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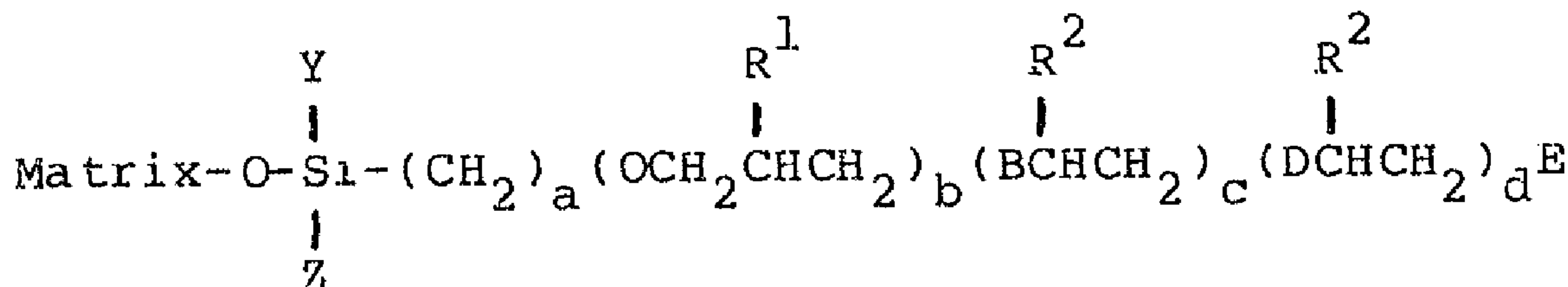
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(54) Titre : METHODE POUR EXTRAIRE ET CONCENTRER CERTAINS IONS A PARTIR DE LEURS SOLUTIONS
(54) Title: PROCESS OF REMOVING AND CONCENTRATING DESIRED IONS FROM SOLUTIONS THEREOF

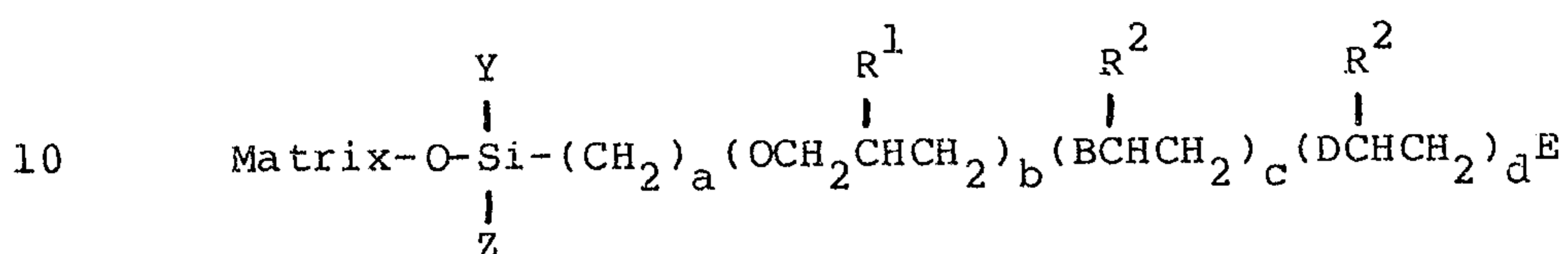


(57) Abrégé/Abstract:

The process of the invention comprises removing and concentrating certain ions, such as the transition metal ions, from solutions thereof admixed with other ions which may be present in much higher concentrations by forming a complex of the desired ion(s) with a compound (see above formula) wherein B and D are each a radical selected from the group consisting of N(R³), N(R³)CH₂, O, OCH₂, S and SCH₂, with the further proviso that if B is selected from the group consisting of O, OCH₂, S and SCH₂, then D must be selected from the group consisting of N(R³) and N(R³)CH₂; E is a radical selected from the group consisting of H, NH(R³), SH, OH, lower alkyl, and N(R³)[CH₂CH(R¹)CH₂O]_b(CH₂)_aSiYZ(O-matrix)]; Y and Z are radicals selected from the group of Cl, OCH₃, OC₂H₅, methyl, ethyl and halogenated substituents thereof, and O-matrix; R¹ is a radical selected from the group consisting of H, SH, OH, lower alkyl and aryl such as phenyl, naphthyl and pyridyl; R² is a radical selected from the group consisting H and lower alkyl; R³ is a radical selected from the group consisting of H, lower alkyl and aryl such as phenyl, naphthyl and pyridyl; a is 2 to about 10; b is 0 or 1; c is 1 to about 2000; d is 0 to about 2000; and where matrix is selected from the group consisting of sand, silica gel, glass, glass fibers, alumina, nickel oxide, zirconia, and titania. The complex which is formed is then broken by contacting a receiving liquid with the complex to remove and concentrate the desired ion(s) in solution in the receiving liquid. The concentrated ions can then be analyzed or recovered from the receiving liquid using well known procedures.

