

Sept. 30, 1958

P. KOLLSMAN

2,854,394

METHOD OF AND APPARATUS FOR FRACTIONATION BY ELECTRODIALYSIS

Filed Nov. 1, 1954

6 Sheets-Sheet 1

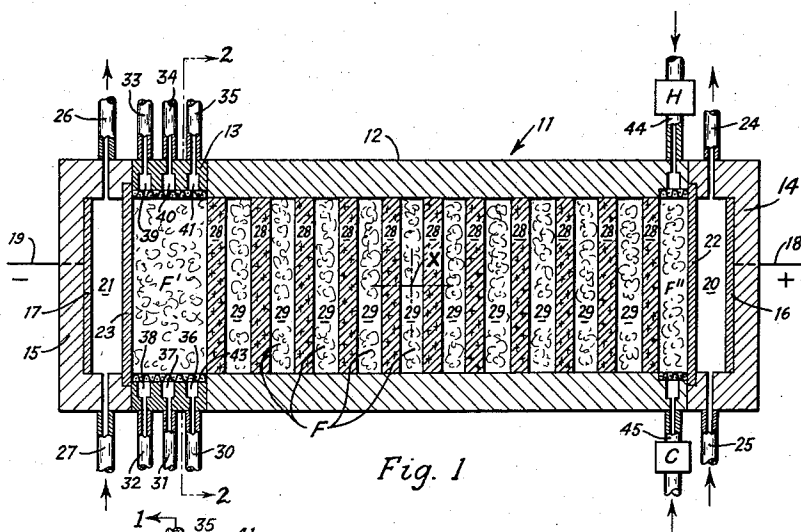


Fig. 1

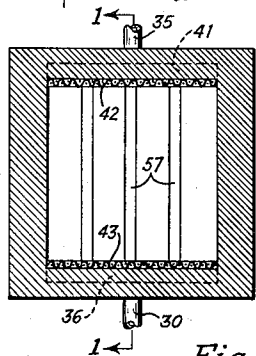


Fig. 2

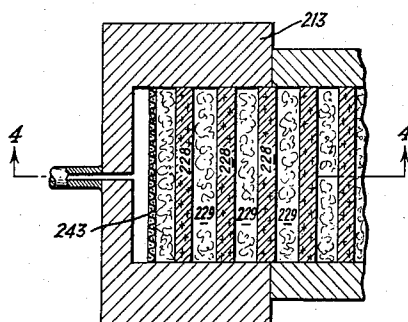


Fig. 3

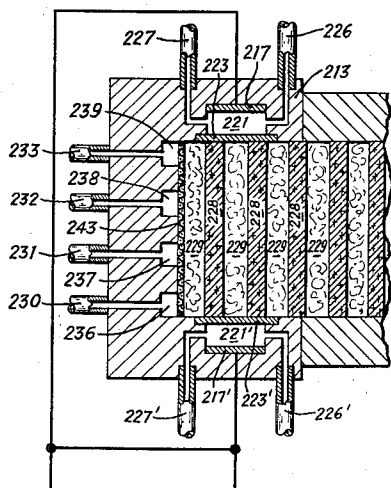


Fig. 4

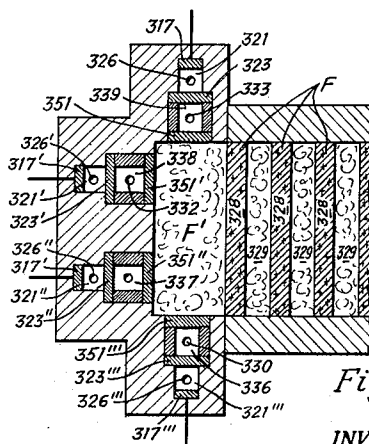


Fig. 5

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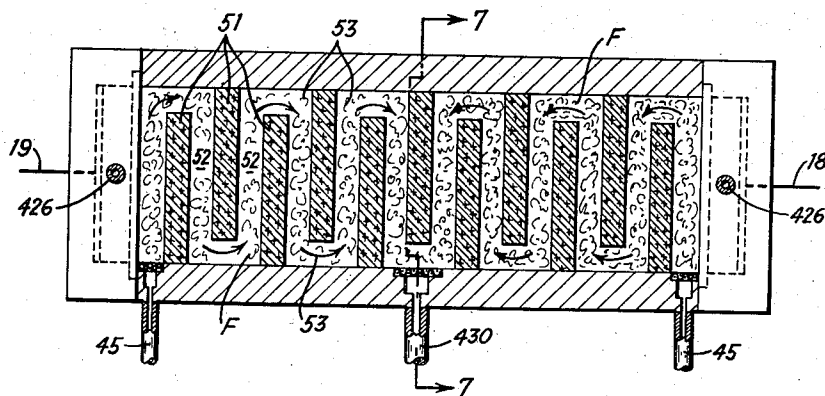


Fig. 6

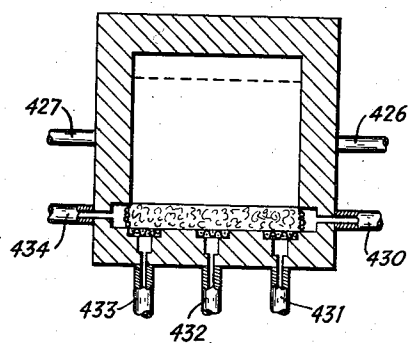


Fig. 7

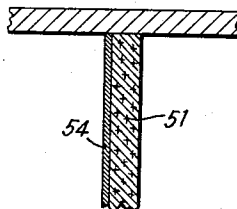


Fig. 8

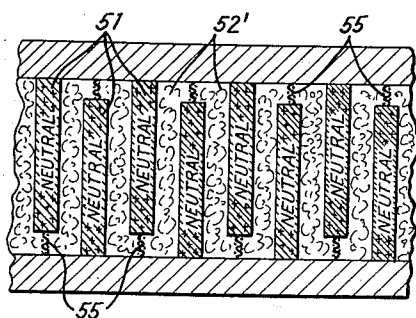


Fig. 9

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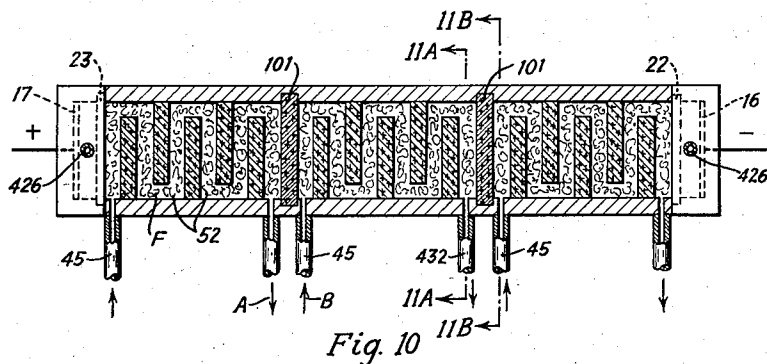


Fig. 10

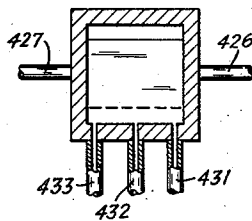


Fig. 11A

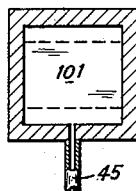


Fig. 11B

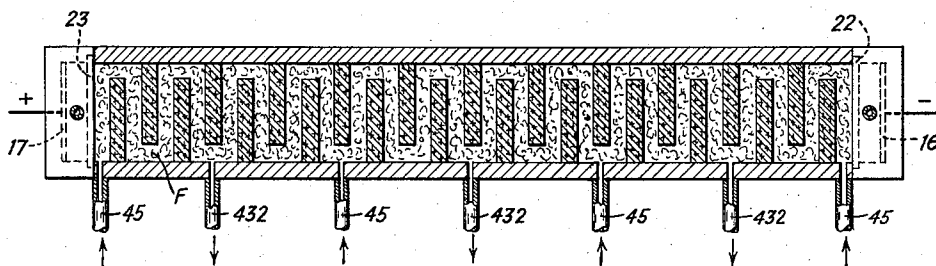


Fig. 12

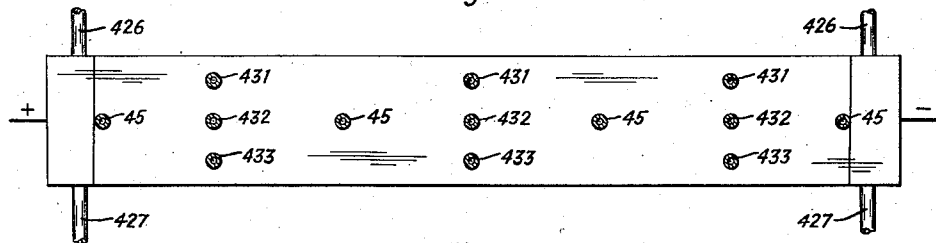


Fig. 13

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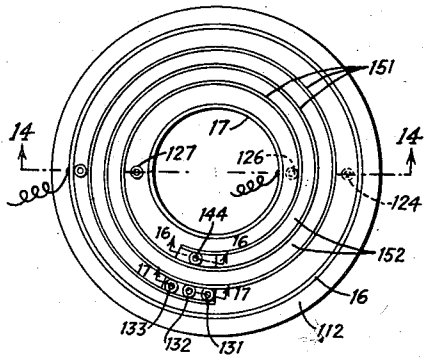


Fig. 15

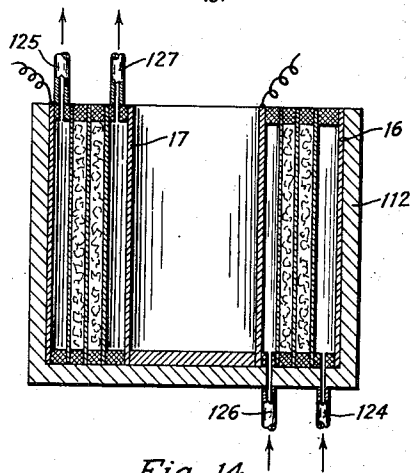


Fig. 14

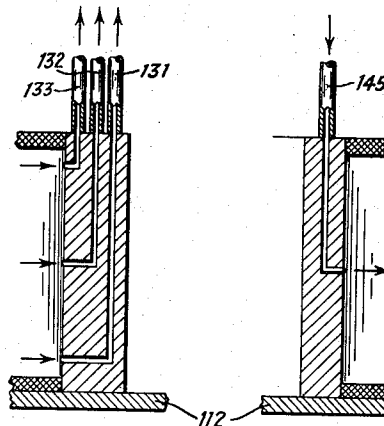


Fig. 17

Fig. 16

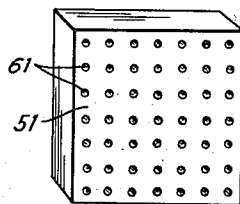


Fig. 18

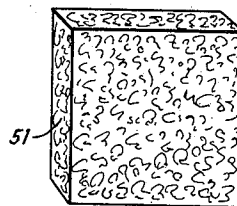


Fig. 19

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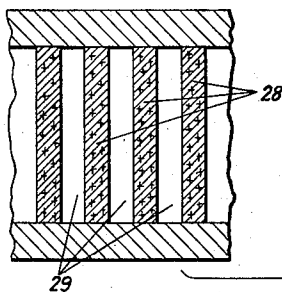
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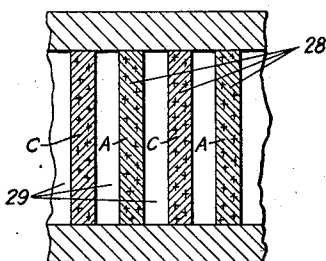
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6 Sheets-Sheet 5



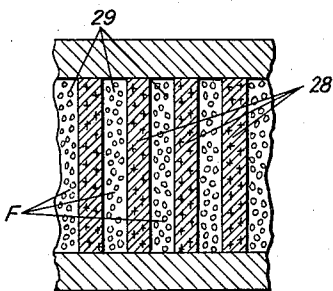
BAFFLES 28
ALL ANION EXCHANGE MATERIAL
OR
ALL CATION EXCHANGE MATERIAL
OR ALL AMPHOTERIC MATERIAL
SPACES 29 VOID EXCEPT FOR LIQUID

Fig. 20



ALTERNATE BAFFLES OF
CATION EXCHANGE MATERIAL
AND ANION EXCHANGE MATERIAL.
SPACES 29 VOID EXCEPT FOR LIQUID
OR IONIC DILUTION SPACES FILLED WITH
AN AMPHOTERIC FILLER

Fig. 21



BAFFLES 28 OF ION EXCHANGE
MATERIAL OF THE SAME POLARITY OR
ALL AMPHOTERIC BAFFLES.
FILLER F

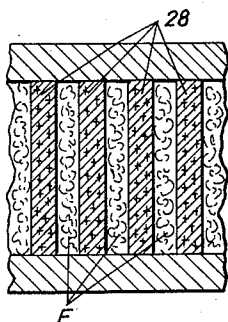
ION NON-CONDUCTIVE
(GLASS FIBERS, BEADS)

