



(51) International Patent Classification:

B01D 15/36 (2006.01) **B01J 41/05** (2017.01)
C07C 51/47 (2006.01) **B01J 41/07** (2017.01)
C12P 7/40 (2006.01)

(21) International Application Number:

PCT/US2016/063219

(22) International Filing Date:

22 November 2016 (22.11.2016)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/261,348 1 December 2015 (01.12.2015) US

(71) Applicants: **DOW GLOBAL TECHNOLOGIES LLC** [US/US]; 2040 Dow Center, Midland, MI 48674 (US). **ROHM AND HAAS COMPANY** [US/US]; 100 Independence Mall West, Philadelphia, PA 19106 (US).

(72) Inventors: **MARTIN, Collin H.**; 400 Arcola Road, Collegeville, PA 19426 (US). **GISCH, Daryl J.**; 1801 Building, Larkin Lab, 1691 North Swede Road, Midland, MI 48674 (US). **PEASE, Stephen**; 400 Arcola Road, Collegeville, PA 19426 (US).

(74) Agent: **BLACK, Edward W.**; The Dow Chemical Company, Intellectual Property, P. O. Box 1967, Midland, Michigan 48641-1967 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: CHROMATOGRAPHIC SEPARATION OF ORGANIC ACIDS USING RESIN HAVING STRONG AND WEAK BASE ANION EXCHANGE CAPACITY

(57) Abstract: A method for chromatographically separating organic acids from a liquid feed mixture including an organic acid and carbohydrate by passing the liquid feed mixture through a bed including an ion exchange resin having both strong base anion exchange groups and weak base anion exchange groups.



WO 2017/095686 A1

CHROMATOGRAPHIC SEPARATION OF ORGANIC ACIDS USING RESIN HAVING STRONG AND WEAK BASE ANION EXCHANGE CAPACITY

FIELD

5 The invention relates the use of ion exchange resins to chromatographically separate organic acids from a liquid feed mixture.

INTRODUCTION

Many industrial processes produce liquid feed streams containing various organic acids.
10 For example, fermentation broths including various saccharides such as glucose and fructose may degrade by bacteriological action to produce lactic acid, malic acid along with other weak organic acids. If not removed from the sugar solution, the taste and color of foodstuffs produced therefrom may be adversely affected. In other processes, the organic acid itself may be the product material of interest.

15 Ion exchange resins have been used as a stationary phase in chromatographic separation of organic acids from fermentation broths. For example, EP0481603 describes the use of a gel-type weak-base anion exchange resin for removing weak organic acids from fermentation broths. Similarly, US8664436 describes the use of one of: strong acid cationic, weak acid cationic, strong base anionic or weak base anionic exchange resins.

20 The inventors of the present invention have determined that strong base anion ("SBA") exchange resins provide better chromatographic separation (resolution) of organic acids as compared with weak base anion ("WBA") exchange resins. That is, SBA exchange resins have a stronger affinity for organic acids as compared with WBA exchange resins. While providing better resolution, this greater affinity for organic acids results in longer retention times and
25 requires more water to elute organic acids from the SBA resin as compared with WBA resin. The use of increased water leads to higher cost and results in a more dilute product that requires more product stream evaporation. The search continues for improved processes for chromatographically separating of organic acids.

30

SUMMARY

The invention provides a new method for chromatographically separating an organic acid from a liquid mixtures containing an organic acid and carbohydrate, e.g. a fermentation broth. In particular, the invention utilizes a specialized ion exchange resin having both strong and weak base
35 anion exchange groups. In particular, the invention includes the step of passing the liquid feed mixture through a bed of the aforementioned ion exchange resin. In a preferred embodiment, the resin includes a ratio of strong base anion exchange groups to weak base anion exchange groups is from 95:5 to 5:95, and more preferably from 80:20 to 20:80 and even more preferably from 70:30 to

30:70. In another preferred embodiment, the subject ion exchange resin has a strong base anion capacity from 0.1 to 4 milliequivalents per gram and a weak base anion capacity from 0.1 to 4 milliequivalents per gram.

