to h_3 may be 6 inches (making h_2 four inches below the tray **37***c*). Substituting these dimensions in Equation 1, the following general equation for the minimum seal required for this particular design can be derived:

$$h_4-h_3=\frac{11d_4-6d_1-5d_2}{d_1-d_3} \quad (2)$$

When complete settling is effected, which would normally occur only with extremely low flow rates, d_1, d_2 and d_4 are each equal to the density of pure heavy phase and d_3 is equal to the density of pure light phase. However, under practical operating conditions all of these liquids will consist of dispersions containing varying proportions of both phases. In a typical case the average compositions of the liquids may be such that they contain the following volumetric fractions of light phase, the balance being heavy phase: In the part of the riser under consideration, 0.55; immediately beneath the riser down to level h_1, 0.45; in the downward channel, 0.87; in the downcomer and immediately above it, up to level h_3, 0.16. If H and L are the densities of pure heavy and light phases, respectively, and f is the volumetric fraction of light phase in a liquid mixture, the average density of the liquid is $H-f(H=L)$. Upon substituting these densities in Equation 2, a minimum value of 11.9 inches is obtained for the distance h_4-h_3, this value being independent of the values H and L. It is evident that the minimum height of seal which will be effective depends, rather, upon the values of f in the various regions described. These values of f vary systematically with flow rates and with the properties of the phases. The relationship has not been established on an exact mathematical basis but can be determined by appropriate flow experiments using an apparatus as shown in Figure 10.

By following the foregoing steps the minimum value for the distance h_4-h_3 to attain a seal under static conditions with any given extraction system can be determined. When such a seal is provided the interface level B is prevented from rising above the wall **41***c* and spillage of heavy phase into the downward channel **54** is substantially prevented, thereby preventing excessive circulation around the tray. During operation, when large rates of flow occur and/or when a constriction is placed in the downcomer to create a pressure drop the interface level B drops to below the top of the wall **41***c*.

When an insufficient seal is provided and the interface level B is above the top of the wall **41***c* the riser is hydrostatically unbalanced and heavy liquid phase is forced over the wall **41***c* and down through the channel **54** to enter the higher inter-tray space through the passageway **53**. This flow aggravates the unbalance in that the density d_3 in the downward channel is increased. The undesired transport of heavy liquid phase through the risers reduces the stage efficiency by causing backmixing (i. e., the flow of a liquid to a stage in a direction opposite to the intended direction of flow of that liquid). It further interferes with the settling in the settling zone because of the increased flow rates tending to promote turbulence and to reduce the available settling time.

As was noted above, perfect settling is in general not

achieved under practical operating conditions and the light liquid phase above the interface A that enters the narrow riser channels contains entrained therein small amounts, e. g., from 1 to 20% v. of heavy liquid phase. A part of the entrained phase is coalesced in the riser channels and in the downward channel 54; a small part of the coalesced material returns to the lower stage through the part of the riser that is not used for transporting light phase and the remaining part settles to interface C at the bottom of the channel 54 and escapes through the passageway 53. Except for this small flow, little or no flow through the latter passageway takes place after equilibrium has been established. However, the passageway 53 plays an important role apart from that of permitting the escape of settled heavy phase in that it prevents siphoning of liquids. Thus, if the passageway 53 were closed off Equation 1 would no longer define the condition of hydrostatic equilibrium and siphoning of light and heavy liquid to the upper ends of the discharge channels at the tops of the baffles 50*a*—50*g* would occur.

Considering next the six conditions previously stated as leading to accomplishment of the objects of the invention:

The first condition, avoidance of excessive dispersion, is achieved by locating the mixing zone only a small vertical distance, e. g., two to ten inches, below the interface A in the inter-tray space. It was found that dispersing the liquid at a greater vertical distance from the interface is deleterious to accomplishment of this condition. This condition is further brought about by discharging the light phase in laminar flow through openings of controlled size, that prevent the emergence of the light phase as excessively fine streams. This condition is also promoted by attainment of condition six, described below, since injection of the light phase into the continuous heavy phase at high velocity with energy equivalent to the potential energy of the light phase measured from the next adjacent settling zone below the mixing zone is detrimental to the accomplishment of the first condition. Accomplishment of this first condition has a beneficial effect toward the establishment of hydraulic balance because it results in favorable values of f as discussed above.

The second condition is attained by the characteristics of the construction which insure the passage of all of the descending heavy phase and all of the ascending light phase over a mixing zone that is horizontally elongated. This condition further requires that there be a sufficient break-up of the light phase to produce sufficient surfaces for the transfer of constituents between the phases; this is achieved by injecting the light phase upwardly into the heavy phase stream which crosses the path of the light phase as a current, the width of which in the horizontal direction transverse to the direction of flow is several times the depth of the current.

The third condition is achieved by confining the mixing to a zone in the upper part and, preferably, in the upper third of the inter-tray space, and by avoiding any directional velocity vector for the dispersion leaving the mixing zone which is downward. The resultant of the horizontal flow of the heavy phase and the vertical or upwardly inclined flow of light phase is at an angle above the horizontal. It was found that this flow avoids turbulence and swirls, while flow that has a downward velocity vector causes large swirling movements which disturb the settling zone and lead to incomplete settling, hence to unfavorable values of f and to entrainment. This condition is further aided by accomplishment of conditions (4) and (5) since flow rates in excess of those required in the absence of entrainment lead to high rates of flow in the settling zone, resulting in only partial settling.