ION-CONDUCTIVE

AMPHOTERIC

OF OPPOSITE POLARITY
WITH REGARD TO
BAFFLES 28

Fig. 22



BAFFLES NEUTRAL
OR AMPHOTERIC.
FILLER
CATION EXCH. MAT.
OR ANION EXCH. MAT.
OR CAT. AND AN. EXCH.
MAT. ALTERNATING

OF SAME POLARITY WITH
REGARD TO BAFFLES 28
BUT OF A DIFFERENT
ION-TO-LIQUID RATIO
FOR THE SAME CONTAINED
IONS AND SOLVENT

Fig. 23

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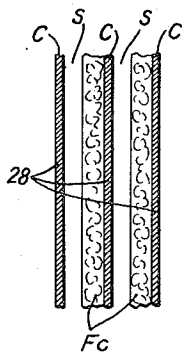


Fig. 24

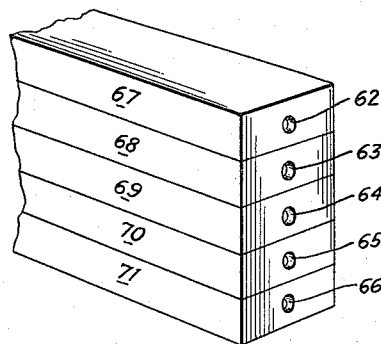


Fig. 25

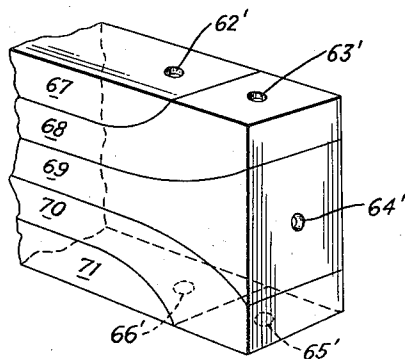


Fig. 26

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METHOD OF AND APPARATUS FOR FRACTIONATION BY ELECTRODIALYSIS

Paul Kollsman, New York, N. Y.

Application November 1, 1954, Serial No. 465,793

17 Claims. (Cl. 204—180)

This invention relates to the art of separating constituents of an ionic solution into fractions under the influence of an electric current.

It has been proposed to separate anionic constituents of a solution from cationic constituents under the influence of an electric current by transferring the anionic constituents and the cationic constituents in opposite directions through permselective membranes into other volumes of fluid. According to the aforementioned proposal, the separation of ionic constituents takes place on the basis of their polarity.

It has also been proposed to separate constituents of the same polarity, for example colloids from ions, on the basis of their size, by applying an electric bias which causes the ionic constituent to migrate through a membrane through which the larger colloidal constituent cannot pass. In an apparatus of this type, the membrane performs the function of a mechanical sieve. A major drawback of apparatus of the last mentioned kind is that the larger particles, for example the colloids, tend to clog up the pores of the membranes. It is therefore necessary to reverse the direction of the current periodically, if the apparatus is to be operated for an appreciable length of time.

In the last mentioned procedure of separating colloidal constituents from smaller ionic constituents, the effect of gravity on the colloidal particles has been utilized, and it has been proposed to shape the bottom and top of the apparatus in the form of a hopper in which the heavier and lighter fractions collect. The hopper is common to all the chambers of the apparatus, and liquid to be fractionated is equally supplied to all the chambers of the apparatus. In the known form of apparatus each chamber operates individually and the lighter fraction and the heavier fraction are withdrawn from it. The known arrangement is a parallel arrangement of individual compartments in which all the chambers are in communication with one another above and below the top and bottom edges of the membranes.

The present invention provides improvements in the art of separating constituents of ionic solutions. Such constituents may be of ionic or non-ionic character. In a larger sense, the invention is concerned with the separation of a fluid of either ionic or non-ionic character, including gases, into fractions which contain preferentially heavier or lighter components of the fluid, respectively. The invention makes use of the influence of acceleration which may be used in the form of centrifugal force, in the event the apparatus is mounted on a centrifuge, or in the form of gravity.

The invention employs barriers of ion exchange material. These barriers are interposed as baffles into the passage of ions migrating towards the electrodes of the apparatus.

In distinction from the known forms of apparatus in which the individual chambers of the apparatus are arranged in parallel, the baffle-separated chambers of apparatus embodying the present invention are arranged

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in series, so that several baffles are encountered by the fluid in its flow through the apparatus substantially transverse to the baffles. The baffles operate in such a way that each successive barrier operates to make the separation of the fractions performed by preceding baffles more distinct.

As the fluid encounters successive baffles, concentration and dilution of the fluid takes place locally at the baffles. For example, at the exit surface of a certain baffle of ion exchange material ionic concentration of the fluid occurs due to the passage through the baffle of ions which the baffle permits to pass and the accumulation of ions of the opposite sign which the baffle tends to block. Ionic dilution takes place at the opposite surface of the baffle.

The baffles are so arranged that acceleration, for example gravity, acts on the fluid with the result that the heavier constituents move in a downward direction, while the lighter constituents move in an upward direction. As the fluid continues to encounter successive baffles, the lighter fractions are predominantly found near the highest point and the heavier fractions near the lowest point. Thus the separation of the fractions of the fluid becomes more and more pronounced as the fluid advances, and distinct strata are formed in the fluid from which the fractions may then be withdrawn through appropriate ducts.

The invention is applicable to the separation of ionic solutions composed of different ionic constituents in a solvent. For example, it is possible to separate the chlorides of lithium and potassium in water. The fractions which are obtained are lithium chloride and water appearing as the dilute or upper stratum and potassium chloride and water as the concentrate, or lower stratum.

The invention is further applicable to the treatment of ionic solutions containing one or more non-ionic constituents. Such non-ionic constituents may be basically of solid, liquid or gaseous character. As an example of the separation of non-ionic constituents, may be mentioned the fractionation of a water and ethyl alcohol mixture in the presence of potassium chloride. This is accomplished by forming a fraction containing preferentially water, potassium chloride concentrate, and a further fraction containing preferentially alcohol, potassium chloride as the dilute, the separation taking place by reason of the fact that water is adsorbed more readily by potassium chloride than is alcohol.

The invention may also be employed for the treatment of non-ionic, non-conductive fluids, liquids as well as gases. As will be seen from the following more detailed description, an ion-conductive filler material is employed in the apparatus to provide an ion-conductive path from one electrode to another. Baffles of ion exchange material are interposed in this path. The filler occupies the space between the baffles and the non-conductive fluid passes through the macropores of the filler.

The invention utilizes the known property of ion exchange materials of producing ion concentration zones and ion dilution zones of fluid at the surfaces of membranes and layers of ion exchange material. This concentrating and diluting action is inherent in the ion exchange material. It is commonly considered to be due to the fact that the ion exchange material comprises bound immovable charges of a certain polarity within its structure. These bound and immovable charges are balanced or countered by opposite charges present in the liquid which fills the micropores of the material. The number of the bound charges and, correspondingly, the number of mobile charges or ions in the fluid filling the micropores, hence, the ionic concentration of the fluid filling the micropores, is a characteristic of the ion exchange material.

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If a membrane or layer of such ion exchange material is immersed in an ionic solution of a lower ionic concentration than the liquid in the pores, the layer membrane performs a concentrating action under the following condition: If the ions of the surrounding ionic solution are caused to travel through the layer or membrane of ion exchange material, for example as a result of an electrical potential applied at electrodes between which the membranes lie, fluid leaves the membranes at an ionic concentration equal to that of the liquid present in the microspores of the ion exchange material. An ionic concentration zone is therefore produced at the exit surface of the layer. On the entrance surface of the layer, at which the layer adsorbs ions, an ionic dilution takes place correspondingly.

The transfer of ions through the membrane is accompanied by a certain transfer of liquid since each ion is accompanied by a solvent shell surrounding it, the size of the solvent shell depending on the ionic concentration of the liquid.

In apparatus whose purpose is to increase or decrease the ionic concentration of liquids by the transfer of ions from one fluid volume into another, it is naturally desirable to keep separate the volumes of fluid of ionic concentration and the volumes of fluid of ionic dilution. In the present invention, in distinction, such separation of the fluid volumes is of lesser importance, in fact, provision is made for maintaining hydraulic communication between adjacent fluid zones in which ionic concentration and ionic dilution takes place. Such zones may be found on opposite sides of the same baffle or at the facing surfaces of adjacent baffles. In the case of a baffle of ion exchange material, hydraulic communication through the baffle may be provided by macroporosity of the baffle, so that hydraulic communication is, in effect, through the baffle. The porosity of a baffle consisting of granular ion exchange material is therefore an asset. If, on the other hand, the baffle has the form of a microporous membrane of ion exchange material, hydraulic communication may be provided around the baffle, that is, past one edge of it or past portions of the baffle, for example by providing apertures, such as perforations or slits in the membrane.

In all instances it is essential that hydraulic flow through or past the baffles should not disturb the strata or fluid layers which form under influence of acceleration or gravity. Hydraulic communication should therefore not be permitted to cause the fluid to traverse alternate baffle-separated fluid chamber in a vertical direction, since such flow would disturb the formation of fraction strata.

Under such provisions the lighter fractions gradually work their way towards the upper portions of the baffles and the heavier fractions move towards the lower portions of the baffles, thus forming strata from which the fractions may then be withdrawn. The number of baffles which the fluid should encounter depends on the difficulty of separation of the constituents.

The various features, applications, and advantages of the invention will appear more fully from the detailed description which follows accompanied by drawings showing, for the purpose of illustration, preferred forms of apparatus for practicing the invention. The invention also consists in certain new and original features of construction and the combination of elements, as well as steps and sequences of steps hereinafter set forth and claimed. Although the characteristic features of the invention which are believed to be novel will be particularly pointed out in the claims appended hereto, the invention itself, its objects and advantages, and the manner in which it may be carried out may be better understood by referring to the following description taken in connection with the accompanying drawings forming a part of it in which:

Fig. 1 is an elevational view, in section, of an apparatus embodying the present invention;

Fig. 2 is a sectional view of the apparatus of Fig. 1, the section being taken on the line 2—2 of Fig. 1;

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Fig. 3 is an elevational view, in section, of a modified form of apparatus embodying the invention;

Fig. 4 is a vertical section taken on line 4—4 of Fig. 3;

Fig. 5 is a sectional plan view of a modified end portion of the apparatus of Fig. 1;

Fig. 6 is a plan view, partly in section, of an apparatus in which the flow of fluid by-passes successive baffles at opposite ends of alternate baffles;

Fig. 7 is a sectional view of the apparatus of Fig. 6, the section being taken on line 7—7 of Fig. 6;

Fig. 8 is a sectional view of a preferred form of baffle for the apparatus of Fig. 6;

Fig. 9 illustrates a modification of the apparatus of Fig. 6;

Fig. 10 illustrates one form of multiple arrangement of the apparatus of Fig. 6;

Fig. 11A is a section, taken on line 11A—11A, of Fig. 10;

Fig. 11B is a section taken on line 11B—11B, of Fig. 10;

Fig. 12 is another form of multiple arrangement of the apparatus of Fig. 6;

Fig. 13 is an elevational view of the apparatus of Fig. 6;

Fig. 14 is an elevational view of a section of an apparatus in which the baffles are curved in the form of a flat spiral;

Fig. 15 is a plan view of the apparatus of Fig. 14;

Figs. 16 and 17 are sectional illustrations of details of the apparatus of Fig. 14, the sections being taken on lines 16—16 and 17—17, respectively;

Figs. 18 and 19 illustrate modified forms of baffles for use in any of the illustrated forms of apparatus;

Figs. 20 to 23 illustrate different baffle assemblies which may be employed in apparatus embodying the invention;

Fig. 24 illustrates another form of baffle combination;

Figs. 25 and 26 are diagrammatic-prospective illustrations of fraction strata and suitable withdrawal points therefor.

In accordance with the invention an elongated confined body of the fluid is subjected to an electrical potential lengthwise of the body with the result that an electric current flows through the fluid. The fluid is maintained flowing between a point of supply and points of withdrawal. At spaced points the body of fluid is maintained in contact with baffles of ion exchange material. The baffles are inclined to the horizontal and extend across the path of the electrical current and also across the general direction in which the fluid advances from the point of supply to the points of withdrawal. At least certain of the baffles are permeable to ions of one sign and passage-resistant to ions of the opposite sign, leading to the formation of zones of ionic concentration and other zones of ionic dilution at the baffles.

As a result of the orientation of the baffles, the fluid within the zones of ionic concentration and ionic dilution follows the influence of an accelerating force, for example gravity. The lighter components tend to rise and the heavier components of the fluid tend to drop.

As the fluid advances from the point of supply to the points of withdrawal, it encounters a plurality of baffles in succession and is subjected to the ionic concentrating and ionic diluting action at each of the baffles.

