$$\alpha = c_{phase\ 1} / c_{phase\ 2,}$$

A special distribution coefficient is K_{ow}, also called the P value, which characterizes the distribution equilibrium of a compound between an octanol and an aqueous phase:

$$K_{ow} = P = c_{octanol} / C_{water}$$

An example of a positively charged organic compound much in demand industrially is 12-aminolauric acid (ALA) and derivatives thereof, especially the methyl ester (ALAME). ALA is an important starting product in the production of polymers, for example for production of pipeline systems and nylon. Conventionally, ALA is produced starting from fossil raw materials in a process with low yield via laurolactam, which is synthesized by trimerization of butadiene, then hydrogenation with formation of cyclododecane, then oxidation to cyclododecanone, reaction with hydroxylaurin and then Beckmann rearrangement. A promising route for the biotechnological production of ALA or ALAME is described in DE10200710060705.

The prior art teaches the production of positively charged organic compounds by contacting an aqueous reaction mixture comprising a biological agent with an organic phase comprising an organic solvent. For example, DE10200710060705 describes obtaining the product ALAME by shaking with ethyl acetate from an aqueous reaction mixture. Asano et al. (2008) disclose the extraction of ALA with toluene from an aqueous reaction solution comprising an ALA synthesizing enzyme.

The problem to be solved by the present ~~invention~~disclosure is therefore to develop a method of removing positively charged organic compounds, especially ω-aminocarboxylic acids, with at least one positive charge from an aqueous reaction mixture, wherein a position of the distribution equilibrium between reaction mixture and a hydrophobic organic phase used as extractant that is as advantageous as possible is desirable, i.e. the distribution equilibrium should lie as far as possible on the side of the hydrophobic organic phase.

Another problem to be solved by the ~~invention~~disclosure consists of developing a method of removing organic compounds with at least one positive charge, especially ω-aminocarboxylic acids, from an aqueous solution comprising a biological agent using a hydrophobic organic phase as extractant, in which the distribution equilibrium is located as far as possible on the side of the hydrophobic organic phase.

Another problem to be solved by the ~~invention~~disclosure consists of developing a method of removing organic compounds with at least one positive charge, especially ω-aminocarboxylic acids, from an aqueous solution using a hydrophobic organic solution as extractant, which impairs or slows down the growth of biotechnologically relevant microorganisms, especially *Escherichia coli*, as little as possible and/or reduces the number of cells capable of dividing and/or viable cells and/or cells with active respiration and/or metabolically and synthetically active cells as little as possible.

Finally, a problem to be solved by the ~~invention~~disclosure is to devise a method of removing an organic compound with at least one positive charge, especially ω-aminocarboxylic acids, from an aqueous solution comprising a biological agent using a hydrophobic organic phase as extractant, in which all of the properties that are decisive for the yield, the overall turnover and rapid practicability of a biotechnological synthesis process on which it is based, especially the toxicity of the organic phase against the biological agent and the uptake of the compound into the organic extractant, are optimized with respect to the total yield or a faster progress or, in the case of a continuous process, usability of the biological agent for as long as possible, especially for the case when the organic compound with at least one positive charge is the product or an intermediate of the synthesis process, which is synthesized with the participation of a catalytic activity of the biological agent.

These and other problems are solved by the subject matter of the present application and especially also by the subject matter of the appended independent claims, wherein embodiments follow from the subclaims.

The problem to be solved by the ~~invention~~disclosure is solved in an ~~first aspect~~embodiment by a method for removing an organic compound having one or more positive charges from an aqueous solution, comprising the steps

a) providing the aqueous solution containing the organic compound and a hydrophobic organic solution, which comprises a liquid cation exchanger,

wherein the liquid cation exchanger is hydrophobic,

b) contacting the aqueous solution and the organic solution, and
c) separating the organic solution from the aqueous solution,

wherein the organic compound is a compound of formula I

$$NH_3^+\text{-A-COOR}^1 \text{ (I)},$$

wherein R^1 is hydrogen, methyl, ethyl or a negative charge and A is an unsubstituted, linear alkylene group with at least three, preferably at least eight carbon atoms,

and wherein the liquid cation exchanger is a fatty acid.