5 DETAILED DESCRIPTION

The invention includes a method for chromatographically separating at least one organic acid from a liquid mixture including an organic acid and carbohydrate. As used herein, the term “organic acid” refers to an organic molecule including at least one carboxylic acid functional group or a corresponding salt thereof. Representative examples include but are not limited to:

10 propionic acid, lactic acid, itaconic acid, succinic acid, maleic acid, citric acid, ascorbic acid, α -ketoglutaric acid, glycolic acid, gluconic acid, malic acid, tartaric acid and saccharic acid along with their corresponding salts. In a preferred embodiment of the invention, the liquid feed mixture includes at least 1 g/L of an organic acid. In addition to the aforementioned organic acids, the liquid feed mixture may additionally include one or more carbohydrates including saccharides (e.g.

15 glucose, fructose, xylose, mannose), amino acids, alcohols (e.g. glycerol), amino acids, proteins, and inorganic salts (e.g. salts of potassium sodium, calcium, magnesium, iron, and particularly sodium sulfate). Representative liquid feed mixtures include those of used in many fermentation processes.

As with traditional chromatographic separations, the liquid feed mixture (mobile phase)

20 passes through a bed or stratum of ion exchange resin (stationary phase). The set up and operation of the bed is not particularly limited, e.g. moving, simulated moving and stationary beds may be used.

The ion exchange resin used in the present invention includes both strong base and weak base anion exchange groups. In a preferred embodiment, the resin includes a ratio of strong base anion exchange groups to weak base anion exchange groups is from 9:1 to 1:9, and more preferably from 8:2 to 2:8 and even more preferably from 7:3 to 3:7. In another preferred embodiment, the subject ion exchange resin has a strong base anion capacity from 0.1 to 4 milliequivalents per gram and a weak base anion capacity from 0.1 to 4 milliequivalents per gram wherein anion capacity as measured by ASTM D2187-94 (reapproved 2009)). An example of a preferred resin is AMBERLITE™ IRA 458 commercially available

30 from The Dow Chemical Company.

The subject ion exchange resins are preferably provided in bead form having a median diameter from 10 to 2000 microns, and more preferably from 100 to 1000 microns. The beads may have a Gaussian particle size distribution or may have a relatively uniform particle size distribution, i.e. “monodisperse” that is, at least 90 volume percent of the beads have a particle

35 diameter from about 0.8 to about 1.2, and more preferably 0.85 to 1.15 times the volume average particle diameter.

The subject ion exchange resins are preferably gel-type. The terms “microporous,” “gellular,” “gel” and “gel-type” are synonyms that describe copolymer resins having pore sizes less than about 20 Angstroms Å. In distinction, macroporous copolymer resins have both mesopores of from about 20 Å to about 500 Å and macropores of greater than about 500 Å. Gel-type copolymer beads, as well as their preparation are described in US4256840 and US5244926. One preferred method is known in the art as a “seeded” polymerization, sometimes also referred to as batch or multi-batch (as generally described in EP 62088A1 and EP 179133A1); and continuous or semi-continuous staged polymerizations (as generally described in US 4,419,245; US 4,564,644; and US 5,244,926). A seeded polymerization process typically adds monomers in two or more increments. Each increment is followed by complete or substantial polymerization of the monomers therein before adding a subsequent increment. A seeded polymerization is advantageously conducted as a suspension polymerization wherein monomers or mixtures of monomers and seed particles are dispersed and polymerized within a continuous suspending medium. In such a process, staged polymerization is readily accomplished by forming an initial suspension of monomers, wholly or partially polymerizing the monomers to form seed particles, and subsequently adding remaining monomers in one or more increments. Each increment may be added at once or continuously. Due to the insolubility of the monomers in the suspending medium and their solubility within the seed particles, the monomers are imbibed by the seed particles and polymerized therein. Multi-staged polymerization techniques can vary in the amount and type of monomers employed for each stage as well as the polymerizing conditions employed.