The first baffle is acted upon by a homogeneous fluid across its entire surface. As a result of the ionic concentrating and diluting action, the heavier components accumulate near the lowest point and the lighter components accumulate near the highest point. The fluid advances toward the next baffle in this condition, and the next baffle is acted upon by lighter components at its upper portion and by the heavier components at its lower portion. The second baffle therefore is acted on by pre-treated, partially separated fluid. For this reason the baffle is able to carry the fractionation to an advanced degree. As each succeeding baffle treats the pre-separated

fluid which arrives from the preceding baffles, the separation is carried to a higher and higher degree.

The flow arrangement is such that the fluid particles are free to seek their proper level or fluid stratum on the basis of their specific gravity under the influence of gravitational force only.

For this purpose the fluid particles are free to move from chamber to chamber from a zone of certain specific gravity in one chamber to a zone of substantially equal specific gravity in the next chamber. This motion of the fluid is not upset by hydraulically enforced flow of the kind commonly employed in apparatus for electrodialysis. More particularly, vertical counterflow on opposite sides of baffles is avoided since such flow would interfere with the formation of the aforementioned levels or strata.

According to the present invention, the flow of fluid either passes through the baffles or the fluid flows around the baffles, or around portions of the baffles.

Baffles of macroporous structure are suited for through-flow as well as for arrangements in which the flow is guided around them. Baffles of a microporous structure require direction of the flow around them or around portions of them.

At the far end of the elongated body of fluid, the fractions are withdrawn separately.

An apparatus for practicing the invention basically comprises a housing within which electrodes are mounted, at or near the ends of the housing. The housing has an inflow duct near one end, and several outflow ducts near the other end, the outflow ducts being so arranged that fluid can be withdrawn through separate ducts from the strata containing the fractions.

A plurality of baffles, ranging in number from less than 10 up to over one thousand, depending on the readiness with which the constituents can be separated, extend across the path of the fluid as it flows through the housing and also across the direction of an electric current passing through the housing.

The baffles act upon the flow of fluid, and the passage of ions in the fluid, in particular. The term baffle according to Merriam Webster's dictionary, second edition, 1953, is defined as: "A plate wall, screen, etc., used to deflect, check or otherwise regulate the flow of a gas, a liquid, sound waves, etc."

The baffles employed by the invention may assume various forms. A baffle may be a layer of ion exchange materials, granules, or beads, disposed in such a way as to form a macroporous wall or screen, the particles of which may be loose or cemented. The ion exchange material may also be bonded together, so as to form a membrane film or coating of generally microporous character. Since microporous membranes offer a very substantial resistance to the flow of fluid, the membranes may be perforated or slotted to permit the flow of fluid to pass through the membranes, or the membranes may be arranged in staggered relationship, so as to permit fluid to flow past and around them.

The several baffles subdivide the housing into compartments. The compartments are normally filled with fluid during the operation of the apparatus. The compartments may be void spaces between the baffles to be occupied by fluid, or they may be filled with a macroporous filler of ion exchange material which is conductive, or may be composed of non-conductive material. If the filler is conductive, it permits the treatment of non-conductive fluids, as will later become apparent.

A relatively simple form of apparatus embodying the present invention is shown in Figures 1 and 2. The apparatus comprises structural components permitting modification of its construction by omission or addition of components, as will later be shown.

The apparatus comprises a housing 11 consisting of a main section 12, a collecting section 13 and end sections 14 and 15. The end sections 14 and 15 comprise electrodes 16 and 17, respectively, from which leads 18 and

19 extend to a suitable source of direct current (not shown). The end sections comprise electrode chambers 20 and 21 separated from the main section 12 by membranes 22 and 23. Ducts 24, 25, 26 and 27 are provided for supplying electrolyte to, and withdrawing electrolyte from, electrode chambers 20 and 21.

The main section 12 comprises a plurality of baffles 28 of ion exchange material subdividing the space of the main section into a plurality of chambers 29 which, during operation of the apparatus, are filled by the fluid to be treated. The baffles may be self-supporting structures, for example membranes of granular material confined between suitable screens. Membrane baffles are preferably provided with passages 57. These may have the form of vertical slots, as shown in the drawing, and permit fluid to flow from one chamber 29 to the next. Such slots or apertures may occupy 1 to 10 percent of the active projected area of the baffle.

The chambers 29 may be void spaces between the baffles. However, the chambers 29 may also be filled with a macroporous filler F, later described in greater detail.

The collecting section 13 comprises a plurality of withdrawal ducts, six ducts being shown in the illustrated example at 30, 31, 32, 33, 34 and 35. Each withdrawal duct preferably extends from a collecting channel, such channels being shown at 36, 37, 38, 39, 40 and 41. The collecting channels extend the full width of the housing and are preferably provided with an entrance screen shown at 42 and 43. The collecting section 13 may be filled with a porous filler F'. The screens 42, 43 serve to keep the filler F' out of the collecting channels.

In a similar manner, the portion of the main section into which supply ducts 44 and 45 extend, may be filled with a filler F'' whose primary function is to distribute the fluid admitted through the ducts 44 and 45 over the entire area of the main section of the housing.

The baffles 28 are made of ion exchange material of relatively high ion conductivity. The so-called "Amberlite," "Dowex" and "Duolite" resins are suitable for this purpose. In the event a filler F is employed, or in the event means are provided for maintaining the baffle material in its proper place, granular or bead-type ion exchange material may be used. If the chambers 29 are void and without a filler, the baffles may be in the form of membranes made from ion exchange material. Such ion exchange membranes are available in the trade under various names and methods of making them have also been described in the literature, for example in the article by Wyllie and Patnode, in the Journal of Physical and Colloid Chemistry, vol. 54, pages 204-226 (1950). The general chemical description and the source of supply of commercially available ion exchangers identified in this description by the trade names by which these materials are known in the art are found in the appendix of the book by F. C. Nachod, "Ion Exchange," Academic Press, New York, 1949, pages 385 to 388.

All the baffles 28 may be of the same polarity, for example, they may be cation permeable and anion-passage-resistant or they may be anion permeable and cation-passage-resistant. An example of a suitable cation exchange material is Amberlite IR-120 and an example of a suitable anion exchange material is IRA-400. According to one form of the invention the baffles are passage-resistant to the polarity of the ions whose fractionation is primarily desired. However, anionic baffles may also alternate with cationic baffles, particularly in forms of apparatus for producing fractions of both polarities, as will later be described. According to another form of the invention baffles may be used which preferentially adsorb and transport the desired fraction.

If a filler F is employed in the chambers 29, it should be of macroporous nature. Such filler material may be non-conductive and inert, such as glass beads or glass fibres, or it may be ion-conductive and consist of ion ex-

change material, as will later be explained. It may also consist of particles which are microporous per se, such as cellophane particles or activated alumina. Silica gel having relatively large micropores and Duolite S-30 are also suitable. These substances are liquid permeated in operation and exhibit relatively low ionic conductivity in that condition.

The operation of the apparatus is best explained by an example. It may be assumed that a dilute aqueous solution containing KCl and LiCl is to be fractionated into its components. In this case, all baffles may be anion permeable and cation-passage-resistant. The anions whose passage is not impeded may be referred to as "driving ions."

An electrical potential is applied to the leads 18 and 19 so that the electrode 16 becomes an anode and the electrode 17 becomes a cathode. All the spaces within the main section are filled with the solution.

The electrode chambers 20 and 21 are filled with an electrolyte, for example with the aforementioned aqueous solution of KCl and LiCl. The electrolyte is continuously circulated through the electrode chambers and fluid to be treated is continuously supplied through ducts 44 and 45. Corresponding volumes of fluid are withdrawn through the ducts 30, 31, 32, 33, 34 and 35.

Anions from the electrode chamber 21 pass through all the compartments 29 and the baffles 28 towards the electrode 16. Passage of the anions through the baffles causes an ionic concentrate to form on the baffle surface from which the anions emerge from the baffles into the liquid layers in the compartments 29. Concentration layers are therefore formed at the right surface of the baffles 28 and dilution layers are formed on the opposite surface of the baffles. These layers are in part the result of the concentrating action inherent in ion exchange materials and operative under certain conditions.

It is known that ion exchange materials carry fixed electric charges which are immovable and constitute part of the structure of the ion exchange material. These fixed charges are countered or balanced by a corresponding number of ions of opposite polarity in the ionic liquid which fills the micropores of the exchange material. If the ionic concentration in the pores of the ion exchange material is higher than the ionic concentration of the liquid filling the compartments of the apparatus, the baffles perform a concentrating operation.

The cations originating in electrode chamber 20 and in the fluid supplied through the ducts 44 and 45 tend to move in the opposite direction towards the cathode 17. The progress of the cations is slowed by the cation-passage-resistant baffles which cause a local ionic concentration of the fastest cations to form on the right side of the baffles. These cations combine with the aforementioned anions moving in the opposite direction and produce a concentration layer on the right side of the baffles. However, a certain number of cations "leak" therethrough and continue their migration towards the cathode 17.

The solution in all the compartments is under the influence of gravity acting on the apparatus. In the first chamber 29, a concentrate of KCl and LiCl forms within the lower portion and dilute solution fills the upper portion of the chamber. As the solution advances towards the cathode, a gradual change takes place pursuant to which K more and more accumulates at the lowest portion of the chambers and Li accumulates above the K. Vertically arranged zones of the liquid therefore contain a progressively higher content of Li and a progressively lower content of K from bottom to top when the liquid moves towards collecting section 13. In the event non-conductive constituents are present in the solution, the non-conductive constituents separate in the same manner after the initial concentration phase.

As the fluid flows through the apparatus it is under the predominant influence of gravity. Its passage from

chamber to chamber does not involve a hydraulic deflection of the flow in an upward or in a downward sense between the baffles which would disturb a formation of the aforementioned zones.

The flow of liquid through the apparatus must be sufficiently slow and the number of baffles sufficiently great to cause the desired degree of separation to take place.

The apparatus may be tilted, either in a downward sense, or in an upward sense, so that the angle which the baffles form with the horizontal is less than 90 degrees. Such tilting reduces the ratio of ionic concentration between the topmost and the bottommost fluid zone and may be employed if the baffles have a large vertical dimension, in other words, if the baffles are very tall.

The heaviest fraction is found at the bottom of the collecting chamber 36 and is withdrawn through the duct 30. The next heaviest fractions are recoverable through ducts 31, 32, 33 and 34 and the lightest fraction is recoverable through duct 35. According to the aforementioned example, the fluid withdrawn through the duct 30 contains the highest potassium content and the lowest lithium content. The fluid withdrawn through duct 35 contains the least amount of potassium and the highest amount of lithium.

The membranes 22 and 23 separating the electrode compartments 20 and 21 from the main section 12 of the apparatus are of a material through which ions are able to pass. The membranes are preferably made of ion-conductive ion exchange material, and may be anion membranes in the given example. However, amphoteric membranes may also be used and even neutral membranes which are conductive by reason of the fact that electrolyte fills their pores. Cellophane is an example of a neutral membrane.

In the event the fluid to be fractionated is the electrolyte supplied to the electrode chamber 20, the membrane 22 may be omitted and the use of ducts 44, 45 be dispensed with. In that event, more fluid is supplied through duct 25 than is withdrawn through duct 24. The apparatus which fractionates cations, by means of anion permeable and cation-passage-resistant baffles, also fractionates the anions contained in the fluid if the rate of fluid flow through the apparatus exceeds the rate at which the anions move in the opposite direction. Ordinarily, the anion fractions are subject to contamination by anions coming from the cathode chamber 21 in a non-fractionated state.

Contamination may be limited to certain outlet ducts (e. g. 32 and 33) by a flow velocity sufficiently high to prevent the contaminating anions from the chamber 31 from moving farther than the stratum or fraction withdrawn through said ducts.

The withdrawal rates of fluid at the ducts 30 to 35 are so adjusted that the withdrawn fluid contains the desired fraction only, or at least predominantly. The desired fractions may be withdrawn from ducts 30 and 35 and from intermediate ducts, depending on the number of fractions. Where an intermediate duct coincides with a boundary zone between two fractions, fluid may be withdrawn from such intermediate duct for reprocessing.

A certain loss of cations occurs through membrane 23. This loss is sustained by the flow sweeping the membrane 23.

If the three top ducts 33, 34 and 35 are used only, the loss affects the heaviest fraction. If this fraction is of a relatively small volume it may be lost entirely. In such a case, it is preferable to withdraw the heaviest fraction through the duct 30 and to permit a lighter fraction to sweep the membrane.

If the bottom ducts 30, 31 and 32 are employed only, the loss is sustained by the lightest fraction.

If fluid is withdrawn through the top and the bottom ducts, an intermediate fraction experiences the loss.

The apparatus of Figure 1 is also suitable for the fractionation of cations with baffles of a cation exchange material. In such a case the fractionation of cations occurs by preferential adsorption, and transport of a certain cation fraction over another by the cation exchange material. For example Amberlite IR-120 or Duolite CS-100 baffles adsorb and transport potassium ions in preference to lithium ions. Another cation exchange material Duolite C-60 adsorbs and transports lithium in preference to potassium. The preferentially transported cation fraction appears at the ion exit surfaces of the baffles in the concentration zone and then tends to move downwardly, while gradually migrating towards the cathode. At the cation intake surface a corresponding depletion of preferentially adsorbed cations occurs in the dilution zone and the residual cations in the dilution zone tend to move upwardly.