In one aspect, there is provided a method for removing an organic compound from an aqueous solution, the method comprising:

a) contacting the aqueous solution comprising an organic compound with a hydrophobic organic solution comprising a hydrophobic liquid cation exchanger, and

b) separating the organic solution from the aqueous solution, wherein the organic compound is a compound of formula I

$$NH_3^+\text{-A-COOR}^1 \text{ (I)},$$

wherein R^1 is hydrogen, methyl, ethyl or a negative charge and A is an unsubstituted, linear alkylene group comprising at least three carbon atoms,
wherein the liquid cation exchanger is a fatty acid, and
wherein the contacting is performed at a temperature of 28 to 70°C.

In a first embodiment of the above~~first~~ aspect, the problem is solved by a method as defined above~~according to one of Claims 1~~, wherein the temperature in step b) is 28 to 70, preferably 30 to 37°C.

In a second embodiment, which is also an embodiment of the first embodiment of the above~~first~~ aspect, the problem is solved by a method as defined above~~according to one of Claims 1 to 2~~, wherein the pH in step b) is 6 to 8, preferably 6.2 to 7.2.

In a third embodiment, which is also an embodiment of the first to second embodiment of the above~~first~~ aspect, the problem is solved by a method wherein the molar ratio of liquid cation exchanger to organic compound is at least 1.

In a third embodiment, which is also an embodiment of the first to third embodiment of the above~~first~~ aspect, the problem is solved by a method wherein the volume ratio of organic solution to aqueous solution is 1:10 to 10:1.

In a fourth embodiment, which is also an embodiment of the first to third embodiment of the above~~first~~ aspect, the problem is solved by a method wherein the liquid cation exchanger is a fatty acid with more than 12, preferably with 14 to 22, more preferably 16 to 18 carbon atoms.

In a fifth embodiment, which is also an embodiment of the first to fourth embodiment of the above~~first~~ aspect, the problem is solved by a method wherein the liquid cation exchanger is an unsaturated fatty acid, preferably oleic acid or erucic acid.

In a sixth embodiment, which is also an embodiment of the first to fifth embodiment of the above~~first~~ aspect, the problem is solved by a method wherein the aqueous solution furthermore comprises a biological agent with catalytic activity.

In a seventh embodiment, which is also an embodiment of the first to sixth embodiment of the above~~first~~ aspect, the problem is solved by a method wherein the biological agent is a cell, preferably a bacterial cell and the cell more preferably has a recombinant alkane monooxygenase, a recombinant transaminase and preferably furthermore at least one enzyme from the group comprising an alcohol dehydrogenase, an alanine dehydrogenase and the AlkL gene product or variants thereof.

In an eighth embodiment, which is also an embodiment of the first to seventh embodiment of the above~~first~~ aspect, the problem is solved by a method wherein the presence of the organic compound has an adverse effect on the catalytic activity, preferably in that the organic compound is a compound that is toxic to the cell.

In a ninth embodiment, which is also an embodiment of the first to eighth embodiment of the above~~first~~ aspect, the problem is solved by a method wherein the organic solution furthermore contains at least one organic solvent, preferably a fatty acid and/or a fatty acid ester.

In a tenth embodiment, which is also an embodiment of the first to ninth embodiment of the above~~first~~ aspect, the problem is solved by a method as defined above~~according to Claim 12~~, wherein the organic solution comprises as liquid cation exchanger 20 to 80 vol%, preferably 25 to 75 vol% oleic acid, and as solvent lauric acid methyl ester and the organic compound is 12-aminolauric acid methyl ester and a bacterial cell is present in the aqueous solution that has a recombinant alkane monooxygenase, a recombinant transaminase and preferably furthermore at least one enzyme from the group comprising an alcohol dehydrogenase, an alanine dehydrogenase and the AlkL gene product or variants thereof.

In another ~~second aspect~~embodiment, the problem to be solved by the ~~invention~~disclosure is solved by a reaction mixture comprising an aqueous solution and a hydrophobic organic solution,

wherein the hydrophobic organic solution comprises a fatty acid, preferably a fatty acid with more than 12 carbon atoms, more preferably an unsaturated fatty acid as liquid cation exchanger,

and wherein the aqueous solution is a compound of formula (I)

NH_3^+-A-$COOR^1$ (I),

wherein R^1 is hydrogen, methyl, ethyl or a negative charge and A is an unsubstituted, linear alkylene group with at least three, preferably at least eight carbon atoms.