The fourth condition is achieved by the use of the seal cap and skirt over the riser with an overlap of the skirt sufficient to form a hydraulic seal that balances the hydrostatic forces; this was explained above in detail. It is, of course, not essential that the overlap be sufficient to provide a complete seal under no-flow conditions, because there is some pressure drop due to flow through the downcomer and riser and the overlap may in some cases be reduced by taking the pressure drop into account. However, this pressure drop is minor and it is not desirable to introduce orifice type flow resistances because this leads to inflexibility as to usable flow rates and types of liquids that can be handled, and it is preferred to provide a seal that is effective without pressure drop. That the narrow riser channels do not afford the necessary resistance is attested by the presence of a flow path through the channels that communicate at the bottom below the interface A, wherein low rates of flow occur; further, in all embodiments except Fig. 9 there is a wide channel in the riser. The large downward channel 54 and passageway 53 also do not afford any appreciable resistance. Hence, it is the hydraulic seal itself that prevents excessive circulation.

The fifth condition is brought about by providing the partition walls 44 in the risers, extending to progressively greater distances beneath the trays, whereby one or more riser channels will be filled with segregated light phase, and mixing of the phases is confined to the last fractional riser channel required with any given position of the interface level A. The separate phases are thus divided, except for a small residual fraction, by partitions that are, in the illustrated embodiments, imperforate; these phases do not remix until the mixing zone is reached.

The sixth condition is accomplished by using a multiplicity of narrow discharge channels between the baffles on the outsides of the skirts, having identical or progressively greater widths such as to cause appreciable fractional pressure drops in the direction of flow. The light liquid phase immediately beneath each tray possesses considerable potential energy in relation to its position at the mixing zone in the next higher inter-tray space, and were it permitted to ascend freely to the mixing zone this energy would be converted into kinetic energy, resulting in high discharge velocities. This kinetic energy would be partly used up in creating new surfaces between the phases, i. e., in the formation of many extremely fine droplets, and partly in creating swirls and eddies, which disturb the settling zone. This condition is undesirable in many cases, particularly when systems having low interfacial tensions are dealt with. By passing the light phase through the narrow discharge channels the excess potential energy is converted into heat by friction, leaving only that kinetic energy required to effect the desired dispersion. By thus holding the exit velocities to a low value turbulence in the exit region is minimized.

The invention is not limited to the use of downcomers and riser assemblies having straight sides and it is possible to employ other geometric shapes. One alternate design is illustrated in Figures 11–13 wherein the downcomers and riser assemblies have arcuate outlines. Thus, a row of complete downcomers 60 and a row of half-downcomers 60*a* may be arranged as shown in Figure 13. Each of these downcomers has cylindrical side walls that extend beneath the tray in the manner previously described for the plates 39, the complete downcomers being circular in cross-section and the half-downcomers being semi-circular. Figures 11 and 12 show a complete riser assembly 61 such as is provided in vertically spaced relation beneath each downcomer 60 on the next lower tray; half-riser assemblies, of similar construction but having narrow riser and discharge channels only on the semi-circular margins and closed to the flow of liquid on the straight sides, are mounted beneath the half-downcomers 60*a*. Each complete riser assembly has an annular riser wall 62 resting on the tray 37 at the margin of a circular hole 63. A plurality of concentric cylin-

drical partition walls 64*a* to 64*f* extending from a common level at the top of the wall 62 to progressively greater distances beneath the tray 37 is supported by radial bolts 65 and spacers 66*a* to 66*f* inclusive, to provide a plurality of annular vertical riser channels of progressively greater downward extension. The widths of the channels are progressively greater toward the center. A seal cap 67 having an annular skirt 68, spaced radially from the wall 62, is mounted in vertically spaced relation to the latter by bolts 69 and spacers 70. A plurality of cylindrical baffles 71*a* to 71*f* extending from a common level at the top of the seal cap 67 to progressively greater distances beneath the bottom of the skirt 68 is secured to the latter by radial bolts 72 and spacers 73*a* to 73*f*. These baffles provide narrow annular discharge channels having progressively greater width starting with the radially innermost channel. The lower margin of the skirt extends well below the top of wall 62 but is spaced from the tray 37 by a distance sufficient to permit the baffles to extend beneath it with the longest baffle 71*f* spaced from the tray to provide a passageway 74.

The operation of the embodiment of Figures 11 to 13 is similar to that previously described, in that light liquid phase from the underside of tray 37 ascends through one or more narrow annular riser channels, overflows the top of the riser wall 62, descends through the downward channel 75 and ascends through one or more discharge channels. The operation of these riser assemblies differs from that of the prior embodiments only in that light liquid phase can flow inward from all radial directions and in that the light phase discharged at the top of the seal cap flows as one or more concentric annular streams into the heavy liquid phase which is discharged downwardly into the center of the seal cap and flows thence radially in all directions. Although the flow at each riser assembly is thus distributed in all radial directions, it will be noted from Figure 13 that the resulting dispersion formed at the margins of the complete seal caps 67 must flow toward the row of complete downcomers 60 or to the row of half-downcomers 60*a*, whereby the general direction of flow is the same as in the first embodiment. The dispersion discharged from the half-seal caps 67*a* flows toward the row of downcomers 60.