A reduction of the gravitational effect may be obtained in the apparatus of Figures 1 and 3 by an upward or a downward tilt of the apparatus about a transverse axis.

The separation of constituents which are difficult to fractionate is facilitated by maintaining a temperature gradient from top to bottom in the liquid in the chambers, the top portion being maintained at a higher temperature than the bottom portion. This may be accomplished by heating the top of the apparatus, cooling the bottom, or conveniently, by supplying the liquid admitted to the top of the apparatus at a higher temperature than the liquid supplied to the bottom. In Figure 1 a heating element H in duct 44 and a cooling element C in duct 45 are shown for this purpose.

Heating and cooling also counteracts the establishment of a higher temperature at the bottom as a result of higher current density. Such heating of the liquid would tend to set up convection currents interfering with the formation of fraction layers or zones.

The aforementioned heating and cooling also decreases the specific gravity of the liquid passing through the upper portions of the chamber relatively to the specific gravity of the liquid passing through the lower portions. This facilitates separation of fractions which are normally difficult to separate because of small differences in specific gravity.

Figures 3 and 4 illustrate a modified collecting end section. The modified collecting section 213 comprises withdrawal ducts 230, 231, 232 and 233 extending from collecting channels 236, 237, 238 and 239. The collecting channels are protected by a screen 243 of a suitable material such as glass fibres or plastic Saran screening. Two electrodes 217 and 217' are mounted in electrode compartments 221 and 221' through which electrolyte flows through ducts 226, 227 and 226', 227'. The electrodes may be connected to a common lead 50. Membranes 223 and 223' close the electrode compartments against the space containing the baffles 228. The outflow channels 236, 237, 238 and 239 lie in the levels or zones in which the fractions collect.

A further modification of the collecting section is shown in Figure 5. This form comprises a plurality of electrodes 317, 317', 317'' and 317''' mounted in individual electrode chambers 321, 321', 321'' and 321'''. Inflow and outflow ducts are provided for each of the electrode chambers, only one duct being visible in the sectional view at 326, 326', 326'' and 326'''. The electrode chambers lie behind withdrawal chambers 336, 337, 338 and 339, and the withdrawal chambers are separated from the electrode chambers by membranes 323, 323', 323'' and 323'''. Withdrawal ducts for the several withdrawal chambers are shown at 330, 331, 332 and 333. The fractions transported into the withdrawal chambers are the driving ions themselves together with their respective solvent shells. Further membranes 351, 351', 351'' and 351''' separate the withdrawal chambers from the space of the apparatus containing the baffles 328 and also a

filler F', corresponding to the filler F' used in the forms of apparatus of Figure 1.

The provision of separate electrodes permits adjustment of the currents passing through several electrode chambers, so as to vary the intake of ionic fractions into the respective collecting chambers.

In the event the ions to be fractionated are cations, the entrance membranes 351, 351', 351'' and 351''' are of cation exchange material, of neutral material or of amphoteric material, but the membranes 323, 323', 323'' and 323''' which close the electrode chambers are of anion exchange material which is cation-passage-resistant and produces ionic concentration in the collection chambers.

The collecting chambers 336, 337, 338 and 339 may be provided with inflow ducts (not shown) to establish a continuous flow of electrolyte through the chambers. Since, however, ions and solvent are transferred through the bordering membranes into the collection chambers, resulting in an accumulation of fluid therein, fluid supply ducts for the collection chambers may be dispensed with if the liquid transfer is sufficient.

If the entrance membranes 351, 351', 351'' and 351''' leading to the collecting chambers are omitted and the membranes 323, 323', 323'' and 323''' are made of neutral, amphoteric, or cation conductive material, the fractions are collected in the several electrode chambers. They may plate out or be withdrawn together with the electrolyte leaving the electrode chambers.

In the foregoing it was assumed, for the sake of simplicity, that the baffles are of a macroporous character permitting fluid to pass through the macropores or interstices of the material. Such baffles are generally constructed as layers of particles of ion exchange material, preferably granules or beads.

If the pore size of the baffles is too small to provide for the flow of fluid through the apparatus, it becomes necessary to arrange for passage of fluid from chamber 29 to chamber 29, through the apparatus, in other ways.

Figures 6 and 7 illustrate an arrangement in which the baffles 51 are arranged in staggered relationship to permit the fluid entering at 45 to flow from one chamber 52 to the next chamber by passing around the end edge of the baffles as indicated by arrows 53. This baffle arrangement has the incidental advantage of simplifying the construction of the central portion of the apparatus, particularly the arrangement of ducts 430, 431, 432, 433 and 434.

The baffles of the apparatus of Figures 6 and 7 may be microporous or macroporous. If a macroporous baffle material is used, it is preferred to prevent flow of fluid through the baffles by suitable means, for example face laminations 54 of a microporous material, for example a sheet of cellophane, as shown in Figure 8 applied to the exit side of the driving ions. The sheet 54 may also consist of microporous membrane of ion exchange material of the same polarity as the baffle.

The spaces 52 between the baffles 51 may be filled with a filler F. Suitable filler materials to be used in connection with different types of baffles are described further below.

Figure 9 shows a modification of the baffle arrangement of Figure 6. The portions 51' are made of a neutral microporous material, for example cellophane or of an amphoteric ion exchange material. The portions 52' are occupied by a macroporous ion exchange material, which may be an anion exchange material, or a cation exchange material. The space 52' may be filled with batches of ion exchange material of different polarity so as to cause fluid flowing through the spaces 52 to flow through one kind of ion exchange material during certain portions of the flow path and through a different kind of ion exchange material during other portions of the flow path, dividing lines between such portions being indicated at 55.

A plurality of cation separating units and anion separating units may be combined as shown in Figures 10, 12 and 13. The apparatus of Figure 10 comprises a single pair of electrodes 16 and 17 between which groups of baffles 51 are arranged in a similar manner as shown in Figure 6. The electrode chambers may be separated from the intermediate fluid spaces by membranes 22 and 23 as described in connection with Figure 1. The groups of baffles are separated from one another by dividing membranes 101 which may be either anion permeable, cation-passage-resistant, or cation permeable, anion-passage-resistant, or amphoteric, or neutral.

Inflow ducts 45 are provided for the fluid to be treated and outflow ducts 431, 432 and 433 are provided for the respective fractions. A filler F may be provided in the fluid spaces 52 as described in connection with the apparatus of Figure 6. The electrode compartments have separate inflow and outflow ducts 426 and 427.

In the apparatus shown in Figure 12 the subdividing membranes 101 are omitted, and the fluid entering through the inflow ducts 45, except adjacent the endmost membranes 22 and 23, is divided to flow in opposite directions. The fractions leave the apparatus through the outlets 431, 432 and 433.

The advantage of the forms of apparatus shown in Figures 10 to 13 lies in the fact that contaminations of the fractions by fluid of the electrode chambers or by ions leaking or migrating from the electrode chambers through the endmost membranes 22 and 23 is negligible. Also, a comparatively high potential may be applied to the electrodes 16 and 17 due to the great number of baffles lying therebetween.

The relatively long and tortuous path of the fluid may also have the form of a flat spiral as shown in Figures 14 to 17.

The apparatus housing 112 is substantially cylindrical and it contains cylindrical electrodes 16 and 17. A membrane or baffle 151 is curved in the nature of a flat spiral and forms a long fluid chamber 152 between adjacent convolutions extending from an inflow 145 for the fluid to be fractionated to outflows 131, 132, 133 for the fractions. The electrode compartments have separate inflow and outflow ducts 124, 125, 126 and 127.

Figure 18 illustrates a baffle of microporous material provided with perforations 61 to permit fluid to pass therethrough.

Figure 19 illustrates a baffle of generally macroporous construction resembling, in general, the structure of a sponge.

Figures 20 to 23 illustrate representative baffle arrangements which may be employed in the forms of apparatus previously described.

As shown in Figure 20, a plurality of baffles 28 are spaced from one another to form liquid chambers 29 therebetween. The thickness of the baffles preferably ranges between 0.1 and 20 mm., the smaller dimensions being for baffles of the membrane type and the larger dimensions being for baffles of the layer type, for example layers of granules or beads. The thickness of the liquid space may be of the order of 0.1 to 20 mm.

The baffles 28 may all consist of ion exchange material which is cation permeable, anion-passage-resistant or they may all consist of ion exchange material which is anion permeable, cation-passage-resistant. The arrangement shown in Figure 18 is suited for the treatment of conductive liquid.

The arrangement shown in Figure 21 differs from that of Figure 20 in that baffles of both polarities are employed. In the illustrated example, every second baffle consists of anion exchange material, indicated by A and the remaining baffles are of cation exchange material, as indicated by C. The spaces 29 between the baffles are void and are occupied by liquid during the operation of the apparatus.

Figure 22 illustrates an arrangement in which the spaces

29 between the baffles 28 are filled with a preferably macroporous filler. The filler F may be non-conductive and inert, examples of the latter type being glass fibres or glass beads.

The filler, however, may also be of ion conductive material, to establish a conductive bridge between the baffles which provides a path for the electric current through the apparatus in the event the fluid to be treated is a non-conductive liquid or gas. An ion conductive filler is also used to advantage in the treatment of conductive fluids. If so used, it improves the conductivity of the dilution zones.

An ion conductive filler may also be amphoteric, that is substantially permeable and conductive with respect to anions and cations. The filler may also be of the same polarity as the baffles. For example, a filler of anion exchange material may be used with baffles of anion exchange material. In that event, the filler must be of a different, preferably lower, ion-to-liquid ratio for the same contained ion and solvent than the baffles. If the ion-to-liquid ratio of the filler material equals that of the baffles, a space must be provided between them, preferably on the side of the baffle on which the anions pass from the baffle into the filler.

Finally, the ion conductive filler may be of a polarity opposite with regard to the polarity of the baffles. In such a case, a filler of anion exchange material is used with baffles of cation exchange material and vice versa.

A filler of anion material between baffles of cation material produces an anion drive or a cation drive depending on whether the filler or the baffles predominate. The filler generally predominates, if the total contained anion equivalent in the filler exceeds the total contained cation equivalent of the baffles, filler and baffles being compared, immersed in the same ionic solution. Predominance of one component is obtainable by increasing the thickness, and/or ionic concentration of the one component with respect to the other.

Therefore a filler of anion exchange material predominating over baffles of cation exchange material produces an anion drive and vice versa.

In a sense, the combination of Figure 22 is comparable to the arrangement of Figure 21 in that ions encounter layers of cation exchange material as they pass through the apparatus.

Figure 23 illustrates an arrangement in which the baffles are either neutral or amphoteric. An example of a neutral baffle is cellophane. Amphoteric baffles may also be produced by a mixture of cation exchange resin beads with anion exchange resin beads, in layer form, cemented or in membrane form. The filler F may consist of cation exchange material throughout, or of anion exchange material throughout, or cation exchange filler portions may alternate with anion exchange filler portions.

Figure 24 illustrates a preferred arrangement of cation membranes C with cation filler F in direct contact with the ion intake side of the membrane and spaces S. The advantage of this arrangement lies in the effective enlargement of the membrane surface at the dilution side.

Figure 25 is a diagrammatic representation of a plurality of fraction strata 67, 68, 69, 70 and 71 and an arrangement of withdrawal ducts 62, 63, 64, 65 and 66 for withdrawing the fractions individually. In the arrangement shown in Figure 25, the withdrawal ducts are substantially aligned with the fraction strata.

Figure 26 illustrates an arrangement of withdrawal ducts corresponding, in part, to the arrangement employed in the apparatus of Figure 1. Only one withdrawal duct 64' is shown aligned with the fraction 69, the remaining withdrawal ducts 62', 63', 65' and 66' are in the top and bottom walls of the apparatus. During withdrawal of fluid through the several ducts, the pattern of the fraction strata changes and assumes substantially the form indicated in Figure 26 with the result that the strata are curved or deflected near the withdrawal ducts.

As a result, the fractions are withdrawn as if the ducts were located as shown in Figure 16. The deflection of the flow pattern may be taken advantage of for the purpose of placing the withdrawal ducts in a convenient location which leaves space for the electrodes situated as shown in Figure 1.

The polarity of the ion drive is preferably selected to be in agreement with the polarity of the filler employed in the apparatus.

Basically, an anion drive is as desirable as a cation drive. Cationic fillers however, are more plentifully available. It is therefore generally preferable to select cations as driving ions.

The choice of baffle and filler materials for an apparatus for the treatment of non-conductive fluids is dictated by two main considerations:

Firstly, it is imperative that at least one element of the baffle-filler combination is of a material whose pore size and pore volume is not affected by the character of the fluid contained therein to such an extent that the pores close against passage of driving ions.