In another aspect, there is reaction mixture comprising an aqueous solution and a hydrophobic organic solution, wherein the hydrophobic organic solution comprises a fatty acid as a liquid cation exchanger, and wherein the aqueous solution is a compound of formula (I)

NH_3^+-A-$COOR^1$ (I),

wherein R^1 is hydrogen, methyl, ethyl or a negative charge and A is an unsubstituted, linear alkylene group comprising at least three carbon atoms, and
wherein the aqueous solution further comprises a cell comprising a recombinant alkane monooxygenase and a recombinant transaminase.

In one embodiment of the abovesecond aspect, the problem to be solved by the invention is solved by a reaction mixture according to the first aspect, wherein the aqueous solution furthermore comprises a cell that has a recombinant alkane monooxygenase, a recombinant transaminase and preferably furthermore at least one enzyme from the group comprising an alcohol dehydrogenase, an alanine dehydrogenase and the AlkL gene product or variants thereof.

Further embodiments of the abovesecond aspect comprise all embodiments of the earlierfirst aspect.

The problem to be solved by the inventiondisclosure is also solved in a fourth aspect by a method for removing an organic compound having one or more positive charges from an aqueous solution, comprising the steps:

a) providing the aqueous solution containing the organic compound and a hydrophobic organic solution, which comprises a liquid cation exchanger,

wherein the liquid cation exchanger is hydrophobic,

and wherein the liquid cation exchanger has one or more negative charges and a negative total charge,

b) contacting the aqueous solution and the organic solution, and

c) separating the organic solution from the aqueous solution.

In a second embodiment of the method as defined above~~fourth aspect of the present invention~~, which also represents an embodiment of the first embodiment of the present ~~invention~~disclosure, the method comprises the step:

d) working-up the organic solution, preferably by backwash of the organic compound into another aqueous solution.

In a third embodiment of the method as defined above~~fourth aspect of the present invention~~, which also represents an embodiment of the first to second embodiment of the present ~~invention~~disclosure, the temperature in step b) of the method according to the ~~invention~~disclosure is 28 to 70°C, preferably 30 to 37°C.

In a fourth embodiment of the method as defined above~~fourth aspect of the present invention~~, which also represents an embodiment of the first to third embodiment of the present ~~invention~~disclosure, the pH in step b) of the method according to the ~~invention~~disclosure is 3 to 8, preferably 6 to 8, especially preferably 6.2 to 7.2.

In a fifth embodiment of the method as defined above~~fourth aspect of the present invention~~, which also represents an embodiment of the first to fourth embodiment of the present ~~invention~~disclosure, the molar ratio of liquid cation exchanger to organic compound in the method is at least 1.

In a sixth embodiment of the method as defined above~~fourth aspect of the present invention~~, which also represents an embodiment of the first to fifth embodiment of the present ~~invention~~disclosure, the volume ratio of organic solution to aqueous solution is 1:10 to 10:1.

In a seventh embodiment of the method as defined above~~fourth aspect of the present invention~~, which also represents an embodiment of the first to sixth embodiment of the present ~~invention~~disclosure, the organic compound has at least one positively charged substituent of formula (I)



$$-N^{+}R^{2}R^{3}R^{4} \quad (I)$$

or, if at least one substituent from the group comprising R^2, R^3 and R^4 is hydrogen, the unprotonated form thereof,

wherein R^2, R^3 and R^4 are selected independently of one another from the group comprising hydrogen, methyl, ethyl, propyl, 2-propyl, butyl, t-butyl, pentyl, hexyl, benzyl, hydroxyl, substituted or unsubstituted and/or linear or branched or cyclic alkyl or alkenyl.

In an eighth embodiment of the method as defined above~~fourth aspect of the present invention~~, which also represents an embodiment of the first to seventh embodiment of the present ~~invention~~disclosure, the organic compound has the formula (II)



$$Z\text{–}A\text{–}N^{+}R^{2}R^{3}R^{4} \quad (II)$$

or, if at least one substituent from the group comprising R^2, R^3 and R^4 is hydrogen, the unprotonated form thereof,

wherein R^2, R^3 and R^4 are selected independently of one another from the group comprising hydrogen, methyl, ethyl, propyl, 2-propyl, butyl, t-butyl, pentyl, hexyl, benzyl, hydroxyl, substituted or unsubstituted and/or linear or branched or cyclic alkyl or alkenyl,

wherein A represents a hydrocarbon chain comprising at least three carbon atoms, preferably an unsubstituted alkenyl group,

and wherein Z is selected from the group that comprises –COOH, $–COOR^5$, –COH, $–CH_2OH$ and unprotonated forms thereof,

wherein R^5 is selected from the group comprising hydrogen, methyl, ethyl, propyl, 2-propyl, butyl, t-butyl, pentyl, hexyl, benzyl, hydroxyl, substituted or unsubstituted and/or linear or branched or cyclic alkyl or alkenyl.