It is not essential that the baffles and/or the partition walls be vertical or parallel; in fact, for certain systems it is advantageous to employ other arrangements. Five modifications of these parts (arrangement of the partitions, of the baffles, of the inlets to the riser channels and discharge channels and the outlets to the discharge channels) are illustrated in Figure 14, it being understood that each of these may be applied separately. In this figure a pair of inclined, upwardly convergent, flat riser walls 76 is mounted at the margins of a rectangular opening in the tray 37 with their upright margins juxtaposed to a pair of vertical end walls 77 that diverge downwardly and extend through the said opening, only one wall 77 appearing in the drawing. A plurality of flat partition walls 78*a* to 78*g* extend the full length of the interval between the end walls 77 adjacent to each riser wall 76 and extend beneath the trays 37 for progressively greater distances, starting from the walls 76. These partition walls are inclined at progressively different angels of inclination with each outermost wall 78*a* having an inclination nearest to that of the wall 76 and each innermost wall 78*g* being vertical, thereby providing two pluralities of narrow riser channels that converge toward the top. The two walls 78*g* provide between them a very wide channel, although this feature is optional and the arrangement of Fig. 9 may be used. These partition walls may be mounted in any desired manner, e. g., by being welded to the end walls 77.

A seal cap 79 rests on the upper ends of the end walls 77 in spaced relation to the upper ends of the walls 76 and has downwardly and outwardly inclined skirts 80 spaced from the walls 76 and parallel thereto to provide downward channels 81. A plurality of baffles 82*a* to 82*g*, inclusive, is mounted on the outside of each skirt 80 between a pair of vertical end walls 83 which close the ends of the seal cap and protrude laterally to close the ends of the discharge channels between the baffles. The baffles have progressively different inclinations as shown, each first baffle 82*a* being inclined only slightly toward the vertical from the inclination of the skirt 80 and each successive baffle being more nearly vertical than the preceding one, whereby the narrow discharge channels diverge toward the top. The baffles protrude beneath the bottom of the skirt 80 for progressively greater distances as shown, the outermost baffles 82*g* being spaced from the tray 37 to provide a passageway 84. The upper ends of the baffles may be terminated at progressively lower levels as shown, whereby the vertical extent of the mixing zone is increased when a greater number of discharge channels comes into operation. The upper ends of these channels may be curved away from the seal cap 79 to direct the light liquid toward the settling zone; however, the axes of the discharge openings should be directed upwardly from the horizontal. Moreover, the lower ends of the partition walls of the riser and of the baffles may be curved toward the approaching stream of light liquid as shown to facilitate entry of the liquid into the channels.

By making the riser channels wider at the bottoms the entry of light liquid phase is facilitated particularly when the liquids are incompletely settled; in this event, globules of one phase, too large to enter the very small rise, may block narrow entrances to the riser channels. As was explained heretofore, additional settling and coalescence takes place in the downward channels 81 so that there is less likelihood of blocking the entrance to the discharge channels between the outer baffles and narrow entrances are usually satisfactory. In this case, however, it is often desirable to discharge the light liquid with extremely low upward velocities and such a reduction and low velocity is obtained by using the upwardly diverging baffles. These channels must be narrow at least at parts thereof, e. g., at the bottoms as shown, to create friction and dissipate excess energy as heat.

The expression downcomer is to be understood to denote any opening in the trays by which heavy liquid phase from an inter-tray settling zone is transported to the feed of the next lower inter-tray space, preferably beneath the inter-face level of the settling zone in the latter space; this does not necessarily imply the presence of a tube or wall that projects downwardly into the inter-tray space. Moreover, the trays need not be horizontal. Both of these points are illustrated in Figure 15 wherein the column 20 has a plurality of inclined trays 85 sloping generally downwardly from the center, alternated with inclined trays 86 that slope downwardly toward the center. Each tray 85 has two downcomers in the form of rectangular openings 87, there being one downcomer near each margin of the tray, at the lowest parts of the tray. These openings have outlines similar to the openings 38*a* shown in Figure 2. A baffle plate 88, supported from the column and spaced therefrom, is positioned directly above each downcomer. Each tray 85 is further provided with a complete, symmetrical riser assembly 89, seal cap 90 and baffles 91 at the center along the ridge thereof. Each tray 86 is provided with a downcomer in a form of a rectangular opening 92 at the center along the lowest portion thereof and directly above the seal cap 90 the next lower tray; this opening and the risers 89 of the trays 85 have like outlines which may have outlines like that of the opening 38 shown in Figure 2. A rectangular baffle 93 is mounted directly above the downcomer opening in spaced relation to the tray. Each tray 86 moreover has at each margin thereof a half riser assembly 94, a seal cap 95 and a plurality of baffles 96 at the margin thereof directly beneath the downcomers

87. The details of the riser assemblies, seal caps and baffles are the same as those described above in connection with Figures 1 to 8 and need not be further described.

In operation, heavy liquid phase descending through the downcomers **92** and **87** is deflected by the seal caps **90** and **95** and flows horizontally above the upper ends of the baffles **91** or **96**. The dispersion formed by the discharge of light liquid phase upwardly through the discharge channels between these baffles flows thence into the settling zone which is gradually enlarged vertically in the direction of flow. In this manner the interface in each inter-tray space is at a level above that of the downcomer supplying that space and of the mixing zone thereof despite the fact that no part of the downcomer protrudes beneath the tray.

The riser channels and/or the discharge channels need not be horizontally elongated, but may be formed as confined channels. Such an arrangement is shown in Figure 16, which is a section on a horizontal plane through a complete riser assembly, seal cap and baffle. *41b* are the upright riser walls of the riser assembly and *48b* are the skirts of the seal cap corresponding to parts **41** and **48**, respectively of Figure 9. A plurality of sheets of corrugated metal *96a* to *96d*, inclusive, is mounted along the inner side of each riser wall *41b*. A flat sheet of metal, *97a* to *97d*, inclusive, is placed on the outer side of each corrugated member, thereby providing a plurality of narrow vertical channels arranged in four parallel rows. The corrugated members have progressively larger corrugations starting at the walls *41b*, whereby the channels of successive rows have progressively greater widths. A similar arrangement is employed at the outside of each skirt *48b* wherein corrugated metal members *98a* to *98d* inclusive, each provided with a flat sheet *99a* to *99d*, are secured as shown to provide four rows of narrow discharge channels of progressively greater widths.

Figs. 17 and 18 show a modified construction which is suitable for dispersing either the lighter or the heavier liquid in the other liquid in accordance with the operating conditions and without inverting the trays. The column **100**, which may have a rectangular cross-section as shown, has a plurality of trays **101** provided with downturned flanges **102** and upturned flanges **103** at opposite margins, forming downcomers and risers respectively, and arranged so that opposed flanges **102** and **103** of adjacent trays are in vertical alignment. A horizontal partition **104** is supported from column **100** intermediate to and vertically spaced from each pair of flanges **102** and **103** and has a vertical seal skirt **105** extending both above and beneath the partition and in spaced relation to the flanges **102** and **103**. The seal skirts overlap the flanges vertically so as to provide upward channels **106** and downward channels **107**. A bundle of vertical flat partition walls **108** is mounted on each flange **102** within each downcomer to provide a plurality of narrow downcomer channels, the upper extremities of the partitions extending above the respective trays for progressively greater heights whereby a variable number of channels will be in operation for transporting heavy liquid. Similarly, a bundle of vertical flat partition walls **109** is mounted on each flange **103**, within each riser with the partitions extending for progressively greater distances beneath the respective trays to provide narrow riser channels. A bundle of flat, parallel, closely spaced baffles **110** is mounted on the outer face of each sealing skirt **105** with the upper and lower extremities of the baffles extending for progressively greater vertical distances beyond the extremities of the skirts, the longest baffle being the most distant from the skirt and being spaced vertically at both top and bottom from the nearby trays by substantial distances so as to leave ample passageways **111** and **112** at the top and bottom.

In operation, when light liquid is to be dispersed in heavy liquid, the column is initially filled with heavy liquid as was described for the first embodiment and light and heavy liquids are thereafter supplied continuously at the bottom and top respectively, while maintaining a liquid-liquid interface at the top of the column. The feed and drawoff conduits, not shown, may be of any suitable type, e. g., as shown in Fig. 1. In this type of operation the partition walls **108** play no essential part and heavy liquid phase descends through each downcomer toward the partitions **104**, flowing primarily through the wide parts of the downcomers beyond the partitions **108** and partly through the narrow downcomer channels between these partitions. Heavy liquid then rises through the upward channels **106** and flows out horizontally through the passageways **111**. The liquid-liquid interface is maintained beneath each tray **101** and above the bottom of the longest partition **109**. Settled light liquid above this interface rises in each riser through one or more narrow riser channels between partitions **109**, descends through the downward channels **107** and again upwardly through one or more discharge channels of each bundle of baffles **110**. Upon emerging from the latter in laminar flow, it is dispersed in the heavy liquid phase, the resulting dispersion being settled upon passing through the settling zone between each passageway **111** and the riser at the other edge of the adjacent center tray **101**.

When the heavy liquid phase is to be dispersed in the light liquid phase the column is initially filled with light liquid and thereafter light and heavy liquids are supplied to the column from the bottom and top respectively, while maintaining a liquid-liqud interface at the bottom of the column. In this case the light liquid phase ascends through the risers passing mostly through the wide channels beyond the partition walls **109** and partly the narrow riser channels, and thereafter flows downwardly through the channels **107** and **112** across the lower ends of the baffles **110**. The liquid-liquid interface is near the bottom of each inter-tray space, beneath the upper ends of the partition walls **108** of highest extent. Heavy liquid flows downwardly within each downcomer through one or more of the narrow downcomer channels between these partitions, up through the upward channels **106**, and downwardly through one or more of the discharge channels between the baffles **110**. Upon emerging from the latter in laminar flow it is dispersed in the light liquid phase. The resulting dispersion is settled in the settling zone beyond the baffles **110**.

We claim as our invention:

1. The method of contacting at least partially immiscible first and second liquids of different densities in a confined contacting stage having horizontally contiguous, intercommunicating mixing and settling zones which comprises: maintaining layers of said liquids separated by a liquid-liquid interface within said settling zone; admitting said first liquid to said confined stage and flowing it through the mixing zone toward the settling zone of said stage with a horizontal velocity component; supplying the said second liquid to a confined feed zone having a level displaced from said mixing zone and from said interface in the settling direction of said first liquid, said feed zone being in direct communication with the layer of said first liquid within said settling zone; flowing the said second liquid from said feed zone with a flow component in its settling direction through a channel which is elongated in the said settling direction and has a width less than the length thereof out of contact with other liquid in said stage and thereby dissipating energy, the level of said direct communication between the feed zone and the layer of first liquid being substantially the same as the level of the inlet end of said channel; and discharging the second liquid from said channel at said mixing zone as at least one narrow stream into said current of first liquid to form a dispersion therein.

2. The method according to claim 1 wherein the said interface is maintained at a level displaced from the mixing zone in the said settling direction of the second liquid.

3. The method according to claim 1 for dispersing the said second liquid at a varying total flow rate wherein the said second liquid is flowed with a flow component in its settling direction through a variable number of narrow channels and is discharged as a plurality of narrow streams, the said number of channels being increased progressively as the said total flow rate increases, while maintaining the discharge velocity of said narrow streams substantially constant.

4. The method of contacting at least partially immiscible first and second liquids of different densities at different total flow rates of at least one of the liquids in a confined contacting stage having horizontally contiguous, intercommunicating mixing and settling zones which comprises: maintaining layers of said liquids separated by a liquid-liquid interface within said settling zone; flowing the first of said liquids through said mixing zone toward said settling zone as a current flowing substantially horizontally and having a horizontal transverse width that is several times the depth of the current, said mixing zone and interface being both situated in the part of the stage toward the settling direction of the second of said liquids with the interface displaced from the mixing zone in the said settling direction; supplying the said second liquid to a point having a level displaced from said mixing zone in the settling direction of said first liquid; moving the said second liquid from said point and injecting it into said current as at least one narrow stream distributed substantially across the entire width of the said current at low velocity with a velocity component in the settling direction of the second liquid to form a dispersion; increasing the number of narrow streams of second liquid by which it is injected into the current as the said total rate of flow thereof is increased while maintaining the injection velocity substantially constant; flowing said dispersion to the settling zone; and settling the dispersion in the settling zone.

5. Method of contacting at least partially immiscible liquids by operations including dispersing the first liquid into the second liquid comprising the steps of flowing said second liquid as a current; dividing the first liquid into a plurality of separate, adjacent narrow laminar streams moving toward and transversely to the direction of flow of said current for distances several times as great as the thickness of the laminar streams; and thereafter injecting the said laminar streams transversely into the said current of second liquid to form a dispersion.

6. Method of contacting at least partially immiscible liquids by operations including dispersing the first liquid into the second liquid, comprising the steps of flowing said second liquid substantially horizontally through a mixing zone as a current having a width equal to several times the height thereof; dividing the first liquid into a plurality of separate, adjacent narrow laminar streams moving substantially vertically toward said current for distances several times as great as the thickness of the laminar streams, said streams extending substantially across the full width of said current and thereafter successive laminar streams being displaced from each other in the direction of flow of the current; and thereafter injecting said laminar streams into said current to form a dispersion.

7. Method of contacting at least partially immiscible, relatively lighter and heavier liquids in a plurality of contacting stages, each stage having a bounded settling zone, which comprises the steps of maintaining upper and lower layers of lighter and heavier liquids, respectively, separated by a liquid-liquid interface within a settling zone; continuously supplying additional amounts of at least one of said liquids to said settling zone at a variable rate, thereby altering the position of said interface; transporting liquid from the layer containing said one liquid as a plurality of horizontally spaced streams segregated from each other and flowing with vertical flow components from progressively different levels distributed throughout the depth of the said layer; and increasing the number of said streams progressively as the position of said interface is altered in a direction opposite to said vertical flow components of said streams so as always to include in said plurality of streams at least one stream starting from the level of said interface.

8. The method of contacting at least partially immiscible first and second liquids of different densities in a plurality of superposed contacting stages defined within confining walls, each stage having a mixing zone and a settling zone bounded at the top and bottom by bounding walls, which comprises: maintaining within the settling zone of a stage layers of said liquids separated by a liquid-liquid interface; supplying the first of said liquids to the mixing zone of the stage; introducing an additional amount of the second of said liquids into the mixing zone of the stage at a variable rate and dispersing it in said first liquid; flowing the resulting dispersion to the settling zone within the stage and therein settling the liquids; flowing settled second liquid in the settling zone with a horizontal velocity component in contact with one of said bounding walls to a draw-off point; transporting said settled second liquid from the draw-off point as a plurality of horizontally spaced streams segregated from each other into an adjoining stage in the settling direction of said second liquid, one of said streams starting substantially from the level of said interface and the other streams starting from other levels situated progressively toward the said settling direction of the second liquid; and increasing the number of said streams progressively as the said rate of introduction of said second liquid increases so as always to include in said plurality of streams at least one stream starting from the level of said interface.

9. In combination with the steps in the method of claim 42, the step of maintaining a column of liquid separate from said streams of settled second liquid and communicating at one part thereof with said streams at the ends thereof corresponding to the said settling direction of the second liquid and communicating at another part thereof with the layer of said first liquid in the said settling zone.

10. The method according to claim 9 wherein the said streams of second liquid are transported to a level beyond the near vertical extremity of said adjoining stage and the transported second liquid is thereafter flowed through a vertical distance in a direction opposite to the said settling direction thereof to a point situated at a level closer to the said near extremity and in direct communication with the layer of first liquid in the adjoining stage, said level being displaced from the interface in the adjoining stage in a direction opposite to said settling direction; the said second liquid is flowed thence again with a velocity component in the said settling direction to the mixing zone of said adjoining stage through at least one channel out of contact with other liquid and there mixed with first liquid supplied thereto; and the first liquid from the said adjoining stage is transported by hydrostatic pressure as a separate stream into said one stage, the said vertical distance of flow of second liquid being at least great enough to balance the hydrostatic pressure tending to cause circulation of first liquid from said one stage through said separate column of liquid to said point in the adjoining stage.

11. Method of contacting at least partially immiscible first and second liquids of different densities by countercurrent flow through a plurality of superposed contacting stages defined by transverse trays within confining walls, each stage having a mixing zone and a settling zone, which comprises: admitting liquids of relatively lower and higher densities to vertically spaced, relatively lower and higher feed stages, respectively; dispersing the second of said liquids at the mixing zone of each stage into first liquid; settling the resulting dispersion in the settling zone of each stage and thereby forming upper and lower layers of the liquids separated by a liquid-liquid interface; with-

drawing settled first liquid from each stage; transporting withdrawn first liquid by hydrostatic pressure from each stage except the feed stage for second liquid to the next stage in the settling direction of first liquid; withdrawing settled second liquid from the feed stage for first liquid; transporting settled second liquid from each stage except said feed stage for first liquid by hydrostatic pressure as at least one transport stream consisting substantially only of settled second liquid and flowing with a vertical flow component in the settling direction of second liquid to a distant level beyond the near vertical extremity of the next stage in the said setling direction of second liquid; maintaining between each pair of adjacent stages a column of liquid that is in direct communication at one part thereof with the end of said transport stream at said distant level and is in communication at another part thereof with the layer of first liquid in the settling zone of the stage from which said transport stream emanated; flowing transported second liquid from each of said distant levels in a direction having a component opposed to the settling direction of second liquid within a confined transport channel to a feed compartment for the said next stage; within each stage maintaining direct communication between the layer of first liquid therein and the transported second liquid in said feed compartment; and flowing said transported second liquid from each said feed compartment with a vertical flow component out of contact with other liquid through one or more restricted discharge channels to the mixing zone of the respective stage, the vertical distance from each said distant level to the level of the feed compartment within the same stage being at least great enough to balance the hydrostatic pressure tending to cause circulation of first liquid from the adjacent stage in the settling direction of first liquid through said column of liquid to said distant level and thence through said confined transport channels to said feed compartment and into the space within said stage.

12. Solvent extraction apparatus for contacting at least partially immiscible light and heavy liquids comprising an enclosure defining a contacting space containing contacting elements, a part of said space forming a settling zone, said apparatus being adapted, when arranged as specified herein, to effect dispersion of the light liquid into the heavy liquid and, when inverted, to effect dispersion of the heavy liquid into the light liquid, said elements including: a wall structure enclosing a confined feed zone at a low level of said contacting space, said structure providing a pressure-equalizing passageway connecting said feed and settling zones at said low level; duct means within said space defining at least one channel, each said channel having an inlet opening which communicates with said feed zone substantially at said low level, being vertically elongated upwards from said inlet opening, having at the top thereof a directed discharge opening which communicates directly with said enclosed contacting space, and being constricted between said inlet and being restricted in thickness between said inlet and discharge openings to dissipate energy of liquid flowing therethrough; means for supplying liquid to be dispersed to said feed zone from a source outside said enclosed contacting space for upward flow through said restricted channel and discharge through the directed opening; means for admitting the other liquid to the contacting space and directing it as a current contiguous to said directed discharge opening and across the stream of liquid emerging therefrom; and vertically spaced outlets for said settling zone for withdrawing settled light and heavy liquids.

13. Solvent extraction apparatus according to claim 12 wherein the directed discharge opening at the top of each channel is disposed to discharge liquid with an upward velocity component and the said means for admitting the other liquid comprises channel means for directing the current of said other liquid above said discharge opening substantially horizontally toward said settling zone.

14. Solvent extraction apparatus according to claim 12 wherein said duct means provides a plurality of confined channels, the inlet openings of the several channels being situated at progressively different levels, whereby a variable number of said channels will be supplied with said liquid to be dispersed when the lower level of said liquid within the feed zone is altered.

15. Solvent extraction apparatus according to claim 14 wherein the widths of the confined channels are progressively greater in accordance with the progressively lower levels of their respective inlet openings.

16. Solvent extraction apparatus for contacting at least partially immiscible light and heavy liquids comprising enclosing walls defining a contacting space containing contacting elements adapted, when arranged as specified herein, to effect dispersion of the light liquid into the heavy liquid and, when inverted, to effect dispersion of the heavy liquid into the light liquid, said elements including: a plurality of closely spaced upright walls defining between them a plurality of laminar channels that open at the top and bottom for restricting the flow of liquid therethrough, the openings at the top being discharge openings directed to discharge liquid with an upward velocity component, said walls dividing said space into a settling zone and a feed compartment for light liquid to be dispersed, said walls being spaced from the bottom wall of said contacting space by progressively greater distances with the wall nearest the settling space closest to said bottom wall and spaced therefrom to provide a passageway interconnecting said feed compartment and the settling zone at the lower levels thereof; means closing the sides of said laminar channels; wall means isolating the top of said feed compartment from said contacting space; means for supplying light liquid into said feed compartment; means for admitting heavy liquid to the contacting space and directing it as a current flowing substantially horizontally over the discharge openings of said laminar channels toward the settling zone; and vertically spaced outlets for withdrawing settled light and heavy liquids from said settling zone.

17. Apparatus for forming a dispersion comprising an enclosure defining a contacting space; conduit means for admitting a first liquid into said space and directing it as a current through said space; a plurality of closely spaced baffle walls extending transversely substantially at right angles to the direction of flow of said current and spaced apart by distances much smaller than the lengths of the walls in the said transverse direction, to define between them a plurality of narrow laminar channels open toward said current; and means for supplying a second liquid to said laminar channels at points spaced from said open parts of the channels substantially by the full lengths of said walls, whereby the second liquid can be injected into said current as a plurality of laminar streams to form a dispersion, said baffle walls diverging slightly toward said current and the channels being fully open toward said current, whereby the velocity of the laminar streams is progressively lowered in approaching the current and are discharged at a low velocity.

18. In combination with a partition separating vertically adjacent stages of solvent extraction apparatus, an assembly for transporting settled liquid as a plurality of segregated streams between said stages, said assembly being adapted, when arranged as specified herein, to operate as a riser for light liquid and, when inverted, to operate as a downcomer for heavy liquid, comprising: an opening in said partition; a wall structure defining a plurality of separate upright riser channels extending upwardly into the upper stage to above the level of said partition, said wall structure being sealed to the margins of said opening to permit the passage of liquid through the opening only through said riser channels, said channels having upper openings placing the upper ends thereof into communication with one another and extending downwardly through said opening, said channels having lower openings communicating with said lower stage at progressively different levels therein and said channels being arranged so

that each lower opening is in free flow communication along a horizontal path with light liquid moving along the under side of said partition toward the duct.

19. In combination with the elements recited in claim 18, a seal cap with a dependent, peripherally sealed skirt located within the upper stage above the riser channels and spaced vertically above said upper openings, said skirt being spaced laterally from said wall structure and extending down to below the said upper openings to provide a downward transport channel for the flow of light liquid that emerges from the said upper openings, the lower part of said skirt being at least in part spaced above said partition to permit the outflow of liquid beneath the skirt into the said upper stage.

20. In combination with the elements according to claim 19, a downcomer through said partition interconnecting the lower part of said upper stage to the lower stage for transporting heavy liquid from said upper stage to the lower stage, said skirt of the seal cap extending beneath the said upper openings of the riser channels for a vertical distance sufficient to balance the hydrostatic pressure tending to force heavy liquid upwards through the riser channels and downwardly through said downward transport channel and downcomer.

21. In combination with the elements recited in claim 20, wall means within said upper stage providing one or more elongated, confined and constricted discharge channels for the restricted flow of light liquid, said channels having inlet openings at the bottom thereof communicating with said downward transport channel near the bottom thereof and having discharge openings at the upper parts thereof communicating with the said upper stage, said skirt and wall structure providing a passageway connecting the bottom of said downward transport channel to the bottom of said upper stage.

22. An assembly for transporting settled liquid as a plurality of segregated streams between vertically adjacent stages of solvent extraction apparatus wherein the stages are separated by trays, said assembly being adapted, when mounted as specified herein, to operate as a riser for light liquid and, when inverted, to operate as a downcomer for heavy liquid, comprising: an enclosing wall structure defining an upright riser duct adapted to be fitted to an opening in said tray and to extend upwardly into the upper stage to a raised level above the said tray and to communicate with said lower stage through said opening substantially at the level of the tray; and a plurality of upright partition walls located partly within said duct and protruding downwardly to extend into the lower stage for progressively greater distances, said partition walls being sealed peripherally to define between them a plurality of separate riser channels open at the bottom of progressively different levels and being open at the upper ends for communication with each other, the partition wall of at least downward extent being at the outer margin of said duct so as to be first traversed by light liquid flowing along the under side of the tray toward the duct.

23. An assembly according to claim 22 wherein the partition walls are parallel and extend substantially vertically throughout their heights, whereby said riser channels have uniform cross-sectional areas.

24. An assembly according to claim 22 wherein the partition walls converge towards the top, whereby said riser channels have upwardly decreasing cross-sectional areas.

25. An assembly according to claim 22 wherein the lower portions of the partition walls are curved outwardly toward the margin of the duct.

26. An assembly according to claim 22 wherein the duct is elongated in plan to a length that is several times the width thereof and at least one long side of said duct is straight; and the partition walls are flat walls extending parallel to said straight side.

27. An assembly according to claim 22 wherein the duct is curvilinear in plan and the partition walls are concentric curvilinear tubes, each tube extending downwardly for a greater distance than the adjacent outer tube.

28. An assembly according to claim 22 wherein the partition walls are closely spaced with intervals that increase progressively, the walls of greatest downward extent having the greatest interval.

29. An assembly according to claim 22 wherein the partition walls extend over only a part of the area of the riser duct, leaving a free space forming a large riser channel with a width equal to several times the width of the other riser channels, said large riser channel extending to a lower level than the other riser channels.

30. An assembly according to claim 22 wherein the partition walls extend upwardly to a common level which is the same as the top of said riser duct.

31. A liquid flow assembly and seal cap combination for transporting settled liquid as a plurality of segregated streams between vertically adjacent stages of solvent extraction apparatus wherein the stages are separated by trays, said assembly being adapted, when mounted as specified herein, to operate as a riser for light liquid and, when inverted, to operate as a downcomer for heavy liquid, comprising: an enclosing wall structure defining an upright duct adapted to be fitted to an opening in said tray and to extend upwardly into the upper stage to a raised level above said tray and to communicate with said lower stage through said opening substantially at the level of the tray; a plurality of partition walls with close spacings fitted closely along the inner face of at least one wall of said duct, said partition walls extending substantially to the top of said duct and protruding below the said one wall of the duct for progressively greater distances with the partition nearest said wall having the least downward extent, said partition walls being sealed peripherally to define between them a plurality of separate riser channels open at the bottom at progressively different levels and being open at the upper ends for communication with each other; a seal cap covering said riser duct in vertically spaced relation; a peripherally spaced skirt depending from said seal cap to below the upper end of said riser channels and spaced laterally from said duct to define a downward transport channel, said skirt being spaced from said tray; and a plurality of closely spaced baffles on the outer side of said skirt extending from substantially the upper level thereof to progressively greater distances beneath the bottom of said skirt, the baffle farthest from the skirt having the greatest downward extent and being at least partly spaced from said tray to provide a passageway interconnecting the bottom of said downward transport channel to the bottom of said upper stage, said baffles defining between them a plurality of separate narrow upward discharge channels open at the top and open at the bottom to said downward transport channel at progressively different levels, said discharge channels being sealed peripherally to isolate the discharge channels.

32. Solvent extraction apparatus for contacting at least partially immiscible light and heavy liquids comprising an upright column with top and bottom closures and conduits for introduction of liquid feeds at the top and bottom thereof, said column containing contacting elements adapted, when arranged as specified, to effect multi-point dispersion of the light liquid into the heavy liquid and, when inverted, to effect multipoint dispersion of the heavy liquid into the light liquid, said elements including: at least two substantially transverse, vertically spaced trays dividing said column into at least upper, middle and lower spaces which communicate only through downcomers and riser assemblies; at least one downcomer through said upper tray located for transporting heavy liquid to a level intermediate said trays to provide a quiet settling space on at least one side thereof immediately beneath said upper tray and above the lower end of the downcomer; drawoff means for settled light

and heavy liquids communicating with each said settling space at the top and bottom thereof, respectively, at points spaced from said downcomer by substantial horizontal distances; a riser assembly extending through said lower tray comprising at least one plurality of upright spaced partition walls from a common level above said tray to progressively greater distances beneath said tray to provide a plurality of separate riser channels, the said partitions being sealed peripherally to isolate the riser channels and each shortest of said partition walls being at an outer margin of the riser assembly and positioned to be first traversed by light liquid flowing horizontally along the under side of said tray; a seal assembly spaced directly above and covering each said riser assembly, said seal assembly comprising an upper seal member with at least one dependent, peripherally sealed skirt which extends downwardly below the upper level of the riser assembly but short of the said tray to allow a substantial clearance, each said skirt being spaced horizontally from the riser assembly to form a downward transport channel communicating at the top with said riser channels; a plurality of upright, closely spaced baffles substantially parallel to each said skirt close to the outer side thereof and peripherally sealed, extending from substantially the height of said seal member to progressively greater distances below the bottom of the skirt to provide a plurality of thin separate discharge channels communicating with said downward transport channel, the baffle of greatest downward extent being farthest from the skirt, said downcomer being positioned to the side of the upper ends of the baffles away from the drawoff means to cause heavy liquid from the downcomer to traverse the upper ends of the discharge channels; and a passageway interconnecting the bottom of said downward transport channel to the bottom of the upper space.

33. Solvent extraction apparatus for contacting at least partially immiscible light and heavy liquids comprising an upright column with top and bottom closures and conduits for introduction of liquid feeds at the top and bottom thereof, said column containing contacting elements adapted, when arranged as specified, to effect multi-point dispersion of the light liquid into the heavy liquid and, when inverted, to effect multi-point dispersion of the heavy liquid into the light liquid, said elements including: at least two substantially horizontal, vertically spaced trays dividing said column into at least upper, middle and lower spaces which communicate only through downcomers and riser assemblies; at least one downcomer elongated horizontally to several times the width thereof extending through said upper tray to a level

intermediate said trays to provide a quiet settling space on at least one side thereof immediately beneath said upper tray and above the lower end of the downcomer; drawoff means for settled light and heavy liquids communicating with each said settling space at the top and bottom thereof, respectively, at points spaced from said downcomer by substantial horizontal distances; a riser assembly extending through said lower tray positioned directly beneath each said downcomer and of like horizontal outline comprising at least one plurality of upright substantially parallel, closely spaced partition walls extending in the direction of elongation of the downcomer and from a common level above said tray to progressively greater distances beneath said tray to provide a plurality of thin riser channels, the said channels being closed at the horizontal ends thereof and each shortest of said partition walls being at an outer margin of the riser assembly and positioned to be first traversed by light liquid flowing horizontally along the under side of said tray; a seal assembly spaced directly beneath each said downcomer with a width at least as great as that of the downcomer and covering said riser assembly in spaced relation, said seal assembly comprising an upper seal member with at least one dependent skirt which extends in the said direction of elongation and downwardly below the upper level of the riser assembly but short of the said tray to allow a substantial clearance, each said skirt being spaced horizontally from the riser assembly and sealed at the ends to form a transport channel for the passage of light liquid from the riser with a reverse direction of flow and thence through said clearance; and a plurality of upright, closely spaced baffles substantially parallel to each said skirt close to the outer side thereof extending from substantially the height of said seal member to progressively greater distances below the bottom of the skirt to provide a plurality of thin discharge channels, said channels being closed at the horizontal ends and the baffle of greatest downward extent being farthest from the skirt and being spaced from the said tray to provide a passageway to the bottom of said upper space.

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