Secondly, it is desirable to select a combination in which at least one element is deformable to produce enlarged contact areas between the particles of said element with the particles of the other element for the purpose of establishing and maintaining a low resistance path from electrode to electrode.

Generally, the pore size of deformable materials is dependent upon the character of the contained fluid. The list of deformable materials whose pore size and pore volume is also dependent on the contained fluid includes the large group of resinous ion exchangers. These include materials which tend to swell and contract considerably in response to changes in ionic concentration and the type of solvents. Such materials include Amberlites IR-112, IR-120 and IRA-400. However, there are other resinous materials which do not swell appreciably such as Duolite C-10 and Duolite CS-100 and Duolite CS-101.

Inorganic ion exchangers are substantially rigid and are, for this reason, substantially unaffected by the liquid or gas contained therein with regard to pore size and pore volume. Examples are: alumina, silica gel at high pH values, aluminosilicates, glauconite, fuller's earth and the like.

Sulfonated coal is of a class between the two aforementioned groups of materials in that it is of a less stable pore size than the inorganic materials, but more stable than the ion exchange resins. Its deformability is greater than that of inorganic ion exchange material.

In the treatment of conductive fluids, the pore size stability of the ion exchange materials forming the baffles and filler are of lesser importance and it is perfectly satisfactory to select any deformable material for both.

If a rigid material forming baffle or filler is combined with a deformable material, the rigid material is preferably used in the form of a single layer of closely arranged particles contacted by the deformable material on both sides of the layer. This arrangement insures the formation of a low resistance path through the layer of rigid material which would not be attained if the path extends through several consecutive contacting rigid particles.

If baffles or fillers are employed which contain more than one layer of relatively rigid organic or inorganic ion exchange material, it is important to insure substantial contact areas between the particles. This is readily accomplished by rounding the normally sharp and angular contours of the ion exchange granules or particles to pebble or bead form by attrition grinding with an abrasive to obtain substantially the same difference in contour, as exists between crushed rock and river gravel, the latter having an irregular, but rounded surface.

The invention is effectively carried out if the materials are selected in accordance with the following governing consideration:

The fluid to be treated passes through alternating layers differing from each other in the ratio of ion content per unit of fluid volume, considering the dissociated ions of one polarity only.

In the case of the baffles, the fluid considered is that which is contained in the micropores of the baffles.

With regard to the spaces between the baffles, two possibilities exist, since the spaces may or may not be occupied by a filler in addition to the fluid.

In the absence of a filler, the ion content of the fluid is readily determinable. Its ion content per fluid volume unit must differ from that of the baffles.

If a filler is present, there are again several possibilities, depending on the nature of the filler.

The filler may be macroporous, inert, and non-conductive. Glass beads are an example of such a filler material. In this case the fluid in the interstices is considered.

The filler may be a macroporous arrangement of microporous particles, which are neutral, non-conductive per se, but conductive if immersed in a conductive liquid. Cellophane particles are an example of such a filler. In this case the fluids in the macroporous interstices and in the micropores are considered for comparison. The ion content per fluid volume unit of at least one of these fluids must differ from that of the baffles.

The filler may be a macroporous arrangement of microporous ion exchange particles. Such a filler is conductive and suited for the treatment of non-conductive fluids. The fluid considered is the fluid contained in the micropores of the filler. Its ion content per fluid volume unit should differ from that of the baffles.

In the event the filler is composed of microporous ion exchange material, substantially free from macropores, it may be considered to assume the role of a baffle, particularly, if the baffle material is neutral, in which case the latter assumes the role of the filler.

Following are combinations of baffles and fillers which may be used for the purposes stated:

Combination I: Baffle of cation exchange material combined with a filler of cation exchange material. In this combination, the filler must have a different ion content relatively to its pore volume ratio than the baffle material. Preferably the ion to pore volume ratio of the filler should be lower than that of the baffle.

This combination is suitable for fractionating a general mixture of a conductive or non-conductive character into its components. Such a general mixture is understood as comprising a solvent, non-ionic components which per se may be of a gaseous, liquid or solid character, and ionic components whose presence renders the mixture conductive.

If a conductive mixture is treated, the fluid in the electrode compartment may be the same fluid mixture which is fed into the main section for the purpose of fractionation, but a different electrolyte may also be used in the electrode compartments. If the fluid mixture is non-conductive, an electrolyte must be used in the electrode compartments. This electrolyte should preferably have a high ionic concentration, at least in the electrode compartment which furnishes the driving ions. This is commonly the anode compartment in which the driving cations originate.

Combination II: Baffles of anion exchange material may be combined with a filler of cation exchange material. In this combination, the cation content of the filler and baffle must exceed the anion content of the baffles. The cation content of the filler material relatively to its pore volume should preferably be lower than the anion content of the baffle material relative to its pore volume.

This combination may be used for fractionation of a general fluid mixture of a conductive or a non-conductive character. If the fluid mixture is non-conductive, an electrolyte must be supplied to the electrode compartments. The electrode compartment containing the anode

is preferably supplied with an electrolyte of high ionic concentration.

Combination III: Baffles of cation exchange material may be combined with an amphoteric filler. In this combination, the cation content of the baffles and filler should exceed the anion content of the filler.

This combination may be employed for the fractionation of ionic as well as non-ionic components of a conductive mixture. The combination is particularly advantageous for anion fractionation.

The combination of cation baffles with an amphoteric filler is also suitable for the fractionation of non-conductive fluids. In order to be operative, the amphoteric filler material must have a ratio of content of cations, or sum of cations and anions with regard to its total pore volume different from, and preferably lower than that of the baffle material.

Combination IV: Baffles of amphoteric material may be combined with a filler of cation exchange material. In this combination, the cation content of both the filler and the baffles should exceed the anion content of the baffles to produce a cation drive. The cation filler must have an ion-to-pore volume ratio different from, and preferably lower than that of the baffles. The respective figure for the baffles is determined by comparing the total content of cations or ions of both polarities of the baffle material with the pore volume of the baffles.

The uses of Combination IV are the same as those of Combination III.

Combination V: Baffles of a neutral material, for example cellophane baffles, may be combined with a filler of cation exchange material. This combination is suitable for the fractionation of all components of a conductive liquid mixture and is particularly suitable for cation fractionation.

Combination VI: Baffles of cation exchange material may be combined with a filler of anion exchange material. If, in this combination, the cation content of the baffles is substantially equal to the anion content of the filler, both an anion drive and a cation drive is obtained in which anions move through the anionic material and cations move through the cationic material. This combination is suitable for the fractionation of all components of conductive solutions and also for non-conductive solution under conditions set forth further below.

Combination VII: Baffles of amphoteric material may be combined with a filler of amphoteric material. The filler material of this combination must differ from the baffle material in its total ions-to-pore volume ratio and/or the ratio of contained cations to contained anions.

The combination serves to separate conductive, as well as non-conductive fluids containing different components of higher or lesser hydrophobic character as, for example, represented by a mixture of acetone and benzene.

The electrolyte for this combination is the solution of a cationic or an anionic surface active agent. It consists of a hydrophilic ion and an ion of a polar group of preferably strong base or strong acid character and a non-polar hydrophobic group of large or small size including carbon atoms ranging in number from 1 to 22.

Examples of cationic surface active agents are tetraethyl ammonium bromide or hydroxide and trimethyl octadecyl ammonium chloride.

Examples of anionic surface active agents are benzene sodium sulfonic acid and mono-octadecyldisodium sulfosuccinic acid.

The drive is a combined drive of hydrophobic and hydrophilic ions. Both ions pass through each of the materials. The hydrophilic ions transport the more hydrophilic components in one direction and the hydrophobic ions transport the more hydrophobic ions in the opposite direction.

The action of the driving ions is based on the stripping of the components from the driving ions when those ions enter the material having the higher ion-to-fluid

ratio. Gravity then acts on the accumulating components. Thus two zones are formed within which accumulation of components occurs as compared to the previous combination in which only a single drive is present through each material.

Mixtures with hydrophilic and hydrophobic components, such as crude oil, acetone and benzene, may be made conductive by admixture of a surface active agent, preferably strong base or strong acid type, and treated in cells without a filler for separation of hydrophilic and hydrophobic components.

If in any of the foregoing combinations, the polarity of the components is reversed, the polarity of the drive is likewise reversed. For example, baffles of cation exchange material combined with a filler of anion exchange material, according to a reversal of Combination II, an anion drive is produced with corresponding results.

Ordinarily, the apparatus is operated at current densities, and with ionic concentrations of the electrolyte such that driving ions pass through the material of their respective polarity without causing substantial numbers of ions of the opposite polarity to pass therethrough.

If the current density is increased or the ionic concentration of the electrolyte is high in both electrode chambers, a substantial number of ions of the opposite polarity pass through the material of the one polarity. The result is not only an energy loss but also a loss of fractionating efficiency since the ions of the opposite polarity undo the work of the driving ions.

However, the aforementioned loss can be turned into an advantage in the fractionation of fluid mixtures comprising components having different degrees of hydrophobic character. In such a case an electrolyte is used consisting of a solution of a cationic or anionic surface active agent containing a hydrophilic ion and an ion of a polar group of preferably strong base or strong acid character and a non-polar hydrophobic group of large or small size including carbon atoms ranging in number from 1 to 22.

Surface active agents with carbon atoms in the range of 8 to 22 are preferably used for fractionating fluids which include components of a very low dielectric constant such as 2.5 to 10.

Particularly suitable combinations for this purpose are Nos. VI and VII. Other combinations may also be used, and in such event the surface active ion should preferably be the driving ion.

Following is a list giving, for the purpose of example, advantageous combinations of baffles and filler material.

BAFFLES	FILLER
<i>Combination I</i>	(in granules or bead form (10-50 mesh))
IR-120 or Dowex 50-16% crosslinking 1 mm. thick Duolite C-60 Duolite C-20 Duolite C-25	Duolite C-10 IR-100 or Dowex 50-2% crosslinking or sulfonated coal or alumino silicates or fuller's earth or ZeoDur or Glaucinite or Decalso Duolite resinous absorbent S-30
<i>Combination II</i>	
IRA-400 Duolite A-41 Duolite A-44 or Dowex 1-2% crosslinking 1 mm. thick	Duolite C-10, 10 mm. thick IR-120, 10 mm. thick Dowex 50, 10 mm. thick ZeoCarb, 20 mm. thick fuller's earth, 30 mm. thick Decalso, 30 mm. thick ZeoDur, 30 mm. thick

Combination III

IR-120
2 mm. thick
Duolite C-10

Duolite adsorbent resin
S-30
a layer of 2-10 mm. of
silica gel of pH 7.0 or
Alumina or
Bentonites or
Clays or
fuller's earth
Glauconite

Combination IV

Mixture of
IR-120 and
IRA-400

a layer 2-10 mm. of
fuller's earth or
ZeoDur or
Dcalso or
Sulfonated coal or
Dowex 50-2% crosslink-
ing or
Alumino silicates
Duolite resinous adsorbent
S-30

Combination V

Cellophane

a layer 5 mm. of
IR-120 or Duolite C-10
ZeoCarb
ZeoDur
Decalso
fuller's earth
Alumino silicates

Combination VI

IRA-120, 3 mm.
Duolite C-10
Duolite C-60
Dowex 50-2% crosslinking
fuller's earth

IRA-400, 3 mm.
Duolite A-44
Duolite A-10
Dowex 1-2% crosslinking
3mm
Alumino silicates

Combination VII

Mixture of
IR-120 and IRA-400
Duolite C-10 and A-70
2 mm. thick
or
Mixture of
Dowex 50-8% crosslink-
ing and Dowex 1-40%
crosslinking
2 mm. thick

Mixture of
Dowex 50-2% crosslink-
ing and Dowex 1-2%
crosslinking
2-10 mm. thick
Alumina
fuller's earth
Glauconite
Bentonite
Silica gel
Duolite resinous adsorbent
S-30

Following is a list of ion exchange materials of both organic and inorganic type which may be used in practicing the invention.

Cationic exchangers—organic—strongly acid.—Amberlite IR-120, Dowex 50, Dowex 30, Amberlite IR-112, Amberlite IR-105, Amberlite IR-100, ZeoCarb, sulfonated coal and carbons, Dowex 50 in various degrees of crosslinking ranging from 16% to 1%, Duolite C-10, Duolites C-60, C-61, C-65.

Weakly acid ion exchangers include Amberlite IRC-50 and Permutit 216, Duolite CS-100, CS-101 and Duolite resinous adsorbent S-30.

Inorganic.—Natural and synthetic alumino silicates, Zeolites such as montmorillonite, kaolinite, glauconite, Permutit, Decalso, ZeoDur, different clays, bentonites, silicates, fuller's earth, silica gel at high pH and the like of different pore size and porosities.

Anionic exchangers—organic—strongly basic.—Amberlite IRA-400, Dowex 1 in various degrees of crosslinking, Duolites A-80, A-41, A-44.

Weakly basic exchangers include Amberlite IR-4B, Amberlite IR-45 and Duolite A-3, A-7, A-6.

Among the inorganic anionic exchange materials are

hydrated alumina, magnesia, heavy metal silicates, clays and bentonites.