In a ninth embodiment of the method as defined above~~fourth aspect of the present invention~~, which also represents an embodiment of the first to eighth embodiment of the present ~~invention~~disclosure, the organic compound has the formula III

$$NH_3^+\text{-A-}COOR^1 \text{ (III)},$$

or an unprotonated form thereof, wherein R^1 is hydrogen, methyl or ethyl and A is an unsubstituted, linear alkylene group with at least three carbon atoms.

In a tenth embodiment of the method as defined above~~fourth aspect of the present invention~~, which also represents an embodiment of the first to ninth embodiment of the present ~~invention~~disclosure, the liquid cation exchanger has at least one alkyl or alkenyl group with at least six carbon atoms and a terminal substituent from the group comprising -COOH, $–OSO_2H$, $–OPO(OH)_2–$ and –OPO(OH)O– and unprotonated forms thereof.

In an eleventh embodiment of the method as defined above~~fourth aspect of the present invention~~, which also represents an embodiment of the first to tenth embodiment of the present ~~invention~~disclosure, the liquid cation exchanger is an unsaturated fatty acid, preferably oleic acid.

In a twelfth embodiment of the method as defined abovefourth aspect of the present invention, which also represents an embodiment of the first to eleventh embodiment of the present inventiondisclosure, the aqueous solution furthermore comprises a biological agent with catalytic activity.

In a thirteenth embodiment of the method as defined abovefourth aspect of the present invention, which also represents an embodiment of the first to twelfth embodiment of the present inventiondisclosure, the biological agent is a cell, preferably a bacterial cell.

In a fourteenth embodiment of the method as defined abovefourth aspect of the present invention, which also represents an embodiment of the first to thirteenth embodiment of the present inventiondisclosure, the presence of the organic compound has an adverse effect on the catalytic activity.

In a fifteenth embodiment of the method as defined abovefourth aspect of the present invention, which also represents an embodiment of the first to fourteenth embodiment of the present inventiondisclosure, the organic solution furthermore contains at least one organic solvent, preferably a fatty acid and/or a fatty acid ester.

In a sixteenth embodiment of the method as defined abovefourth aspect of the present invention, which also represents an embodiment of the first to fifteenth embodiment of the present inventiondisclosure, the organic solution comprises, as liquid cation exchanger, 20 to 80 vol%, preferably 25 to 75 vol% of oleic acid, and lauric acid methyl ester as solvent, and the organic compound is 12-aminolauric acid methyl ester and in the aqueous solution a bacterial cell is present that has a catalytic activity involved in the synthesis of 12-aminolauric acid methyl ester.

In another fifth aspectembodiment, the problem to be solved by the inventiondisclosure is solved by a bioreactor comprising an aqueous solution, comprising a biological agent, and a hydrophobic organic solution comprising a liquid cation exchanger. In a preferred embodiment of the present inventiondisclosure, the term "bioreactor", as used herein, means any vessel in which biotechnologically usable microorganisms are cultured in controlled conditions and/or can be used for a biotechnological process, preferably the synthesis of an organic compound.

In a second embodiment of the bioreactor as defined abovefifth aspect, which is also an embodiment of the first embodiment of the third aspect of the present inventiondisclosure, the liquid cation exchanger is a fatty acid, preferably oleic acid.

In a third embodiment of the bioreactor as defined abovefifth aspect, which is also an embodiment of the first to second embodiment of the third aspect of the present inventiondisclosure, the hydrophobic organic solution furthermore comprises a fatty acid ester, preferably lauric acid methyl ester.

In a fourth embodiment of the bioreactor as defined abovefifth aspect, which is also an embodiment of the first to third embodiment of the second aspect of the present inventiondisclosure, the hydrophobic organic solution comprises oleic acid as cation exchanger and 25 to 75 vol% lauric acid methyl ester as solvent.

In a fifth embodiment, which is also an embodiment of the first to fourth embodiment of the fifth aspect of the present inventiondisclosure, the organic compound is a compound according to one of the embodiments as defined abovecof the first aspect of the invention.

In another sixth aspectembodiment, the problem to be solved by the present inventiondisclosure is solved by a method of producing an organic compound with one or more positive charges, wherein the organic compound is toxic to cells, comprising culturing, in an aqueous solution, cells involved in the synthesis of the organic compound, preferably cells that catalyse at least one step of the synthesis, in the presence of a hydrophobic organic solution comprising a liquid cation exchanger and optionally an organic solvent.

In a second embodiment of the sixth aspectabove embodiment of the present inventiondisclosure, the organic compound is 12-aminolauric acid or methyl ester thereof, and the organic solvent is lauric acid methyl ester.

Further embodiments of the embodiments as defined abovefourth, fifth and sixth aspect comprise all embodiments of the first and second aspect of the present inventiondisclosure.

The inventors of the present inventiondisclosure found that the efficiency of removing an organic compound with one or more positive charges from an aqueous solution into a hydrophobic organic solution can, surprisingly, be increased when said organic solution comprises a liquid cation exchanger. Without wishing to be bound to any theory, the inventors of the present inventiondisclosure presume that the negative charge or the negative charges of the liquid cation exchanger interacts/interact ionically with the one positive charge or the several positive charges of the organic compounds and that this interaction leads to a masking of at least one positive charge, which increases the solubility in the organic phase.

In a preferred embodiment, the term "liquid cation exchanger", as used herein, means a compound that is soluble in a hydrophobic organic solvent, and owing to one or more negative permanent charges is

Claims

1. *Method for removing an organic compound from an aqueous solution, comprising the steps*

   a) providing the aqueous solution containing the organic compound and a hydrophobic organic solution, which comprises a liquid cation exchanger,

   wherein the liquid cation exchanger is hydrophobic,

   b) contacting the aqueous solution and the organic solution, and

   c) separating the organic solution from the aqueous solution,

   wherein the organic compound is a compound of formula I

   $$NH_3^+\text{-A-COOR}^1 \quad (I),$$

   wherein R^1 is hydrogen, methyl, ethyl or a negative charge and A is an unsubstituted, linear alkylene group with at least three, preferably at least eight carbon atoms,

   and wherein the liquid cation exchanger is a fatty acid.

2. Method according to one of Claims 1, wherein the temperature in step b) is 28 to 70, preferably 30 to 37°C.

3. Method according to one of Claims 1 to 2, wherein the pH in step b) is 6 to 8, preferably 6.2 to 7.2.

4. Method according to one of Claims 1 to 3, wherein the molar ratio of liquid cation exchanger to organic compound is at least 1.

5. Method according to one of Claims 1 to 4, wherein the volume ratio of organic solution to aqueous solution is 1:10 to 10:1.

6. Method according to one of Claims 1 to 5, wherein the liquid cation exchanger is a fatty acid with more than 12, preferably with 14 to 22, more preferably 16 to 18 carbon atoms.

7. Method according to one of Claims 1 to 6, wherein the liquid cation exchanger is an unsaturated fatty acid, preferably oleic acid or erucic acid.

8. Method according to one of Claims 1 to 7, wherein the aqueous solution further comprises a biological agent with catalytic activity.

9. Method according to Claim 8, wherein the biological agent is a cell, preferably a bacterial cell and the cell more preferably has a recombinant alkane monooxygenase, a recombinant transaminase and preferably moreover at least one enzyme from the group comprising an alcohol dehydrogenase, an alanine dehydrogenase and the AlkL gene product or variants thereof.

10. Method according to one of Claims 8 to 9, wherein the presence of the organic compound has an adverse effect on the catalytic activity, preferably in that the organic compound is a compound that is toxic to the cell.

11. Method according to one of Claims 1 to 10, wherein the organic solution furthermore contains at least one organic solvent, preferably a fatty acid and/or a fatty acid ester.