The seed particles employed may be prepared by known suspension polymerization techniques. In general the seed particles may be prepared by forming a suspension of a first monomer mixture in an agitated, continuous suspending medium as described by F. Helfferich in Ion Exchange, (McGraw-Hill 1962) at pp. 35-36. The first monomer mixture comprises: 1) a first monovinylidene monomer, 2) a first crosslinking monomer, and 3) an effective amount of a first free-radical initiator. The suspending medium may contain one or more suspending agents commonly employed in the art. Polymerization is initiated by heating the suspension to a temperature of generally from about 50-90°C. The suspension is maintained at such temperature or optionally increased temperatures of about 90-150° C until reaching a desired degree of conversion of monomer to copolymer. Other suitable polymerization methods are described in US 4,444,961; US 4,623,706; US 4,666,673; and US 5,244,926 - each of which is incorporated herein in its entirety.

The monovinylidene aromatic monomers employed herein are well-known and reference is made to Polymer Processes, edited by Calvin E. Schildknecht, published in 1956 by Interscience Publishers, Inc., New York, Chapter III, “Polymerization in Suspension” at pp. 69-109. Table II (pp. 78-81) of Schildknecht lists diverse types of monomers which are suitable in practicing the present invention. Of the monomers listed, styrene and substituted styrene are preferred. The term

“substituted styrene” includes substituents of either/or both the vinylidene group and phenyl group of styrene and include: vinyl naphthalene, alpha alkyl substituted styrene (e.g., alpha methyl styrene) alkylene-substituted styrenes (particularly monoalkyl-substituted styrenes such as vinyltoluene and ethylvinylbenzene) and halo-substituted styrenes, such as bromo or chlorostyrene and vinylbenzyl chloride. Additional monomers may be included along with the monovinylidene aromatic monomers, including monovinylidene non-styrenics such as: esters of α,β -ethylenically unsaturated carboxylic acids, particularly acrylic or methacrylic acid, methyl methacrylate, isobornyl-methacrylate, ethylacrylate, and butadiene, ethylene, propylene, acrylonitrile, and vinyl chloride; and mixtures of one or more of said monomers. Preferred monovinylidene monomers include styrene and substituted styrene such as ethylvinylbenzene. The term “monovinylidene monomer” is intended to include homogeneous monomer mixtures and mixtures of different types of monomers, e.g. styrene and isobornylmethacrylate. The seed polymer component preferably comprises a styrenic content greater than 50 molar percent, and more preferably greater than 75, and in some embodiments greater than 95 molar percent (based upon the total molar content). The term “styrenic content” refers to the quantity of monovinylidene monomer units of styrene and/or substituted styrene utilized to form the copolymer. “Substituted styrene” includes substituents of either/or both the vinylidene group and phenyl group of styrene as described above. In preferred embodiments, the first monomer mixture used to form the first polymer component (e.g. seed) comprises at least 75 molar percent, preferably at least 85 molar percent and in some embodiments at least 95 molar percent of styrene.

Examples of suitable crosslinking monomers (i.e., polyvinylidene compounds) include polyvinylidene aromatics such as divinylbenzene, divinyltoluene, divinylxylene, divinyl-naphthalene, trivinylbenzene, divinyl-diphenylsulfone, as well as diverse alkylene diacrylates and alkylene dimethacrylates. Preferred crosslinking monomers are divinylbenzene, trivinylbenzene, and ethylene glycol dimethacrylate. The terms “crosslinking agent,” “crosslinker” and “crosslinking monomer” are used herein as synonyms and are intended to include both a single species of crosslinking agent along with combinations of different types of crosslinking agents. The proportion of crosslinking monomer in the copolymer seed particles is preferably sufficient to render the particles insoluble in subsequent polymerization steps (and also on conversion to an ion-exchange resin), yet still allow for adequate imbibition of an optional phase-separating diluent and monomers of the second monomer mixture. In some embodiments, no crosslinking monomer will be used. Generally, a suitable amount of crosslinking monomer in the seed particles is minor, i.e., desirably from about 0.01 to about 12 molar percent based on total moles of monomers in the first monomer mixture used to prepare the seed particles. In a preferred embodiment, the first polymer component (e.g. seed) is derived from polymerization of a first monomer mixture comprising at least 85 molar percent of styrene (or substituted styrene such as ethylvinylbenzene) and from 0.01 to about 10 molar percent of divinylbenzene.