Amphoteric exchangers may consist of mixtures of cationic and anionic materials. These may be resinous synthetic or natural. An example of a commercially available amphoteric ion exchange material is Duolite Zwitterion.

Examples of natural amphoteric exchangers are the silica gels, fuller's earth, bentonites, alumina at different degrees of dehydration and many clays, treated or untreated. These substances are generally predominantly anion exchangers at low pH of the contacting electrolytes, and are predominantly cation exchangers at high pH of the contacting electrolyte. At intermediate pH ranges, which differ for each substance, they are capable of acting as anion as well as cation exchangers.

For example, a certain bentonite has a cation (NH_4) exchange capacity of 2.4 milliequivalents at pH 3.5. At pH 5.5 the same material is an anion (SO_4) exchanger of 7 milliequivalents capacity. At pH 4.25 the material is amphoteric and has an exchange capacity for both cations and anions of 4.2 milliequivalents each.

Amphoteric fillers and baffles may also be made from an amphoteric substance such as Duolite Zwitterion or from a mixture of equivalent quantities of beads or granules of cation and anion exchange material. Amphoteric fillers may be formed by layers of alternating cation and anion exchange material granules or beads, each layer extending from baffle to baffle across the chambers. However, filler beads or granules and baffles may also be made from amphoteric ion exchange material.

Such amphoteric ion exchange material in either bead or membrane form may be made from a mixture of finely ground particles, or of beads or pebbles of ion exchange resin of a mesh size 100 to 1,000 and finely ground thermoplastic bonding material such as polyethylene, polystyrene or methyl methacrylate resin, at a volume ratio 70 to 80% dry ion exchange resin and 20 to 30% bonding material. The material is compression molded under high pressure up to 5,000 pounds per square inch and high temperatures, as well known in the art, to produce sheets or bulk material which may then be ground to suitable bead or particle size.

The finely ground ion exchange resin particles may also be cemented together by a porous cement. They may be cemented with a viscose solution and subsequently treated with HCl solution for regeneration of the viscose to ethyl cellulose. They may also be cemented with cellulose acetate solution with subsequent saponification of the acetate to ethyl cellulose. Polystyrene solutions may also be used as cements with subsequent evaporation of the solvent, leaving a porous polystyrene structure bonding the resin particles together.

Similarly, a quantity of anion resin chain polymer solution and equivalent quantity of cation resin chain polymer solution may be mixed with a suitable copolymerizing solution and the mixture polymerized. The chain polymers may consist of 2 to 500 monomers. The effective pore size of the amphoteric resin may be varied by suitable choice of the degree of crosslinking during polymerization or copolymerization and by suitable choice of the relative quantity of the copolymerizing agent. Techniques are well known for carrying out the aforementioned manufacturing procedure, and the control of such processes permits predetermined characteristics of the material to be attained.

In many instances, especially when used in contact with ionic liquids of substantial ionic concentration, cationic or anionic ion exchange materials of low ion to pore volume ratio such as Duolites C-10 and A-10 are capable of conducting both polarities of ions and act to a large extent as an amphoteric material.

In practicing the invention, ion exchange material of strong base and strong acid type are preferred because

of the high degree of dissociation of the contained ions leading to a high effective ion content which is substantially independent of the pH of the contacting liquid.

In the treatment of non-conductive liquids in which the driving ions are furnished by an electrolyte introduced into the electrode chambers, the transfer of solvent into the treatment chambers from the electrode chambers is maintained small by interposition of a suitable layer or membrane between the chamber, furnishing the driving ions and the treatment chambers. Such a layer or membrane should be "tight," that is, it should have a high ion content in relation to its pore volume. This is the case in the Amberlites IR-120 and IRA-400. Ions passing through such a layer or membrane are accompanied by a relatively small solvent shell. The size of this solvent shell represents the amount of solvent transferred into the treatment chambers along with the driving ions.

In order to facilitate withdrawal of transferred solvent from the treatment chambers, it is preferable to interpose a layer or membrane between the treatment chambers and the opposite electrode chamber which has a relatively low ion content in relation to its pore volume, and, accordingly, passes ions into the electrode compartment with relatively large solvent shells.

In the fractionation of any fluids which must not be contaminated by the electrolyte, it is important that the electrolyte should consist of components of an adsorbability to the ion exchange materials equal to or greater than the components of the fluid flow. Assuming, for example the mixture to be separated is methyl alcohol and benzene, a suitable electrolyte would be water or methyl alcohol, rather than ethyl alcohol or acetone. The ethyl alcohol or acetone solvent shells accompanying the driving ions upon entry into the treatment chambers are immediately exchanged for methyl alcohol shells and thereafter continue to travel with the driving ions through the treatment chambers into the other electrode chamber, and the released ethyl alcohol or acetone mixes with the mixture fluid and contaminates it.

The flow rates, the spacing of the baffles, and the number of the baffles are so chosen that they produce fluid flow velocities between the baffles in the range of 1 mm. per second to 20 cm. per second.

The dynamic pressure drop measured between the inflow and outflow ends of the chambers is preferably greater than the mean weight of a column of liquid of a height equal to the spacing of the baffles or membranes, and preferably the dynamic pressure drop between inflow and outflow is greater than the difference in the weight of two fluid columns of two different fractions or preferably of the heaviest fraction and the lightest fraction of fluid at the outflow.

Following are examples of fractionation and separation conducted on a laboratory scale, it being understood that the dimensions given are not optimum dimensions for commercial operation on a larger scale.

Example 1

Equipment.—Substantially as in Figure 10, 360 membranes of IR-120 1 mm. thick, 2 mm. spacing, 150 mm. wide, 150 mm. high, one slot of 3 mm. width at membranes of zigzag flow, 3 subcells of 120 membranes each with sealing membranes, same material between each subcell and electrode compartments, each subcell has 1 fluid inlet and 3 outlets.

Operational data.—Fluid treated: A solution containing 7.46 g. of KCl and 4.24 g. of LiCl per 1000 cc. of water. Solution flow through electrode compartments 10 cc. per second. Cathode in electrode compartment towards which solution flows. Current 900 ma. Solution inflow: 5 cc. per second. Top outflow: 3 cc. per second. Intermediate outflow: 1.2 cc. per second. Bottom outflow: 0.8 cc. per second. Time of operation: 200 seconds.

Results.—Top outflow: 600 cc. containing 2.6 g. LiCl and 0.67 g. KCl. Center outflow: 240 cc. containing 1.09 g. LiCl and 1.63 g. KCl. Bottom outflow: 160 cc. containing 0.53 g. LiCl and 5.12 g. KCl.

Example 2

Same as Example 1 except that the apparatus was tilted 70 degrees to the horizontal to cause the fluid to flow upwardly. Current 1.2 amps.

Results.—Top outflow: 600 cc. containing 2.84 g. LiCl and 0.49 g. KCl. Center outflow: 240 cc. containing 1.09 g. LiCl and 1.67 g. KCl. Bottom outflow: 160 cc. containing 0.41 g. LiCl and 5.29 g. KCl.

Example 3

Equipment.—Same as in Example 1, but with two outlets for each subcell only.

Operational data.—Fluid treated: Seawater containing 3½% salts. Seawater flow through each electrode compartment at the rate of 2 cc. per second. Current 4 amps. Total fluid inflow: 10 cc. per second.

Results.—Top outflow: 6 cc. per second containing 51 mg. of salts. Bottom outflow: 4 cc. per second containing 299 mg. of salts. Mean flow velocity between membranes about 11 mm. per second.

Example 4

Equipment.—180 membranes of IR-120 and 180 membranes of IRA-400 alternating order. Membranes thickness 1 mm., height 150 mm., width 150 mm. One slot of 3 mm. width at membranes for zigzag flow. Spacing 2 mm. End membranes amphoteric IR-120 and IRA-400 mixtures of equivalent quantities. 4 fluid inlets, 3 intermediate fluid outlet locations with 2 vertically spaced outlets each.

Operational data.—Fluid treated: Seawater containing 3½% salts. Seawater flow through each electrode compartment at rate of 2 cc. per second. Current: 4 amps. Total fluid inflow: 10 cc per second.

Results.—Top outflow: 6 cc. per second containing 46 mg. of salts. Bottom outflow: 4 cc. per second containing 304 mg. of salts.

Example 5

Equipment.—Same as in Example 4, but with three outlets at each outlet location.

Operational data.—Fluid treated: A solution of 581 mg. of KF and 424 mg. of LiCl per 1000 cc. of water. Solution flow through each electrode compartment 10 cc. per second. Current: 800 ma. Total solution inflow rate: 5 cc. per second. Outflow rates: Top: 2.9 cc. per second. Center: 1.4 cc. per second. Bottom: 0.7 cc. per second. Time: 200 seconds.

Results.—Top outflow: 580 cc. containing 39 mg. Li, 62.5 mg. K, 101 mg. F, 67.5 mg. Cl. Center outflow: 280 cc. containing 20 mg. Li, 121 mg. K, 57 mg. F, 106 mg. Cl. Bottom outflow: 140 cc. containing 10.5 mg. Li, 270 mg. K, 32.5 mg. F, 180 mg. Cl.

Example 6

Equipment.—Same as in Example 1, except that all membranes are made of IRA-400.

Operational data.—Fluid treated: the same as in Example 1. Operation the same as in Example 1, except that current is 950 ma.

Results.—Top outflow: 600 cc. containing 2.72 g. LiCl and 0.51 g. KCl. Center outflow: 240 cc. containing 1.06 g. LiCl and 1.78 g. KCl. Bottom outflow: 160 cc. containing 0.46 g. LiCl and 5.17 g. KCl.

Example 7

Equipment.—Same as in Example 6, except that there are 12 subcells with 30 membranes each spaced 5 mm. Filler IR-120 beads 0.9 mm. diameter.

Operational data.—Fluid treated the same as in Ex-

ample 6. Operation the same as in Example 6, except that current is 1100 ma.

Results.—Top outflow: 600 cc. containing 2.97 g. LiCl and 0.24 g. KCl. Center outflow: 240 cc. containing 1.11 g. LiCl and 1.79 g. KCl. Bottom outflow: 160 cc. containing 0.16 g. LiCl and 5.43 g. KCl.

Example 8

Equipment.—360 membranes of Amberlite IRA-400 1/2 mm. thick, 150 mm. high, 150 mm. wide, spaced 10 mm. with filler of granules 1 mm. diameter of Duolite C-10. Membranes have one slot 10 mm. wide arranged for zigzag flow. End membranes are IRA-400. 13 fluid inlets and 12 intermediate outlet locations with 3 vertically spaced outlets each.

Operational data.—Fluid treated: A mixture of 50% acetone and 50% benzene. Electrolyte: a 15% LiCl solution flowing through each electrolyte compartment at a rate of 1 cc. per second. Current 1.4 A. Total fluid inflow: 6 cc. per second.

Results.—Top outflow: 2 cc. per second containing 1.76 cc. of acetone and 0.24 cc. of benzene. Center outflow: 2 cc. per second containing 0.97 cc. of acetone and 1.03 cc. of benzene. Bottom outflow: 2 cc. per second containing 0.27 cc. of acetone and 1.73 cc. of benzene.

Example 9

Equipment.—Same as in Example 8, except that membranes consist of IR-120 and 1 mm. thick and space between membranes is 5 mm. wide.

Operational data.—Fluid treated: A mixture of 50% acetone and 50% benzene. Electrolyte: a 15% LiCl solution in water flowing through each electrode compartment at rate of 1 cc. per second. Current: 1.6 A. Total fluid inflow: 6 cc. per second.

Results.—Top outflow: 2 cc. per second containing 1.84 cc. of acetone and 0.16 cc. of benzene. Center outflow: 2 cc. per second containing 0.98 cc. of acetone and 1.02 cc. of benzene. Bottom outflow: 2 cc. per second containing 0.18 cc. of acetone and 1.82 cc. of benzene.

Example 10

Equipment.—Same as in Example 9, except that space between membranes is filled with glauconite pebbles of 1.5 mm. diameter.

Operational data.—Fluid treated: A mixture of 20% water and 80% acetone. Electrolyte of 6% KCl in water at rate of 2 cc. per second flows through each electrode compartment. Current: 600 ma. Total fluid inflow: 6 cc. per second.

Results.—Top outflow: 2 cc. per second containing 0.07 cc. of water and 1.93 cc. of acetone. Center outflow: 2 cc. per second containing 0.19 cc. of water and 1.81 cc. of acetone. Bottom outflow: 2 cc. per second containing 0.94 cc. of water and 1.06 cc. of acetone.

Example 11

Equipment.—Same as in Example 8.

Operational data.—Fluid to be treated: Humid air containing 24 mg. of water per liter of air. Operation same as in Example 8, except that current is 400 ma. Total inflow 75 cc. per second.

Results.—Top outflow: 25 cc. per second containing 46 mg. of water per liter of air. Center outflow: 25 cc. per second containing 18 mg. of water per liter of air. Bottom outflow: 25 cc. per second containing 8 mg. of water per liter of air.