12. Method according to Claim 11, wherein the organic solution comprises as liquid cation exchanger 20 to 80 vol%, preferably 25 to 75 vol% of oleic acid, and as solvent lauric acid methyl ester and the organic compound is 12-aminolauric acid methyl ester and a bacterial cell is present in the aqueous solution, which has a recombinant alkane monooxygenase, a recombinant transaminase and preferably moreover at least one enzyme from the group comprising an alcohol dehydrogenase, an alanine dehydrogenase and the AlkL gene product or variants thereof.

13. Reaction mixture comprising an aqueous solution and a hydrophobic organic solution,

wherein the hydrophobic organic solution comprises a fatty acid, preferably a fatty acid with more than 12 carbon atoms, more preferably an unsaturated fatty acid as liquid cation exchanger.

and wherein the aqueous solution is a compound of formula (I)

$$NH_3^+\text{-A-COOR}^1 \text{ (I)},$$

wherein R^1 is hydrogen, methyl, ethyl or a negative charge and A is an unsubstituted, linear alkylene group with at least three, preferably at least eight carbon atoms.

14. Reaction mixture according to Claim 13, wherein the aqueous solution further comprises a cell that has a recombinant alkane monooxygenase, a recombinant transaminase and preferably furthermore at least one enzyme from the group comprising an alcohol dehydrogenase, an alanine dehydrogenase and the AlkL gene product or variants thereof.

CLAIMS

1. A method for removing an organic compound from an aqueous solution, the method comprising:

a) contacting the aqueous solution comprising an organic compound with a hydrophobic organic solution comprising a hydrophobic liquid cation exchanger, and

b) separating the organic solution from the aqueous solution, wherein the organic compound is a compound of formula I

$$NH_3^+\text{-A-COOR}^1 \text{ (I)},$$

wherein R^1 is hydrogen, methyl, ethyl or a negative charge and A is an unsubstituted, linear alkylene group comprising at least three carbon atoms,

wherein the liquid cation exchanger is a fatty acid, and

wherein the contacting is performed at a temperature of 28 to 70°C.

2. The method of claim 1, wherein the contacting is perform at a pH of 6 to 8.

3. The method of claim 1, wherein a molar ratio of the liquid cation exchanger to the organic compound is at least 1.

4. The method of claim 1, wherein a volume ratio of the organic solution to the aqueous solution is 1:10 to 10:1.

5. The method of claim 1, wherein the liquid cation exchanger is a fatty acid comprising more than 12 carbon atoms.

6. The method of claim 1, wherein the liquid cation exchanger is an unsaturated fatty acid.

7. The method of claim 1, wherein the aqueous solution further comprises a biological catalyst agent having catalytic activity.

8. The method of claim 7, wherein the biological agent is a cell.

9. The method of claim 7, wherein the presence of the organic compound has an adverse effect on the catalytic activity of the biological agent having catalytic activity.

10. The method of claim 1, wherein the organic solution further comprises an organic solvent.

11. The method of claim 10, wherein

the organic solution comprises as the liquid cation exchanger 20 to 80 vol%, of oleic acid, and as the organic solvent lauric acid methyl ester,

the organic compound is 12-aminolauric acid methyl ester and

a bacterial cell is present in the aqueous solution, wherein the bacterial cell comprises a recombinant alkane monooxygenase and a recombinant transaminase.

12. A reaction mixture comprising an aqueous solution and a hydrophobic organic solution, wherein the hydrophobic organic solution comprises a fatty acid as a liquid cation exchanger,

and wherein the aqueous solution is a compound of formula (I)

$$NH_3^+\text{-A-COOR}^1 \text{ (I)},$$

wherein R^1 is hydrogen, methyl, ethyl or a negative charge and A is an unsubstituted, linear alkylene group comprising at least three carbon atoms, and

wherein the aqueous solution further comprises a cell comprising a recombinant alkane monooxygenase and a recombinant transaminase

13. The method of claim 12, wherein A in formula I is an unsubstituted, linear alkylene group comprising at least eight carbon atoms.

14. The method of claim 12, wherein the contacting is performed at a temperature of 30 to 37°C.

15. The method of claim 12, wherein the contacting is performed at a pH of 6.2 to 7.2.

16. The method of claim 12, wherein the liquid cation exchanger is a fatty acid comprising 14 to 22 carbon atoms.

17. The method of claim 12, wherein the liquid cation exchanger is a fatty acid comprising 16 to 18 carbon atoms.

18. The method of claim 12, wherein the liquid cation exchanger is oleic acid or erucic acid.