ABSTRACT OF THE INVENTION

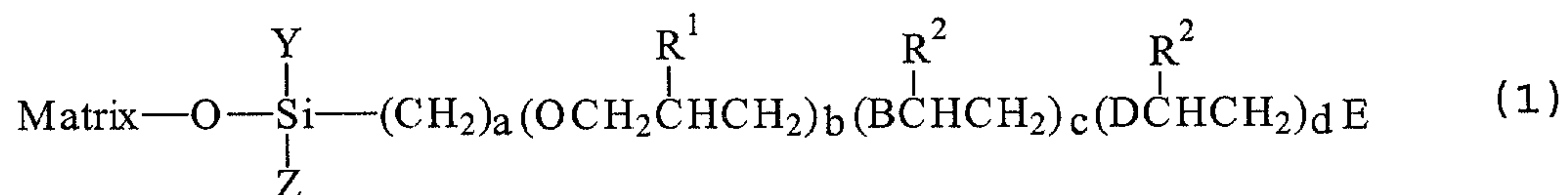
The process of the invention comprises removing and concentrating certain ions, such as the transition metal ions, from solutions thereof admixed with other ions which may be present in much higher concentrations by forming a complex of the desired ion(s) with a compound



wherein B and D are each a radical selected from the group consisting of $\text{N(R}^3\text{)}$, $\text{N(R}^3\text{)CH}_2$, O, OCH_2 , S and SCH_2 , with the further proviso that if B is selected from the group consisting of O, OCH_2 , S and SCH_2 then D must be selected from the group consisting of $\text{N(R}^3\text{)}$ and $\text{N(R}^3\text{)CH}_2$; E is a radical selected from the group consisting of H, $\text{NH(R}^3\text{)}$, SH, OH, lower alkyl, and $\text{N(R}^3\text{)[CH}_2\text{CH(R}^1\text{)CH}_2\text{O]}_b\text{(CH}_2\text{)}_a\text{SiYZ(O-matrix)}$]; Y and Z are radicals selected from the group of Cl, OCH_3 , OC_2H_5 , methyl, ethyl and halogenated substituents thereof, and O-matrix; R^1 is a radical selected from the group consisting of H, SH, OH, lower alkyl and aryl such as phenyl, naphthyl and pyridyl; R^2 is a radical selected from the group consisting H and lower alkyl; R^3 is a radical selected from the group consisting of H, lower alkyl and aryl such as phenyl, naphthyl and pyridyl; a is 2 to about 10; b is 0 or 1; c is 1 to about 2000; d is 0 to about 2000;

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and where matrix is selected from the group consisting of sand, silica gel, glass, glass fibers, alumina, nickel oxide, zirconia, and titania. The complex which is formed is then broken by contacting a receiving liquid with the complex to
5 remove and concentrate the desired ion(s) in solution in the receiving liquid. The concentrated ions can then be analyzed or recovered from the receiving liquid using well known procedures.



5

In formula (1),

B and D are each a radical selected from the group consisting of $\text{N}(\text{R}^3)$, $\text{N}(\text{R}^3)\text{CH}_2$, O and OCH_2 , with the proviso that at least one of B and D must be selected from the group
10 consisting of $\text{N}(\text{R}^3)$ and $\text{N}(\text{R}^3)\text{CH}_2$;

E is a radical selected from the group consisting of H, $\text{NH}(\text{R}^3)$, SH, OH, lower alkyl, and $\text{N}(\text{R}^3) [\text{CH}_2\text{CH}(\text{R}^1)\text{CH}_2\text{O}]_b (\text{CH}_2)_a \text{SiYZ}(\text{O-matrix})$;

Y and Z are each a radical selected from the group of
15 Cl, OCH_3 , OC_2H_5 , methyl, ethyl and halogenated substituents thereof, and O-matrix;

R^1 is a radical selected from the group consisting of H, SH, OH, lower alkyl and aryl such as phenyl, naphthyl and pyridyl;

20 R^2 is a radical selected from the group consisting of H and lower alkyl;

R^3 is a radical selected from the group consisting of H, lower alkyl and aryl such as phenyl, naphthyl and pyridyl;

a is 2 to about 10;

25 b is 0 or 1;

c is 1 to about 2000;

d is 0 to about 2000; and

Matrix is selected from the group consisting of sand, silica gel, glass, glass fibers, alumina, nickel oxide, zirconia, and titania.

5 Preferred values are: Matrix is silica gel or titanized silica gel; a is 3; b is 1; c is 1 to 5; d is 0; R^1 is OH; R^2 is H; R^3 is H; B is NH; E is $\text{NHCH}_2\text{CH}(\text{OH})\text{CH}_2\text{O}(\text{CH}_2)_3\text{Si}(\text{O-silica gel})_3$ or $\text{NHCH}_2\text{CH}(\text{OH})\text{CH}_2\text{O}(\text{CH}_2)_3\text{Si}(\text{O-titanized silica gel})_3$, provided that when Matrix is silica gel, then E is
10 $\text{NHCH}_2\text{CH}(\text{OH})\text{CH}_2\text{O}(\text{CH}_2)_3\text{Si}(\text{O-silica gel})_3$ and when Matrix is titanized silica gel, then E is $\text{NHCH}_2\text{CH}(\text{OH})\text{CH}_2\text{O}(\text{CH}_2)_3\text{Si}(\text{O-titanized silica gel})$; and Y and Z are each selected from O-silica gel, O-titanized silica gel and OCH_3 , provided that when Matrix is silica gel, then Y and Z are each O-silica gel or
15 OCH_3 and when Matrix is titanized silica gel, then Y and Z are each O-titanized silica gel or OCH_3 .