Example 12

Equipment.—Same as in Example 11, except that membranes are made of IR-120 and filler consists of attapulgite granules 1 1/2 mm. diameter.

Operational data.—Fluid treated: Air containing 19 mg. of acetone per liter. Electrolyte a 2% solution of tetramethylammonium chloride in acetone flowing through

each electrode compartment at rate of 2 cc. per second. Current: 350 ma. Total fluid inflow: 75 cc. per second.

Results.—Top outflow: 25 cc. per second containing 2 mg. of acetone per liter of air. Center outflow: 25 cc. per second containing 5 mg. of acetone per liter of air. Bottom outflow: 25 cc. per second containing 12 mg. of acetone per liter of air.

Example 13

Equipment.—120 membranes amphoteric made of mixture of equivalent quantities of Duolites C-3 and A-40. End membranes of the same material. Thickness 1 mm., height 150 mm., width 150 mm. Space between membranes is 3 mm. 13 fluid inlets and 12 intermediate fluid outlet locations with 3 vertically spaced outlets each.

Operational data.—Fluid treated: A mixture of 80% acetone and 20% water with admixture of 1/8 % of tetraethylammonium chloride. Electrolyte consists of a 2% solution of tetraethylammonium chloride flowing at rate of 2 cc. per second through each electrode compartment. Current: 1 amp. Total fluid inflow: 6 cc. per second.

Results.—Top outflow: 2 cc. per second containing 0.16 cc. of water and 1.84 cc. of acetone. Center outflow: 2 cc. per second containing 0.27 cc. of water and 1.73 cc. of acetone. Bottom outflow: 2 cc. per second containing 0.77 cc. of water and 1.23 cc. of acetone.

Example 14

Equipment.—Same as in Example 13, except that spaces are filled with attapulgite granules 1 1/2 mm. diameter.

Operational data.—Fluid treated: A mixture of 20% water and 80% acetone. Operation same as in Example 13, except that current is 800 ma. Total mixture inflow: 6 cc. per second.

Results.—Top outflow: 2 cc. per second containing 0.12 cc. of water and 1.88 cc. of acetone. Center outflow: 2 cc. per second containing 0.25 cc. of water and 1.75 cc. of acetone. Bottom outflow: 2 cc. per second containing 0.83 cc. of water and 1.17 cc. of acetone.

Example 15

Equipment.—100 membranes of IR-120 1 mm. thick, 150 mm. high and 150 mm. wide spaced by Saran screening 1 mm. 3 cathode compartments vertically spaced and sealed by membranes 1 mm. thick of IRA-400 and with associated membranes of cellophane sealing towards the treatment chambers and forming 3 collecting concentration chambers with individual outlets. Filler between collecting chambers and treatment chamber a layer of sand granules 1/2 mm. diameter, 1 mm. thick.

Operational data.—Solution treated: A solution of 7.46 g. KCl and 4.24 g. of LiCl in water. All compartments are filled with solution initially and solution flows through each electrode compartment at rate of 2 cc. per second. Current between anode and each cathode: 350 ma. Bottom of cell is water cooled by flowing water. 1 hour operation after equilibrium.

Results.—Top outflow contains 1.64 mg. of Li and trace of K. Center outflow contains 86 mg. of Li and 498 mg. of K. Bottom outflow contains 9.91 mg. K and trace of Li.

Example 16

Equipment.—Same as in Example 14, except main membranes are made of Amberlite IRA-400.

Operational data.—Fluid treated: A solution of 2 N KCl and 2 N LiCl in water. Solution flows through anode compartment at rate of 2 cc. per second. A 0.1 N HCl solution in water flows through each cathode compartment at rate of 2 cc. per second. Fluid inflow at anode side of cell: 0.6 cc. per second. Fluid outflows at each cathode collection compartment 0.2 cc. per second. Current: 2 A at each cathode.

After equilibrium condition is established, the results are: Top outflow and top cathode compartment outflow

contain K and Li with Li predominating. Center outflow and center cathode compartment outflow contain K and Li. Bottom outflow and bottom cathode compartment outflow contain K and Li with K predominating.

For reasons of convenience many ion exchange materials have been identified in this description by the names under which they are offered to, and are known to the trade.

Grouped according to their chemical composition, the following strong cation exchangers are sulfonated copolymers of polystyrene and divinyl benzene:

Amberlites IR-120 and IR-112

Dowex 50

Duolites C-10 and C-25

The following strong cation exchangers are phenolic methylene sulfonic resins:

Amberlites IR-100 and IR-105

Dowex 30

The following cation exchangers are phenolic carboxylic resins:

Amberlite IRC-50

Permutit 216

Duolite CS-100

Duolite CS-101 is a crosslinked acrylic with carboxylic acid as functional groups

The following anion exchangers are copolymers of polystyrene and divinyl benzene with quaternary ammonium groups:

Amberlite IRA-400

Dowex 1

Duolites A-41 and A-44 have a halogenated polyvinyl aromatic matrix with quaternary ammonium groups.

The following anion exchangers are modified phenol formaldehyde polyamine condensates:

Amberlites IR-4B and IR-45

Duolites A-3; A-6 and A-7

Duolite C-60 is a cationic resin with phosphonous acid groups. Duolite C-61 is a resin with phosphonic acid groups.

Glauconite, De Calso and ZeoDur are aluminum silicates.

ZeoCarb is sulfonated coal.

Saran is a neutral thermoplastic resin also known as vinylidene chloride.

What is claimed is:

1. An apparatus for fractionating constituents of an ionic solution under the influence of an electric current and gravity, the apparatus comprising, a substantially horizontally extended housing having two horizontally spaced ends; electrodes of opposite polarity at opposite ends of the housing; a plurality of substantially parallel spaced baffles of an ion exchange material of a certain polarity, said material being repellant to ions of said certain polarity and permeable to ions of the opposite polarity, said spaced baffles being at an angle to the horizontal and transverse to the general path of the electric current flowing from one electrode to the other, said spaced baffles subdividing said housing into substantially parallel liquid chambers; supply duct means for supplying solution into the apparatus at a chamber which is nearer to an electrode of the one polarity than it is to an electrode of the opposite polarity; withdrawal duct means downstream with respect to said supply duct means for withdrawing fluid fractions from a portion of said housing which is closer to an electrode of the opposite polarity than it is to an electrode of the one polarity, said withdrawal means comprising at least two separate ducts having intake ports, said intake ports being vertically spaced to withdraw liquid from separate vertically spaced liquid strata, the withdrawal means being separated from the fluid supply means by a plu-

rality of baffle-separated intermediate chambers, said intermediate chambers being so constructed as to provide passage for fluid from one intermediate chamber to the next substantially transversely to said baffles, each baffle and its bordering chamber presenting a certain hydraulic flow resistance to the fluid flowing from a preceding chamber to the next chamber, the flow resistance of successive baffles with their respective bordering chambers being proportionately the same for corresponding levels of the baffles, so as to permit the fluid to flow from chamber to chamber without baffle-induced deflection of the flow in an upward or downward sense.

2. An apparatus for fractionating constituents of an ionic solution under the influence of an electric current and gravity, the apparatus comprising, a substantially horizontally extended housing having two horizontally spaced ends; electrodes of opposite polarity at opposite ends of the housing; a plurality of substantially parallel spaced baffles of an ion exchange material of a certain polarity, said material being repellant to ions of said certain polarity and permeable to ions of the opposite polarity, said spaced baffles being at an angle to the horizontal and transverse to the general path of a current flowing from one electrode to the other, said spaced baffles subdividing said housing into substantially parallel liquid chambers; supply duct means for supplying solution into the apparatus at a chamber which is nearer to an electrode of the one polarity than it is to an electrode of the opposite polarity; withdrawal duct means downstream with respect to said supply duct means for withdrawing fluid fractions from a withdrawal chamber which is nearer to an electrode of the opposite polarity than it is to an electrode of the one polarity; means for subdividing said withdrawal chamber into vertically spaced individual compartments, said withdrawal means comprising separate withdrawal ports for said individual compartments, the withdrawal means being spaced from the fluid supply means by a plurality of said baffle-separated intermediate chambers, said intermediate chambers being so constructed as to provide passage of fluid from chamber to chamber to said withdrawal means through said chambers substantially transversely to said baffles.

3. An apparatus for fractionating constituents of an ionic solution under the influence of an electric current and gravity, the apparatus comprising, a substantially horizontally extended housing having two horizontally spaced ends; electrodes of opposite polarity at opposite ends of the housing, there being at least one electrode of one polarity at the one end of the housing and at least two electrodes of the opposite polarity at the other end of the housing; a plurality of substantially parallel spaced baffles of an ion exchange material of a certain polarity, said material being repellant to ions of said certain polarity and permeable to ions of the opposite polarity, said spaced baffles being at an angle to the horizontal and transverse to the general path of the electric current flowing from one electrode to the other, said spaced baffles subdividing said housing into substantially parallel liquid chambers; supply duct means for supplying solution into the apparatus at a chamber which is nearer to an electrode of the one polarity than it is to an electrode of the opposite polarity; withdrawal means for withdrawing fluid fractions from a portion of the housing which portion comprises said electrodes of the opposite polarity; means for subdividing said portion into individual compartments, each compartment containing an electrode of the opposite polarity, said withdrawal means comprising separate vertically spaced withdrawal ports for said individual compartments, the withdrawal ports being separated from the fluid supply means by a plurality of said baffle-separated intermediate chambers, said intermediate chambers being so constructed as to provide substantially unimpeded horizontal passage for fluid from one of said intermediate chambers to the next substantially transversely to said baffles.

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4. An apparatus for fractionating constituents of an ionic solution under the influence of an electric current and gravity, the apparatus comprising, a substantially horizontally extended housing having two horizontally spaced ends; electrodes of opposite polarity at opposite ends of the housing, there being at least one electrode of one polarity at the one end of the housing and at least two electrodes of the opposite polarity, vertically spaced, at the other end of the housing; a plurality of substantially parallel spaced baffles of an ion exchange material of a certain polarity, said material being repellant to ions of said certain polarity and permeable to ions of the opposite polarity, said spaced baffles being at an angle to the horizontal and transverse to the general path of the electric current flowing through the apparatus from said one electrode to the other electrodes, said spaced baffles subdividing said housing into substantially parallel liquid chambers; supply means for supplying solution into the apparatus at a chamber which is nearer to an electrode of the one polarity than it is to an electrode of the opposite polarity; withdrawal means for withdrawing fluid fractions from a withdrawal chamber which is nearer to the electrodes of the opposite polarity than it is to the electrode of the one polarity; means for subdividing said withdrawal chamber into vertically spaced individual compartments substantially at the vertical levels of said vertically spaced electrodes, said withdrawal means comprising separate withdrawal ports for said individual compartments, said withdrawal chamber being separated from said fluid supply means by a plurality of baffle-separated intermediate chambers, said intermediate chambers being so constructed as to provide substantially unimpeded horizontal passage for fluid from one intermediate chamber to the next substantially transversely to said baffles.

5. An apparatus for fractionating constituents of an ionic solution under the influence of an electric current and gravity, the apparatus comprising, a substantially horizontally extended housing having two horizontally spaced ends; electrodes of opposite polarity at opposite ends of the housing; a plurality of substantially parallel spaced baffles of an ion exchange material of a certain polarity, said material being repellant to ions of said certain polarity and permeable to ions of the opposite polarity, said spaced baffles being at an angle to the horizontal and transverse to the general path of the electric current flowing through the apparatus from said one electrode to the other, said spaced baffles subdividing said housing into substantially parallel liquid chambers; supply means for supplying solution into the apparatus at a chamber which is nearer to an electrode of the one polarity than it is to an electrode of the opposite polarity; withdrawal means for withdrawing fluid fractions from a portion of the housing which portion is closer to an electrode of the opposite polarity than it is to an electrode of the one polarity; means for subdividing said housing portion into individual vertically spaced compartments spaced to receive liquid from separate vertically spaced liquid strata, said withdrawal means comprising separated vertically spaced withdrawal ports for said individual compartments, said compartments being separated from said fluid supply means by a plurality of baffle-separated intermediate chambers, said intermediate chambers being so constructed as to provide substantially unimpeded horizontal passage for fluid from one intermediate chamber to the next substantially transversely to said baffles.

6. An apparatus for fractionating constituents of an ionic solution under the influence of an electric current and gravity, the apparatus comprising, a substantially horizontally extended housing having two horizontally spaced ends; electrodes of opposite polarity at opposite ends of the housing; a plurality of substantially parallel spaced baffles of an ion exchange material of a certain polarity, said material being repellant to ions of said

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certain polarity and permeable to ions of the opposite polarity, said spaced baffles being at an angle to the horizontal and transverse to the general path of the electric current flowing through the apparatus between the electrodes, said spaced baffles subdividing said housing into substantially parallel liquid chambers; supply duct means for supplying solution into the apparatus at a supply chamber which is nearer to an electrode of the one polarity than it is to an electrode of the opposite polarity, said chambers further including a withdrawal chamber which is nearer to an electrode of the opposite polarity than it is to an electrode of the one polarity; means for subdividing said withdrawal chamber into vertically spaced compartments; duct means for supplying liquid into said compartments; and separate withdrawal ducts for withdrawing liquid from individual vertically spaced compartments, said withdrawal chamber being separated from said supply chamber by a plurality of baffle-separated intermediate chambers, said intermediate chambers being so constructed as to provide substantially unimpeded horizontal passage for fluid from one intermediate chamber to the next substantially transversely to said baffles.