Polymerization of the first monomer mixture may be conducted to a point short of substantially complete conversion of the monomers to copolymer or alternatively, to substantially complete conversion. If incomplete conversion is desired, the resulting partially polymerized seed particles advantageously contain a free-radical source therein capable of initiating further
5 polymerization in subsequent polymerization stages. The term “free-radical source” refers to the presence of free-radicals, a residual amount of free-radical initiator or both, which is capable of inducing further polymerization of ethylenically unsaturated monomers. In such an embodiment of the invention, it is preferable that from about 20 to about 95 weight percent of the first monomer mixture, based on weight of the monomers therein, be converted to copolymer and more preferably
10 from about 50 to about 90 weight percent. Due to the presence of the free radical source, the use of a free-radical initiator in a subsequent polymerization stage would be optional. For embodiments where conversion of the first monomer mixture is substantially complete, it may be necessary to use a free-radical initiator in subsequent polymerization stages.

The free-radical initiator may be any one or a combination of conventional initiators for
15 generating free radicals in the polymerization of ethylenically unsaturated monomers. Representative initiators are UV radiation and chemical initiators, such as azo-compounds including azobisisobutyronitrile; and peroxygen compounds such as benzoyl peroxide, t-butylperoxoate, t-butylperbenzoate and isopropylpercarbonate. Other suitable initiators are mentioned in US 4192921, US 4246386 and US 4283499 – each of which is incorporated in its entirety. The free-
20 radical initiators are employed in amounts sufficient to induce polymerization of the monomers in a particular monomer mixture. The amount will vary as those skilled in the art can appreciate and will depend generally on the type of initiators employed, as well as the type and proportion of monomers being polymerized. Generally, an amount of from about 0.02 to about 2 weight percent is adequate, based on total weight of the monomer mixture.

25 The first monomer mixture used to prepare the seed particles is advantageously suspended within an agitated suspending medium comprising a liquid that is substantially immiscible with the monomers, (e.g. preferably water). Generally, the suspending medium is employed in an amount from about 30 to about 70 and preferably from about 35 to about 50 weight percent based on total weight of the monomer mixture and suspending medium. Various suspending agents are
30 conventionally employed to assist with maintaining a relatively uniform suspension of monomer droplets within the suspending medium. Illustrative suspending agents are gelatin, polyvinyl alcohol, magnesium hydroxide, hydroxyethylcellulose, methylhydroxyethyl cellulose methylcellulose and carboxymethyl methylcellulose. Other suitable suspending agents are disclosed in US4419245. The amount of suspending agent used can vary widely depending on the monomers and suspending
35 agents employed. Latex inhibitors such as sodium dichromate may be used to minimize latex formation.

In the so-called "batch-seeded" process, seed particles comprising from about 10 to about 50 weight percent of the copolymer are preferably suspended within a continuous suspending medium. A second monomer mixture containing a free radical initiator is then added to the suspended seed particles, imbibed thereby, and then polymerized. Although less preferred, the seed particles can be imbibed with the second monomer mixture prior to being suspended in the continuous suspending medium. The second monomer mixture may be added in one amount or in stages. The second monomer mixture is preferably imbibed by the seed particles under conditions such that substantially no polymerization occurs until the mixture is substantially fully imbibed by the seed particles. The time required to substantially imbibe the monomers will vary depending on the copolymer seed composition and the monomers imbibed therein. However, the extent of imbibition can generally be determined by microscopic examination of the seed particles, or suspending media, seed particles and monomer droplets. The second monomer mixture desirably contains from about 0.5 to about 25 molar percent, preferably from about 2 to about 17 molar percent and more preferably 2.5 to about 8.5 molar percent of crosslinking monomer based on total weight of monomers in the second monomer mixture with the balance comprising a monovinylidene monomer; wherein the selection of crosslinking monomer and monovinylidene monomer are the same as those described above with reference to the preparation of the first monomer mixture, (i.e. seed preparation). As with the seed preparation, the preferred monovinylidene monomer includes styrene and/or a substituted styrene. In a preferred embodiment, the second polymer component (i.e. second monomer mixture, or "imbibed" polymer component) has a styrenic content greater than 50 molar percent, and more preferably at least 75 molar percent (based upon the total molar content of the second monomer mixture). In a preferred embodiment, the second polymer component is derived from polymerization of a second monomer mixture comprising at least 75 molar percent of styrene (and/or substituted styrene such as ethylvinylbenzene) and from about 1 to 20 molar percent divinylbenzene.

In an in-situ batch-seeded process, seed particles comprising from about 10 to about 80 weight percent of the copolymer product are initially formed by suspension polymerization of the first monomer mixture. The seed particles can have a free-radical source therein as previously described, which is capable of initiating further polymerization. Optionally, a polymerization initiator can be added with the second monomer mixture where the seed particles do not contain an adequate free radical source or where additional initiator is desired. In this embodiment, seed preparation and subsequent polymerization stages are conducted in-situ within a single reactor. A second monomer mixture is then added to the suspended seed particles, imbibed thereby, and polymerized. The second monomer mixture may be added under polymerizing conditions, but alternatively may be added to the suspending medium under conditions such that substantially no polymerization occurs until the mixture is substantially fully imbibed by the seed particles. The

composition of the second monomer mixture preferably corresponds to the description previously given for the batch-seeded embodiment.

The copolymer product is preferably chloromethylated and subsequently aminated. The specific means and conditions for chloromethylating the copolymers are not particularly limited and many applicable techniques are documented in the literature, as illustrated by: G. Jones, 5 "Chloromethylation of Polystyrene," Industrial and Engineering Chemistry, Vol. 44, No. 1, pgs. 2686-2692, (Nov 1952), along with US 2008/0289949 and US 6756462 - both of which are incorporated herein in their entirety. Chloromethylation is typically conducted by combining the polymer with a chloromethylation reagent in the presence of a catalyst at a temperature of from 10 about 15 to 100°C, preferably 35 to 70°C for about 1 to 8 hours. A preferred chloromethylation reagent is chloromethyl methyl ether (CMME); however, other reagents may be used including CMME-forming reactants such as the combination of formaldehyde, methanol and hydrogen chloride or chlorosulfonic acid (as described in US 2004/0256597), or hydrogen chloride with methylated formalin. The chloromethylating reagent is typically combined with the polymer in an 15 amount of from about 0.5 to 20, preferably about 1.5 to 8 mole of CMME per mole of polymer. While less preferred, other chloromethylation reagents may be used including but not limited to: bis-chloromethyl ether (BCME), BCME-forming reactants such as formaldehyde and hydrogen chloride, and long chain alkyl chloromethyl ethers as described in US 4568700.

Catalyst useful for conducting chloromethylation reactions are well known and are often 20 referred to in the art as "Lewis acid" or "Friedel-Crafts" catalyst. Non-limiting examples include: zinc chloride, zinc oxide, ferric chloride, ferric oxide, tin chloride, tin oxide, titanium chloride, zirconium chloride, aluminum chloride and sulfuric acid along with combinations thereof. Halogens other than chloride may also be used in the preceding examples. A preferred catalyst is ferric chloride. The catalyst is typically used in an amount corresponding to about 0.01 to 0.2, preferably from about 25 0.02 to 0.1 mole catalyst per mole of polymer repeating unit. Catalyst may be used in combination with optional catalyst adjuncts such as calcium chloride and activating agents such as silicon tetrachloride. More than one catalyst may be used to achieve the desired chloromethylation reaction profile.

Solvents and/or swelling agents may also be used in the chloromethylation reaction. 30 Examples of suitable solvents including but are not limited to one or more of: an aliphatic hydrocarbon halides such as ethylene dichloride, dichloropropane, dichloromethane, chloroform, diethyl ether, dipropyl ether, dibutyl ether and diisomyl ether. When CMME is used as the chloromethylation agent, such solvents and/or swelling agents are often not necessary.

The chloromethylated vinyl aromatic polymer is reacted with an amine to form an ion 35 exchange resin including functional amine groups. Examples of applicable amination reactions are provided in: US5141965 which discloses a sequential amination of a chloromethylated crosslinked vinyl aromatic polymer with a primary or secondary amine followed by a subsequent amination

with a tertiary amine, US3317313 which discloses a sequential amination including a first amination with a tertiary amine followed by an amination with a secondary amine and US6059975 which discloses amination with a tertiary amine having relatively large ($\geq C5$) alkyl groups followed by a second amination with a tertiary amine having smaller alkyl groups.

5

EXAMPLES

Twenty milliliters of a mixture of 50 g/L each of glucose, citric acid, lactic acid, and succinic acid in water was fed to a column packed with resin. The packed resin column ("bed") was 1000 mm long and 25 mm in diameter and was maintained at 60°C. A 2 g/L sulfuric acid solution in water was fed into the top of the column at either 8 or 25 mL/min to elute the mixture of glucose and organic acids. The resulting retention times in column volumes (i.e. bed volumes "BV") are shown in the table below, along with resolution coefficients between each pair of compounds.

The results show that both resolution coefficient and elution volume generally increase with increasing SBA content at both flow rates. In most cases, the elution volume increases sharply when using a resin that is 100% SBA versus 80% SBA. This is not desired as a higher peak elution volume requires more eluent to be expended to recover the product. This dilutes the product stream and requires additional energy expenditure and waste production to process the product.

Resolution coefficient increased noticeably even at 7% SBA content. Because peak elution time did not appreciably increase until 100% SBA resin was used, the benefits of SBA content (increased resolution coefficient) can be obtained without an increase in compound elution volumes by using a resin of mixed SBA and WBA functionality.

Resin Name	AMBERLITE FPA53		AMBERLITE FPA55		AMBERLITE IRA70RF		AMBERLITE IRA458		AMBERLITE IRA958	
% SBA Content	0%		7%		39%		80%		100%	
% WBA Content	100%		93%		61%		20%		0%	
Flow Rate (mL/min)	8	25	8	25	8	25	8	25	8	25
Glucose Elution Volume (BV)	0.678	0.711	0.702	0.744	0.683	0.694	0.660	0.677	0.800	0.790
Citric Acid Elution Volume (BV)	1.478	1.358	1.438	1.406	1.345	1.284	1.465	1.372	1.506	1.374
Lactic Acid Elution Volume (BV)	0.802	0.790	0.819	0.868	0.835	0.837	0.807	0.818	0.934	0.904
Succinic Acid Elution Volume (BV)	0.994	0.990	1.009	1.072	1.018	0.998	1.013	1.028	1.112	1.068
Resolution Coefficient (Glucose/Citric Acid)	0.896	0.594	0.940	0.637	0.962	0.495	1.166	0.651	1.456	0.737
Resolution Coefficient (Glucose/Lactic Acid)	0.237	0.112	0.236	0.159	0.289	0.163	0.312	0.179	0.358	0.206
Resolution Coefficient (Glucose/Succinic Acid)	0.571	0.331	0.572	0.368	0.552	0.304	0.610	0.377	0.750	0.436
Resolution Coefficient (Citric Acid/Lactic Acid)	0.519	0.519	0.801	0.513	0.741	0.380	0.950	0.525	1.215	0.583
Resolution Coefficient (Citric Acid/Succinic Acid)	0.299	0.299	0.529	0.288	0.427	0.220	0.565	0.286	0.768	0.344
Resolution Coefficient (Lactic Acid/Succinic Acid)	0.357	0.235	0.361	0.227	0.301	0.164	0.354	0.229	0.443	0.252

CLAIMS:

1. A method for chromatographically separating organic acids from a liquid feed mixture comprising organic acids and carbohydrates by passing the liquid feed mixture through a bed comprising an ion exchange resin, wherein the resin is characterized by including both strong base anion exchange groups and weak base anion exchange groups.
2. The method of claim 1 wherein the ratio of strong base anion exchange groups to weak base anion exchange groups is from 95:5 to 5:95.
3. The method of claim 1 wherein the ion exchange resin has a strong base anion capacity of from 0.1 to 4 milliequivalents per gram and a weak base anion capacity from 0.1 to 4 milliequivalents per gram.
4. The method of claim 1 wherein the ion exchange resin comprises a crosslinked copolymer matrix derived from reaction of at least one monovinyl monomer and a polyvinyl aromatic crosslinking monomer.
5. The method of claim 4 wherein the monovinyl monomer comprises an acrylate monomer.
6. The method of claim 1 wherein the ion exchange resin is a gel-type resin.
7. The method of claim 1 wherein the liquid feed mixture further comprises one or more of: an alcohol and an inorganic salt.
8. The method of claim 1 wherein the ion exchange resin is provided in bead form having a median diameter of from 100 to 1000 microns.

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/063219

A. CLASSIFICATION OF SUBJECT MATTER INV. B01D15/36 C07C51/47 C12P7/40 B01J41/05 B01J41/07 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) B01D C07C C12P B01J		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 068 419 A (KULPRATHIPANJA SANTI [US] ET AL) 26 November 1991 (1991-11-26) column 2, line 51 - line 65 column 13, line 39 - line 44; claims; table 2	1-8
X	US 5 068 418 A (KULPRATHIPANJA SANTI [US] ET AL) 26 November 1991 (1991-11-26) column 2, line 19 - line 32 column 9, line 66 - column 10, line 7; table 2 claims	1-8
----- -/--		
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 10 February 2017		Date of mailing of the international search report 20/02/2017
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Fourgeaud, Damien

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/063219

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	WO 2016/054065 A2 (RENNOVIA INC [US]) 7 April 2016 (2016-04-07) paragraph [0005] - paragraph [0007] paragraph [0038] - paragraph [0039] paragraph [0049] - paragraph [0054] example II -----	1-8
A	US 4 177 140 A (SMAKMAN ROBERT [NL]) 4 December 1979 (1979-12-04) claims -----	1-8
A	EP 0 377 430 A1 (JUNGBUNZLAUER AG [AT]) 11 July 1990 (1990-07-11) page 1, line 42 - line 48 page 3, line 26 - line 57 -----	1-8

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/063219

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5068419	A	26-11-1991	NONE
US 5068418	A	26-11-1991	NONE
WO 2016054065	A2	07-04-2016	TW 201617307 A 16-05-2016 US 2016090346 A1 31-03-2016 WO 2016054065 A2 07-04-2016
US 4177140	A	04-12-1979	BE 863285 A1 16-05-1978 CA 1095190 A 03-02-1981 DE 2802642 A1 27-07-1978 FR 2378559 A1 25-08-1978 GB 1567719 A 21-05-1980 IT 1092354 B 12-07-1985 JP S5394288 A 18-08-1978 JP S6243755 B2 16-09-1987 NL 7700763 A 28-07-1978 US 4177140 A 04-12-1979
EP 0377430	A1	11-07-1990	CA 2007126 A1 05-07-1990 EP 0377430 A1 11-07-1990