The compounds of formula (1) can be used in a novel process of selectively and quantitatively removing and concentrating a selected ion or group of ions of the transition
20 metal type, e.g., copper, silver, mercury, lead, zinc, and other transition metals, present at low concentrations from a plurality of other ions in a multiple ion solution in which the other ions may be present at much higher concentrations. Preferably, those transition metal ions are Cu(II), Pb(II),
25 Ag(I), Ru(III), Pd(II), Ir(III), Zn(II), Rh(II), Cd(II), Hg(II), Os(II), Mn(II), Au(I), Au(II), Pt(II), Pt(IV), Co(III), Co(II), Cr(II) and Cr(III). The process comprises bringing the multiple ion solution into contact with a compound of formula (1) to complex the desired ion(s) with the compound and
30 breaking the complex with a receiving liquid to render the ion(s) soluble in the receiving solution in a concentrated form. The receiving liquid may then be analyzed by known

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methods, or the ion(s) may be recovered therefrom by known methods. The preferred embodiment disclosed herein involves carrying out the process by bringing a large volume of the multiple ion solution into contact with a compound of formula (1) of the invention in a separation column. The multiple ion solution flows through the column and the desired ion or ions form a complex with the compound of formula (1). A smaller volume of a receiving liquid such as dilute aqueous hydrochloric or nitric acid, for example, is then passed through the column to break the complex by chemical or thermal means. The receiving liquid further dissolves the desired ions and carries them out of the column in a concentrated form. Instead of using a column, the compound of formula (1) may be slurried in a suitable liquid such as water. The multiple ion mixture can be present in the slurring liquid or subsequently added to the slurry, the

desired ion(s) complex with the compound of formula (1) in the slurry, and the slurry is then filtered. The resulting solids are washed with a receiving solution to break the complex and recover the desired ion(s) in the receiving liquid. The desired ions may then be analyzed by known methods, or recovered from the receiving phase by well known procedures.

In a particularly preferred embodiment of the process the bonded matrix-amine compound of formula (1) is placed in a contacting device such as a tall column. The multiple ion mixture is passed through the column with the desired ions from the multiple ion mixture forming a complex with the bonded matrix to separate the desired ions from the rest of the mixture which flows out of the column. A small volume of the receiving liquid is thereafter passed through the column to break the complex as well as to dissolve and carry out of the column the desired ion(s). The desired ions may then be analyzed by known methods such as atomic absorption spectroscopy. In addition, the ion(s) can be recovered from the receiving liquid by well known procedures.

BACKGROUND OF THE INVENTION

The fact is known that amine-containing hydrocarbon ligands present as solutes in a solvent such as water are characterized by their ability to selectively form strong bonds with the transition metal ions or groups of these ions present as solutes in the same solvent as described in a book

by R.M. Smith and A.E. Martell, CRITICAL STABILITY CONSTANTS
VOL. 2: AMINES, Plenum Press, New York, 1975, pp. 1-401.

However, researchers have not previously been able to
effectively incorporate amine-containing hydrocarbon ligands
5 into separation systems where the behavior of the amine-
containing ligands in the separation systems in comparison to
that of the amine-containing ligand as a solute is unchanged
and/or the amine-containing ligand will remain in the
separation system for repeated separations of cations.

10 Articles such as those entitled SILANE COMPOUNDS FOR
SILYLATING SURFACES by E.P. Plueddemann, in "Silanes,
Surfaces and Interfaces Symposium, Snowmass, 1985," Ed. by
D.E. Leyden, Gordon and Breach, Publishers, 1986, pp. 1-25
and SILANE COUPLING AGENTS by E.P. Plueddemann, Plenum Press,
15 1982, pp. 1-235 list many different types of organic
materials which have been attached to silane compounds and
discusses some of their properties. The preparation and uses
of amine-containing hydrocarbons attached to silane or silica
through a hydrocarbon linkage is discussed. The structures
20 reported in those publications contained only aminopropyl and
ethylene diaminopropyl groups [formula (1) where a is 3, b is
0, c is 0 or 1, d is 0, B is NH, D is not present, E is H or
NH₂ and R² is H]. These latter compounds were used to
complex copper ions.

25 E.P. Plueddemann in METAL EXTRACTION FROM SOLUTION AND
IMMOBILIZED CHELATING AGENTS USED THEREFORE, Canadian Patent
number 1,196,618 of November 12, 1985 reported the

preparation of a variety of amine-containing silica gel materials. These materials were made by first reacting chloropropyltrimethoxysilane with the amine forming a trimethoxysilane containing the amine function which was coated onto silica gel and heated to effect a covalent attachment of the amine to the silica gel. The resulting compound had the amine function three carbon atoms removed from silica. These materials do complex and thus remove heavy metals. However, these types of aminopropyl functions are not completely stable as discussed in the next paragraph. The Plueddemann Canadian patent lists other references concerning the same type of silica gel-bound amine complexing materials.

It is a known fact that amine functional groups attached to silica gel, where the amine function is three carbon atoms removed from the silica gel, are not completely stable. E.P. Plueddemann, in the above mentioned article in the book edited by D.E. Leyden, reported that his amine materials (amine group three atoms removed from silane) slowly lost their ability to complex copper II. D.M. Wonnacott and E.V. Patton in HYDROLYTIC STABILITY OF AMINOPROPYL STATIONARY PHASES USED IN THE SIZE-EXCLUSION CHROMATOGRAPHY OF CATIONIC POLYMERS, Journal of Chromatography, vol. 389, pp. 103-113 (1987) and T.G. Waddell, D.E. Leyden and M.T. DeBello in THE NATURE OF ORGANOSILANE TO SILICA-SURFACE BONDING, Journal of Americal Chemical Society, vol. 103, pp. 5303-5307 (1981) discuss the stability of the aminopropyl-silica gel types of

materials. In the conclusion to the Wonnacott and Patton article it is stated that "aminoalkyl silanes which have been used extensively in the synthesis of silica-based, weak ion exchangers do not lend themselves to this type of chromatography due to their hydrolytic instability."

Bonded silica gel phase supports containing amine functions have been prepared by reacting the amine with 3-glycidoxypropylsilane bonded to silica gel. S.H. Chang, K.M. Gooding and F.E. Regnier in USE OF OXIRANES IN THE PREPARATION OF BONDED PHASE SUPPORTS, Journal of Chromatography, vol. 120, pp. 321-333 (1976) and M-A Bagnoud, J-L Veuthey and W. Haerdi in INTERACTIONS SILICE METALLIQUE-SOLUTE: POSSIBILITE d'APPLICATIONS en PRECONCENTRATION et en CHROMATOGRAPHIE d'ECHANGE de LIGANDS (LEC), Chimica, vol. 40, pp. 432-434 (1986) have reacted amines with 3-glycidoxypropyl-bonded silica gel. Chang, Gooding and Regnier reported on four such compounds prepared from diethylamine [formula (1), where a is 3, b is 1, c and d is 0, R^1 is OH, and E is N (ethyl)₂], dimethylaminoethanol [formula (1), where a is 3, b is 1, c is 1, d is 0, B is 0, R^1 is OH, R^2 is H, E is N (methyl)₂], diethylaminoethanol [same as the previous structure except N(ethyl)₂ at the end], and polyethyleneamine [formula (1), same as previous formula except c is a large number and E is NH₂]. These materials were used to separate proteins but not metal cations. Bagnoud, Veuthey and Haerdi prepared a compound from a cyclic tetraamine (cyclam) which does not have a structure

similar to the structures of figure (1). This material was used to bind metal ions and the bound metallic material was used in liquid exchange chromatography to separate certain organic compounds. In neither of these studies were metal ions separated and recovered. There is a particular need in modern society to (1) measure the concentrations of heavy metal cations in the low part per billion (PPB) concentration, (2) remove low levels of toxic heavy metal ions from solutions such as potable water, and (3) recover valuable metal ions present in solution at low levels. For example the allowable amounts of lead, mercury, cadmium and silver ions in drinking water are in the low PPB levels. Present methods for analysis of these cations are not accurate at those levels without time consuming methods to concentrate the cations up to the low part per million level. Furthermore, removal of the metals is not selective, but is expensive and equipment intensive using present methods. Thus, the complexing properties of hydrolytically stable amine-containing hydrocarbon ligands attached to an inorganic support such as silica gel or titanized silica gel are of the utmost importance for the repeated separation and concentration of certain heavy metal cations for analysis and/or recovery purposes. The process of the present invention using the amine-containing materials of formula (1) accomplish this feat.

SUMMARY OF THE INVENTION

The process of the present invention uses compounds of formula (1) having the amine-containing hydrocarbon ligand covalently bonded to an inorganic support, e.g. sand, or silica gel, glass, glass fibers, alumina, nickel oxide, zirconia or titania. The compounds of formula (1), are characterized by high selectivity for and removal of desired metal ions or groups of metal ions such as the transition metal ions present at low concentrations from the source phase containing a mixture of these metal ions with other ions. The ions which are not desired to be removed may be present in much greater concentrations in the solution than the metal ions which are to be removed. The process of the present invention comprises selectively removing and concentrating the desired ion(s) and is characterized by the ability to quantitatively complex from a large volume of solution the desired ion(s) when they are present at low concentrations. The desired ions are complexed with a compound of formula (1) when brought into contact with such compound. For this purpose, the solution from which the desired ions are to be removed is passed through a column containing the compound of formula (1). The desired ions are then recovered from the separation column by flowing through it a small volume of a receiving phase which contains a solubilized reagent which need not be selective, but which will strip the ions from the ligand quantitatively. The analysis of the desired metal ions in the concentrated

solution is accomplished by known methods such as atomic absorption spectroscopy. The recovery of the desired metal ions from the receiving phase is easily accomplished by well known procedures. The process for producing the compounds of formula (1) will be mentioned but is not a part of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described and illustrated by reference to a drawing in which:

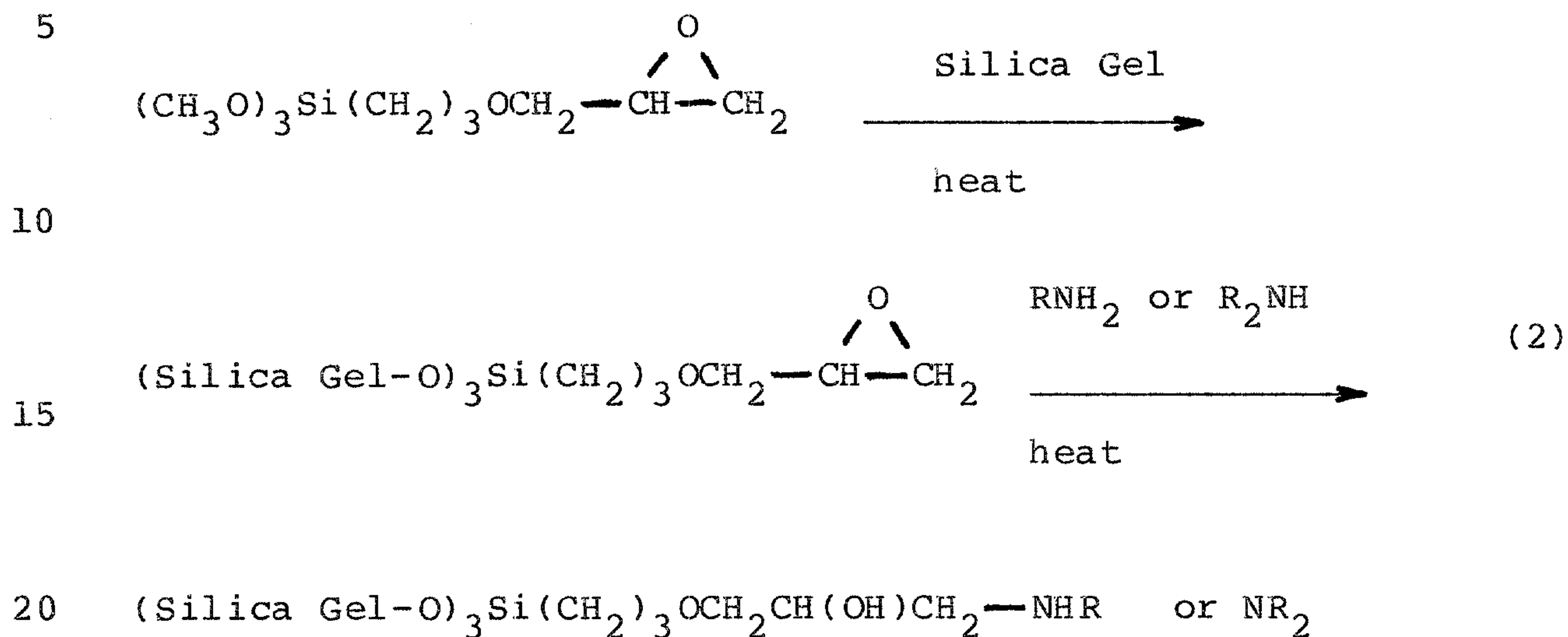
Fig. 1 represents schematically a suitable column for holding the matrix bonded amine-containing hydrocarbon ligand material through which a solution of metal ions can be flowed to complex selectively with a desired ion or group of ions in accordance with the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT OF THE INVENTION

The preferred embodiment of the ion-recovery process of the invention utilizes the compounds represented by formula (1). The process of producing these new compounds is not an aspect of the present invention but will be mentioned briefly here.

Amine-containing hydrocarbon ligands are covalently bonded to the inorganic support. For example, the inorganic support such as silica gel is first heated with 3-glycidoxypropyltrimethoxysilane to produce a 3-glycidoxypropyl-bound silica gel. This gel is then heated with the appropriate

amine to effect a covalent bond as shown in equation (2).
The nature of the amine will determine what B, D, E and R²
are in formula (1).



25 The following examples are given to illustrate two
representative compounds which have been made in accordance
with formula (1) of the present invention. Other amine-
containing hydrocarbons bonded to an inorganic support were
and can be made in the same manner.

30

Example 1

In this example, an amine-containing hydrocarbon bonded
to a silica gel was made corresponding to a compound of
formula (1) wherein a is 3, b is 1, c is 5, d is 0, R¹ is
35 hydroxy, R² is hydrogen, B is NH, D is not present since d is
0, E is NHCH₂CH(OH)CH₂O(CH₂)₃Si(O-silica gel)₃, and Y and Z
are 0-silica gel groups.

Silica gel (60-200 mesh)(1.6 kilograms) was suspended in 7 liters of toluene which contained 304 grams of 3-glycidoxypropyltrimethoxysilane. The gel was stirred slowly to insure that the gel was not physically damaged, and the mixture was heated at 100°C for 8 to 18 hours. Then, 175 to 225 grams of pentaethylenehexamine was slowly added and the mixture was slowly stirred for 5-10 hours while maintaining a temperature of 100°C. The solvent was filtered and the solid amine-bound silica gel was dried in air in a well ventilated hood.

Example 2

In this example, an amine-containing hydrocarbon bonded to titanized silica gel was made corresponding to a compound of formula (1) wherein a is 3, b is 1, c is 5, d is 0, R¹ is hydroxy, R² is hydrogen, B is NH, D is not present, E is NHCH₂CH(OH)CH₂O(CH₂)₃Si(O-Titanized Silica gel)₃, and Y and Z are O-Titanized Silica gel groups.

The titanized silica gel was first prepared by suspending 60-200 Mesh silica gel (50g) in 200 ml of dry toluene. Tetraisopropoxytitanium (20 ml) was slowly added to the stirred reaction mixture. Heat was evolved. The resulting mixture was allowed to stand for 16 hours and filtered. The residue was washed successively with 100 ml of toluene, 100 ml of methanol and 100 ml of water and allowed to air dry at room temperature. The overall weight of the silica gel

increased to 52.5 g resulting in 1.25 mmoles of TiO_2 per gram of material.

Pentaethylenehexamine was attached to the titanized silica gel in the same manner as in Example 1 using 20 g of titanized silica gel and 4 ml of 3-glycidoxypropyl-trimethoxysilane in 50 ml of toluene to give the 3-glycidoxypropyl-titanized silica gel material, and then 10 g of this latter titanized silica gel was reacted with 3 ml of pentaethylenehexamine in 50 ml of refluxing methanol for 1 hour.

METAL ION RECOVERY AND CONCENTRATION PROCESS

The metal ion recovery and concentration process of the invention relates to the selective recovery of desired metal ions from mixtures thereof with other metal ions using the compounds of formula (1) of the invention as defined above. Effective methods of recovery and/or separation of metal ions, particularly the transition metal ions, from other metal ions in water supplies, waste solutions, deposits and industrial solutions and silver recovery from waste solutions, e.g., from emulsions on photographic and X-ray film, represent a real need in modern technology. These ions are typically present at low concentrations in solutions containing other ions at much greater concentrations. Likewise there is a need to concentrate these metal ions so that an effective analysis using well known methods such as atomic absorption spectroscopy can be carried out. Hence,

there is a real need for a process to selectively recover and concentrate these metal ions. The present invention accomplishes this separation and concentration effectively and efficiently by the use of compounds selected from the families represented by formula (1).

The amine-containing inorganic matrix material of formula (1) is placed in a column as shown in Figure 1. An aqueous solution containing the desired ion or ions, in a mixture of other ions which may be in a much greater concentration, is passed through the column. The flow rate for the solution may be increased by applying pressure (with a pump) on the top of the column or applying a vacuum in the receiving vessel. After the solution has passed through the column, a much smaller volume of a recovery solution, i.e. an aqueous acid solution, which will protonate the amine groups of the ligands thereby releasing the metal ions, is passed through the column. This receiving solution contains only the desired metal ions in a concentrated form for subsequent analysis and/or recovery.

The following examples of separations and recoveries of transition metal ions by the inorganic support-bound amine-containing materials of Examples 1 and 2 and materials prepared in a similar manner are given as illustrations. These examples are illustrative only, and are not comprehensive of the many separations of transition metal ions that are possible using the materials of formula (1).

Example 3

In this example, 2 grams of the silica gel-bound amine-containing hydrocarbon of Example 1 was placed in a column as shown in Figure 1. A 500 ml solution of about 10 ppm of Cu^{2+} in 0.1 M aqueous MgCl_2 was passed through the column using a vacuum pump at 600 torr to increase the flow rate. A 10 ml aqueous solution of 1 M HCl was passed through the column. An analysis of the recovery solution by atomic absorption spectroscopy (AA) showed that greater than 99% of the copper II ions originally in the 500 ml copper II solution was in the 10 ml recovery solution.

Example 4

The experiment of Example 3 was repeated with about 1 ppm of Cd^{2+} in an aqueous solution of 0.1 M MgCl_2 . Again, greater than 99% of the Cd^{2+} ion in the original solution was found in the recovery solution.

Example 5

The experiment of Example 3 was repeated with about 13 ppm of Hg^{2+} in an aqueous solution of 0.1 M MgBr_2 . In this case, 42% of the Hg^{2+} ion in the original solution was found in the recovery solution.

Example 6

In this example, the titanized silica gel-amine material of Example 2 was used to separate 10 ppm Cu^{2+} in an aqueous

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solution of 0.1 M MgCl_2 as in Example 3. The Cu^{2+} was removed and concentrated in the same manner and with the same results as the Example 3.

5

Example 7

The amine material of Example 1 has also been used to make separations among the transition metals and the common salt ions in solution. An example of this is the separation and concentration of Cd^{2+} , Pb^{2+} and Cu^{2+} from Na^+ , K^+ , Mg^{2+} and Ca^{2+} solutions normally found in potable water. The solution (1000 ml) was passed through the column, then a 10 ml of 1 M aqueous HCl recovery solution. The 10 ml recovery solution contained Cd^{2+} , Pd^{2+} and Cu^{2+} in concentrated form. The concentrated solution was analyzed by atomic absorption spectroscopy and found to contain the expected amounts of the three cations.

10

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Example 8

The experiment of Example 7 was repeated with trace concentrations of Zn^{2+} , Mn^{2+} and Ni^{2+} in an aqueous solution containing the common salts found in ocean water at the concentrations found in ocean water. The 10 ml recovery solution was found to contain only Zn^{2+} , Mn^{2+} and Ni^{2+} in the expected concentrations.

20

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Example 9

In this example, 2 grams of the silica gel-bound amine-containing hydrocarbon was prepared following the procedure of Example 1, except that ethylene diamine was used rather than pentaethylenhexamine of Example 1. The amine-containing silica gel used in Example 9 was that shown in formula (1) where a is 3, b is 1, c is 1, d is 0, B is NH, E is $\text{NHCH}_2\text{CH}(\text{OH})\text{CH}_2\text{O}(\text{CH}_2)_3 \text{Si}(\text{O-silica gel})_3$, R^1 is OH and R^2 is H. Solutions (500 ml) of Cu^{2+} and Pd^{2+} ions in aqueous 0.1 M $\text{Mg}(\text{NO}_3)_2$ solutions were each separated as in Example 3. In both cases, over 99% of the Cu^{2+} or Pd^{2+} was recovered in the recovery solutions.

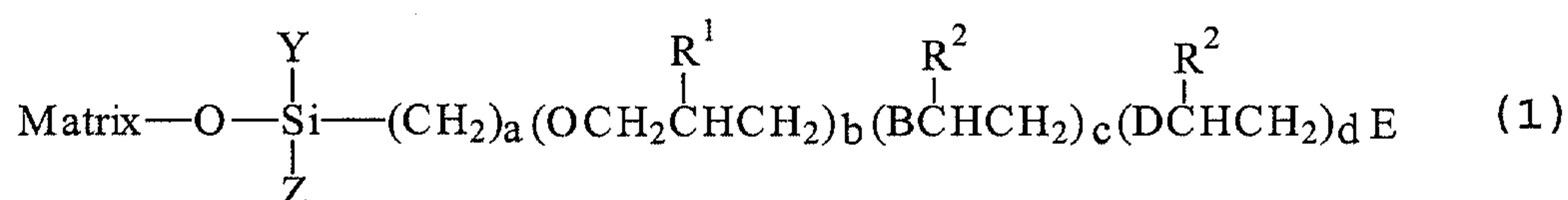
From the foregoing, it will be appreciated that the inorganic matrix-bound amine-containing hydrocarbon ligands of formula (1) of the present invention provide a material useful for the separation and concentration of the transition metal cations from mixtures of those cations with other metal cations. The transition metals can then be analyzed and/or recovered from the concentrated recovery solution by standard techniques known in the science of these materials.

Although the process of separating and concentrating certain metal ions in this invention has been described and illustrated by reference to certain specific silica gel-bound amine-containing hydrocarbon ligands of formula (1), processes using analogs of these amine-containing hydrocarbon ligands are within the scope of the processes of the invention as defined in the following claims.

CLAIMS:

1. A process of removing and concentrating a desired ion from a mixture thereof in a solution with at least one other ion, which process comprises:

5 complexing the desired ion in the solution with a compound having the structural formula:



10 (wherein:

B and D are each a radical selected from the group consisting of $\text{N}(\text{R}^3)$, $\text{N}(\text{R}^3)\text{CH}_2$, O and OCH_2 , with the proviso that at least one of B and D must be selected from the group consisting of $\text{N}(\text{R}^3)$ and $\text{N}(\text{R}^3)\text{CH}_2$;

15 E is a radical selected from the group consisting of H, $\text{NH}(\text{R}^3)$, SH, OH, lower alkyl, and $\text{N}(\text{R}^3) [\text{CH}_2\text{CH}(\text{R}^1)\text{CH}_2\text{O}]_b (\text{CH}_2)_a \text{SiYZ}(\text{O-matrix})$;

20 Y and Z are each a radical selected from the group of Cl, OCH_3 , OC_2H_5 , methyl, ethyl and halogenated substituents thereof, and O-matrix;

R^1 is a radical selected from the group consisting of H, SH, OH, lower alkyl and aryl;

R^2 is a radical selected from the group consisting of H and lower alkyl;

25 R^3 is a radical selected from the group consisting of H, lower alkyl and aryl;

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a is 2 to 10;

b is 0 or 1;

c is 1 to 2000;

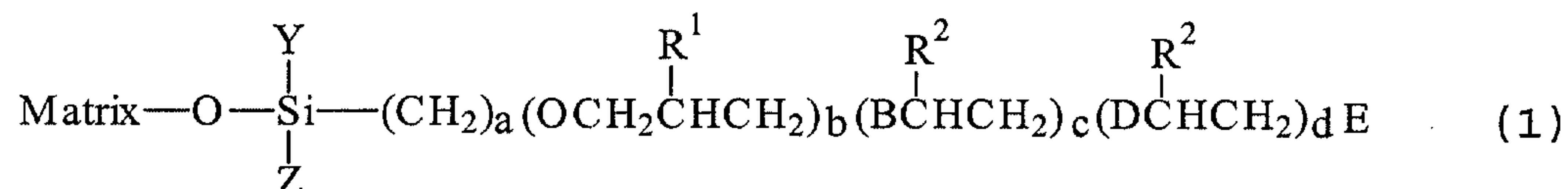
d is 0 to 2000; and

5 Matrix is selected from the group consisting of sand, silica gel, glass, glass fibers, alumina, nickel oxide, zirconia, and titania), to form a complex of the desired ion with the compound, and

10 breaking the complex to liberate the complexed ion with and dissolving the liberated ion in a receiving liquid in much smaller volume than the volume of the solution from which the desired ion has been removed.

2. A process of separating a selected metal ion or ions from a plurality of other ions including Ca(II), Mg(II), Na⁺ and 15 K⁺ in a multiple ion solution, which process comprises:

contacting the multiple ion solution with a compound having the structural formula:



20

(wherein:

B and D are each a radical selected from the group consisting of N(R³), N(R³)CH₂, O and OCH₂, with the proviso that at least one of B and D must be selected from the group 25 consisting of N(R³) and N(R³)CH₂;

A

E is a radical selected from the group consisting of H, NH(R³), SH, OH, lower alkyl, and N(R³) [CH₂CH(R¹)CH₂O]_b(CH₂)_aSiYZ(O-matrix)];

Y and Z are each a radical selected from the group of Cl, OCH₃, OC₂H₅, methyl, ethyl and halogenated substituents thereof, and O-matrix;

R¹ is a radical selected from the group consisting of H, SH, OH, lower alkyl and aryl;

R² is a radical selected from the group consisting H and lower alkyl;

R³ is a radical selected from the group consisting of H, lower alkyl and aryl;

a is 2 to 10;

b is 0 or 1;

c is 1 to 2000;

d is 0 to 2000; and

Matrix is selected from the group consisting of sand, silica gel, glass, glass fibers, alumina, nickel oxide, zirconia, and titania), thereby forming a complex between the selected metal ion or ions and the compound and removing the selected metal ion or ions from the multiple ion solution; and

breaking the complex to free and recover the selected ion or ions in a receiving liquid.

3. The process as set forth in claim 2, in which Matrix is silica gel, a is 3, b is 1, c is 5, d is 0, R¹ is OH, R² is H, R³ is H, B is NH, D is absent since d is 0, E is

A

NHCH₂CH(OH)CH₂O(CH₂)₃Si(O-silica gel)₃, and Y and Z are selected from the group consisting of O-silica gel and OCH₃.

4. The process set forth in claim 2, in which Matrix is silica gel, a is 3, b is 1, c is 1, d is 0, R¹ is OH, R² is H, 5 R³ is H, B is NH, E is NHCH₂CH(OH)CH₂O(CH₂)₃Si(O-silica gel)₃, and Y and Z are selected from the group consisting of O-silica gel and OCH₃.

5. The process as set forth in claim 2, in which Matrix is titanized silica gel, a is 3, b is 1, c is 5, d is 0, R¹ is 10 OH, R² is H, R³ is H, B is NH, D is absent since d is 0, E is NHCH₂CH(OH)CH₂O(CH₂)₃Si(O-titanized silica gel)₃, and Y and Z are selected from the group consisting of O-titanized silica gel and OCH₃.

6. The process as set forth in any one of claims 2 to 5, 15 in which the selected metal ion is a member selected from the group consisting of Cu(II), Pb(II), Ag(I), Ru(III), Pd(II), Ir(III), Zn(II), Rh(II), Cd(II), Hg(II), Os(II), Mn(II), Au(I), Au(II), Pt(II), Pt(IV), Co(III), Co(II), Cr(II), Cr(III) and mixtures thereof.

20 7. The process according to claim 1, wherein:

the desired ion is a cation of a transition metal; and

the complexing step is conducted by flowing the solution through a chromatography or separation column packed with the compound of the formula (1) and then the complex breaking step 25 is conducted by flowing the receiving liquid through the column; or the complexing step is conducted by forming an aqueous slurry of the compound of the formula (1) with the solution and the slurry is filtered to obtain solids and the complex breaking step is conducted by washing the solids with 30 the receiving liquid.

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8. The process according to claim 7, wherein a tall column is used as the chromatography or separation column.
9. The process according to claim 7 or 8, wherein the receiving liquid is dilute aqueous hydrochloric or nitric acid.
- 5 10. The process according to any one of claims 7 to 9, wherein Matrix is silica gel or titanized silica gel; a is 3; b is 1; c is 1 to 5; d is 0; R^1 is OH; R^2 is H; R^3 is H; B is NH; E is $\text{NHCH}_2\text{CH}(\text{OH})\text{CH}_2\text{O}(\text{CH}_2)_3\text{Si}(\text{O-silica gel})_3$ or $\text{NHCH}_2\text{CH}(\text{OH})\text{CH}_2\text{O}(\text{CH}_2)_3\text{Si}(\text{O-titanized silica gel})_3$; and Y and Z are
10 each selected from O-silica gel, O-titanized silica gel and OCH_3 , provided that when Matrix is silica gel, then E is $\text{NHCH}_2\text{CH}(\text{OH})\text{CH}_2\text{O}(\text{CH}_2)_3\text{Si}(\text{O-silica gel})_3$ and Y and Z are each O-silica gel or O- CH_3 and when Matrix is titanized silica gel, then E is $\text{NHCH}_2\text{CH}(\text{OH})\text{CH}_2\text{O}(\text{CH}_2)_3\text{Si}(\text{O-titanized silica gel})$ and Y
15 and Z are each O-titanized silica gel or O- CH_3 .
11. The process according to claim 10, wherein Matrix is silica gel, E is $\text{NHCH}_2\text{CH}(\text{OH})\text{CH}_2\text{O}(\text{CH}_2)_3\text{Si}(\text{O-silica gel})_3$ and Y and Z are each O-silica gel; or Matrix is titanized silica gel, E is $\text{NHCH}_2\text{CH}(\text{OH})\text{CH}_2\text{O}(\text{CH}_2)_3(\text{O-titanized silica gel})$ and Y and Z are
20 each titanized silica gel.
12. The process according to any one of claim 7 to 10, wherein the other ion is contained in the solution at a concentration much higher than the desired ion.
13. The process according to claim 12, wherein the
25 desired ion is Cu^{2+} and the other ion is Mg^{2+} .
14. The process according to claim 12, wherein the desired ion is Cd^{2+} and the other ion is Mg^{2+} .
15. The process according to claim 12, wherein the desired ion is Hg^{2+} and the other ion is Mg^{2+} .

16. The process according to claim 12, wherein the desired ion is a mixture of Cd^{2+} , Pb^{2+} and Cu^{2+} and the other ion is a mixture of Na^+ , K^+ , Mg^{2+} and Ca^{2+} .

17. The process according to claim 12, wherein the
5 desired ion is a mixture of Zn^{2+} , Mn^{2+} Ni^{2+} and the other ion is a mixture of Na^+ , K^+ , Mg^{2+} and Ca^{2+} .

18. The process according to claim 12, wherein the desired ion is a mixture of Cu^{2+} and Pd^{2+} and the other ion is Mg^{2+} .

10 19. The process according to claim 12, wherein:

the desired ion is at least one member selected from the group consisting of Cu(II) , Pb(II) , Ag(I) , Ru(III) , Pd(II) , Ir(III) , Zn(II) , Rh(II) , Cd(II) , Hg(II) , Os(II) , Mn(II) , Au(I) , Au(II) , Pt(II) , Pt(IV) , Co(III) , Co(II) , Cr(II) and Cr(III) ;

15 and

the other is at least one member selected from the group consisting of Na^+ , K^+ , Mg^{2+} and Ca^{2+} .

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Fig. 1