7. An apparatus for fractionating constituents of an ionic solution under the influence of an electric current and gravity, the apparatus comprising, a substantially horizontally extended housing having two horizontally spaced ends; electrodes of opposite polarity at opposite ends of the housing; a plurality of substantially parallel spaced baffles of an ion exchange material of a certain polarity, said material being repellant to ions of said certain polarity and permeable to ions of the opposite polarity, said spaced baffles being at an angle to the horizontal and transverse to the general path of the electric current flowing through the apparatus between the electrodes, said spaced baffles subdividing said housing into substantially parallel liquid chambers, there being electrode chambers containing said electrodes and intermediate chambers lying between said electrode chambers; supply duct means for supplying solution into the apparatus at a chamber which is nearer to an electrode of the one polarity than it is to an electrode of the opposite polarity; withdrawal means for withdrawing fluid fractions from a portion of said housing which portion is closer to an electrode of the opposite polarity than it is to an electrode of the one polarity; means other than said baffles for subdividing said housing portion into vertically spaced individual compartments, said withdrawal means comprising separate withdrawal ducts for said individual compartments; a barrier of an ion exchange material between said subdivided portion and the electrode of the opposite polarity, said barrier being of a material repellant to ions of the polarity of the fractions and permeable to ions of a polarity opposite of the fractions; means for passing a flow of liquid through the electrode chamber containing the electrode of the opposite polarity, said withdrawal means being separated from the fluid supply means by a plurality of baffle-separated intermediate chambers, said intermediate chambers being so constructed as to provide substantially unimpeded horizontal passage for fluid from one intermediate chamber to the next substantially transversely to said baffles.

8. An apparatus for fractionating constituents of an ionic solution under the influence of an electric current and gravity, the apparatus comprising, a substantially horizontally extended housing having two horizontally spaced ends; electrodes of opposite polarity at opposite ends of the housing; a plurality of substantially parallel spaced baffles, said baffles being at an angle to the horizontal and transverse to the general path of the electric current flowing through the apparatus between the electrodes, said spaced baffles subdividing said housing into transversely disposed liquid chambers, there being electrode chambers containing said electrodes and intermediate liquid chambers lying between said electrode cham-

bers; supply means for supplying solution into said apparatus at a chamber which is nearer to one end of the housing than it is to the other end of the housing; withdrawal means downstream with respect to said supply means for withdrawing fluid fractions from a portion of said housing nearer to the other end of the housing than it is to said one end of the housing; a macroporous filler of an ion exchange material of at least one polarity in said liquid chambers; said withdrawal means comprising at least two withdrawal ducts having intake ports, said intake ports being vertically spaced to withdraw liquid from separate vertically spaced liquid strata.

9. An apparatus for fractionating constituents of an ionic solution under the influence of an electric current and gravity, the apparatus comprising, a substantially horizontally extended housing having two horizontally spaced ends; electrodes of opposite polarity at opposite ends of the housing; duct for supplying solution into said housing near one electrode, withdrawal means downstream with respect to said supply duct means for withdrawing fluid fractions from a portion of said housing near the other electrode, said withdrawal means comprising at least two separate ducts having intake ports; a plurality of baffles in the path of liquid flowing from the supply means to said withdrawal means, at least certain of said baffles being of ion exchange material of a certain polarity, repellant to ions of said certain polarity and permeable to ions of the opposite polarity, said baffles being at an angle to the horizontal and substantially transverse to the general path of an electric current flowing through the apparatus between the electrodes, said baffles subdividing said housing into substantially parallel liquid chambers, said baffles being so constructed with respect to the liquid flow as to permit liquid flow from chamber to chamber along a substantially horizontal path, said outlet ports being located on vertically fanned-out radii of different inclination with respect to the horizontal to withdraw liquid from separate vertically spaced liquid strata.

10. An apparatus as set forth in claim 9 in which said baffles are composed of layers of granules of ion exchange material.

11. An apparatus as set forth in claim 9 in which said baffles are in the form of membranes having perforations therethrough permitting flow of liquid from chamber to chamber.

12. An apparatus as set forth in claim 9 in which said baffles are formed of a plurality of spaced particles of ion exchange material, said particles being arranged in a layer or plane, the particles having a larger dimension in the direction of the plane than at right angles thereto.

13. An apparatus for separating a fluid containing certain components by producing separate volumes of heavier and lighter fluids containing said components in different proportions, the apparatus comprising, a substantially horizontally extended housing having two horizontally spaced ends; electrodes of opposite polarity at opposite ends of the housing; duct means for supplying fluid to be separated into said housing near one electrode; withdrawal means downstream with respect to said supply duct means for withdrawing fluid fractions from a portion of said housing near the other electrode; said withdrawal means including at least two separate ducts having intake ports; a plurality of baffles in the path of fluid flowing from said supply means to said withdrawal means, at least certain of said baffles being of an ion exchange material of a certain polarity repellant to ions of said certain polarity and permeable to ions of the opposite polarity, said baffles being at an angle to the horizontal and substantially transverse to the general path of an electric current flowing through the apparatus between said electrodes and also substantially transverse to the flow of fluid, said baffles subdividing said housing into substantially parallel fluid chambers, said chambers being so constructed as to provide fluid flow from chamber to chamber substantially

transversely to said baffles, each baffle and its bordering chamber presenting a certain hydraulic flow resistance to the fluid flowing from chamber to chamber, the flow resistance of successive baffles with their respective bordering chambers being proportionately the same for corresponding levels of the baffles so as to permit the fluid to flow from chamber to chamber freely without baffle-induced deflection of the flow in an upward or downward sense, said intake ports being located on vertically fanned-cut radii of different inclination with respect to the horizontal to withdraw fluid from separate vertically spaced fluid strata; and a macroporous ion conductive filler in at least certain of the spaces, said filler being in contact with the said baffles, filler being of a microporous ion exchange material having a concentration of ionic groups of the polarity of the baffles different from the ionic concentration of the material of said baffles on the basis of number of ionic groups per unit of pore volume, said filler providing a conductive path between baffles in said certain fluid chambers.

14. A process for treating an ionic liquid to produce a volume of heavier and a volume of lighter liquid containing certain constituents of the liquid in different proportions which comprises subjecting a confined body of said liquid to an electrical potential lengthwise of said body, said potential being applied at spaced electrodes, thereby producing an electric current through the liquid; maintaining said body of liquid in contact at spaced portions thereof with successive liquid pervious baffles of ion exchange material, said baffles forming individual liquid chambers between them, at least certain of said baffles being permeable to ions of one sign and passage resistant to ions of the opposite sign, whereby zones of ionic concentration are formed along one surface of said certain baffles and zones of ionic dilution are formed along the opposite surface, subjecting the body of liquid and said baffles to a mechanical accelerating force, said baffles being disposed transverse to the electric current and in a general direction parallel to said force, as distinguished from a direction at right angles to said force, to move heavier liquid in the direction of said force and lighter liquid in the opposite direction in said chambers; supplying liquid to be treated near one end of said liquid body; moving said liquid by hydraulic flow from one side of a baffle to the other side of the same baffle, and in like manner from one side of the succeeding baffle to its other side, the direction of flow being substantially at an angle to the direction of said force, as distinguished from a direction parallel to said force, so that the bottom portion of liquid from one chamber flows into the bottom portion of the liquid in the next chamber and that the top portion of the liquid from the one chamber flows into the top portion of the liquid in the next chamber; and continuously withdrawing liquid near the other end of said body from separate liquid strata spaced in the direction of said force.

15. A process for treating a liquid containing non-conductive non-ionic components to produce a volume of heavier and a volume of lighter liquid containing said components in different proportions, the process comprising, confining a body of said liquid between endwisely arranged ion-permeable membranes, applying an electrical potential to electrodes on the far side of said membranes with respect to said body of liquid, maintaining an electrolyte in the spaces between the electrodes and the respective membranes; maintaining said body of liquid in contact at spaced portions thereof with successive liquid pervious baffles of ion exchange material, said baffles forming individual liquid chambers between them, subjecting the body of liquid and said baffles to a mechanical accelerating force, said baffles being disposed transverse to the electric current and in a general direction parallel to said force, as distinguished from a direction at right angles to said force to move heavier liquid in the direction of said force and lighter liquid in

the opposite direction in said chambers; maintaining an ionically conductive path from membrane to membrane and through said baffles by an ion conductive porous filler in said chambers, said filler having an ionic concentration different from that of said baffles; supplying liquid to be treated near one end of said liquid body; moving said liquid by hydraulic flow from one side of a baffle to the other side of the same baffle, and in like manner from one side of the succeeding baffle to its other side, the direction of flow being substantially at an angle to the direction of said force as distinguished from a direction parallel to said force, so that the bottom portion of liquid from one chamber flows into the bottom portion of the liquid in the next chamber and that the top portion of the liquid from the one chamber flows into the top portion of the liquid in the next chamber; and continuously withdrawing liquid near the other end of said body from liquid strata spaced in the direction of said force.

16. A process for treating a liquid containing non-conductive non-ionic components to produce a volume of heavier and a volume of lighter liquid containing said components in different proportions, the process comprising, admixing to the liquid a surface active agent; subjecting a confined body of said liquid mixture to an electrical potential lengthwise of said body thereby producing an electric current through said liquid; maintaining said body of liquid in contact at spaced portions thereof with successive baffles of ion exchange material, said baffles forming individual liquid chambers between them, the ionic concentration of the said ion exchange material being greater than that of the mixture, whereby zones of concentration of one component are formed along one surface of said certain baffles and zones of concentration of the other component are formed along the opposite surface, subjecting the body of liquid and said baffles to a mechanical accelerating force, said baffles being disposed transverse to the electric current and in a general direction parallel to said force, as distinguished from a direction at right angles to said force to move heavier liquid in the direction of said force and lighter liquid in the opposite direction in said chambers; continuously supplying said liquid and surface active agent mixture near one end of said liquid body; moving said liquid mixture by hydraulic flow from one side of a baffle to the other side of the same baffle, and in like manner from one side of the succeeding baffle to its other side, the direction of flow being substantially at an angle to the direction of said force, as distinguished from a direction parallel to said force, so that the bottom portion of liquid from one chamber flows into the bottom portion of the liquid in the next

chamber and that the top portion of the liquid from the one chamber flows into the top portion of the liquid in the next chamber; and continuously withdrawing liquid near the other end of said body from separate strata spaced in the direction of said force.

17. A process for separating components of substances in the gaseous state, such as gas-vapor mixtures or vapor mixtures, the process comprising, applying an electrical potential at spaced electrodes; introducing the gaseous mixture into the space between substantially parallel spaced baffles of ion exchange material, said baffles lying between said electrodes and forming lateral boundaries of treatment compartments for said mixtures; maintaining an electrolyte in the spaces between the electrodes and the respective endmost baffles; maintaining an ion conductive path between said baffles by an ion conductive porous filler in said compartments, resulting in a flow of a current from electrode to electrode through said chambers and the filler in a direction at an angle to said baffles; subjecting the filler and said baffles to a mechanical accelerating force acting in a general direction parallel to said baffles, as distinguished from a direction at right angles to said baffles; supplying mixture to be treated nearer one of said electrodes and advancing said mixture by flow from one side of a baffle to the other side of the same baffle, and in like manner from one side of the succeeding baffle to its other side, the direction of flow being substantially at an angle to the direction of said force, as distinguished from a direction parallel to said force, so that the bottom portion of effluent from one chamber flows into the bottom portion of the next chamber and that the top portion of the effluent from one chamber flows into the top portion into the next chamber; and withdrawing product volumes from a chamber nearer the other electrode from strata spaced in the direction of said force, whereby gas volumes of enlarged and reduced vapor content are separately recoverable.

References Cited in the file of this patent

UNITED STATES PATENTS

1,577,660	Ruppel	Mar. 23, 1926
2,502,614	Zender	Apr. 4, 1950
2,708,658	Rosenberg	May 17, 1955
2,758,965	Block et al.	Aug. 14, 1956

FOREIGN PATENTS

505,752	Great Britain	May 15, 1939
675,253	Great Britain	July 9, 1952

OTHER REFERENCES

"Fortune Magazine," July 1951, page 109.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 2,854,394

September 30, 1958

Paul Kollsman

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 19, line 63, for "of", first occurrence, read -- for --;
column 25, line 60, for "separated" read -- separate --; column 27, line 18,
after "duct" insert -- means --; column 28, line 14, strike out "said" and
insert the same before "filler", same line.

Signed and sealed this 14th day of July 1959.

(SEAL)
Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents