Claims

1. A method for reducing the amount of CO_2 in a carbon dioxide-containing source by using a regeneratable ion exchange material, comprising the following steps of:
   a) providing at least one ion exchange material comprising at least one earth alkali metal cation,
   b) providing at least one carbon dioxide-containing source,
   c) providing at least one source of at least one cation which is capable of replacing the at least one earth alkali metal cation of the at least one ion exchange material,
   d) providing at least one source of at least one earth alkali metal cation,
   e) contacting the at least one ion exchange material of step a) with the at least one source of at least one cation of step c) such as to obtain a mixture comprising
      i) at least one ion exchange material, and
      ii) at least one earth alkali metal cation released from the at least one ion exchange material of step a),
   f) separating the at least one earth alkali metal cation of step ii) from the at least one ion exchange material of step i),
   g) contacting the at least one earth alkali metal cation obtained in step f) with the at least one carbon dioxide-containing source of step b) such as to obtain a carbonate salt of the at least one earth alkali metal cation, and
   h) contacting the at least one ion exchange material obtained in step f) with the at least one source of at least one earth alkali metal cation of step d) such as to regenerate the at least one ion exchange material of step a).

2. The method of claim 1, wherein the at least one ion exchange material of step a) is selected from a natural ion exchange material, a modified ion exchange material, a synthetic ion exchange material, and mixtures thereof.

3. The method of claim 1 or 2, wherein the at least one ion exchange material of step a) comprises a natural ion exchange material selected from the group comprising phyllosilicates, zeolite, mica, montmorillonite, mauritzite and mixtures thereof and/or a synthetic ion exchange material selected from the group comprising EDTA, ion exchange resins and mixtures thereof, preferably phyllosilicates.

4. The method of any one of the preceding claims, wherein the at least one ion exchange material of step a) comprises at least one earth alkali metal cation selected from the group comprising magnesium, calcium, strontium and mixtures thereof, preferably calcium and/or magnesium.

5. The method of any one of the preceding claims, wherein the at least one ion exchange material of step a) is provided in form of a solid or an aqueous suspension or an emulsion or a filter material or a fluidized bed.

6. The method of any one of the preceding claims, wherein the at least one ion exchange material of step a) is provided in form of an aqueous suspension having an ion exchange material content of from 2 to 50 wt.-%, preferably from 5 to 40 wt.-%, more preferably from 7.5 to 30 wt.-% and most preferably from 10 to 20 wt.-%, based on the total weight of the aqueous suspension.

7. The method of any one of the preceding claims, wherein the at least one ion exchange material of step a) consists of bentonite comprising various clay minerals selected from the group comprising montmorillonites and concomitant minerals such as quartz, mica, kaolinite, feldspar, pyrite, calcite, cristobalite and mixtures thereof.

8. The method of any one of the preceding claims, wherein the at least one ion exchange material of step a) consists of bentonite having a montmorillonite content of at least 60 wt.-%, preferably of at least 80 wt.-%, e.g. between 85 and 95 wt.-%, based on the total weight of the bentonite.

9. The method of any one of the preceding claims, wherein the ion exchange material of step a) consists of bentonite whose interlayer spaces are occupied primarily with calcium and/or magnesium ions.

10. The method of any one of the preceding claims, wherein the at least one ion exchange material of step a) consists of bentonite having a weight median particle size d_{50} from 0.02 to 100 μm, from 0.075 to 50 μm, or from 0.1 to 5 μm, preferably from 0.2 to 3 μm.

11. The method of any one of the preceding claims, wherein the at least one carbon dioxide-containing source of step b) is selected from a gas, liquid, solid, complex, ion exchange material and mixtures thereof, preferably a gas.

12. The method of any one of the preceding claims, wherein the at least one carbon dioxide-containing source of step b) is selected from air, industrial exhaust gas streams, waste gas streams, volcanic outgassing and mixtures thereof.

13. The method of any one of the preceding claims, wherein the at least one carbon dioxide-containing source of step b) comprises carbon dioxide providing a partial pressure of at least 0.02 Pa, preferably of at least 0.05 Pa, more preferably at least 0.1 Pa, even more preferably at least 0.15 Pa and most preferably at least 0.2 Pa.

14. The method of any one of the preceding claims, wherein the at least one source of at least one cation of step c) and/or the at least one source of at least one earth alkali metal cation of step d) is an aqueous solution, preferably an aqueous solution comprising at least 50 wt.-%, more preferably at least 75 wt.-% and most preferably at least 90 wt.-%, based on the total weight of the aqueous solution, of water.

15. The method of any one of the preceding claims, wherein the at least one source of at least one cation of step c) is a naturally occurring source of at least one monovalent and/or divalent cation capable of replacing the at least one earth alkali metal cation of the at least one ion exchange material, preferably a naturally occurring source of at least one monovalent cation capable of replacing the at least one earth alkali metal cation of the at least one ion exchange material.

16. The method of any one of the preceding claims, wherein the at least one source of at least one cation of step c) is sea water.

17. The method of any one of the preceding claims, wherein the at least one carbon dioxide-containing source of step b) and/or the at least one source of at least one cation which is capable of replacing the at least one earth alkali metal cation of the at least one ion exchange material of step c) and/or the at least one source of at least one earth alkali metal cation are provided in form of an aqueous solution, preferably an aqueous solution having a pH of between 5 and 12, preferably between 6 and 11 and most preferably between 7 and 10.5.

18. The method of any one of the preceding claims, wherein the at least one cation of the at least one source of at least one cation of step c) is selected from the group comprising lithium, sodium, potassium, magnesium, strontium and mixtures thereof, preferably sodium.

19. The method of any one of the preceding claims, wherein the at least one source of at least one cation of step c) comprises the at least one cation in an amount of from 0.1 to 150 g/l, preferably of from 1 to 100 g/l, more preferably of from 5 to 75 g/l and most preferably of from 10 to 50 g/l.

20. The method of any one of the preceding claims, wherein the at least one source of at least one earth alkali metal cation of step d) is a naturally

occurring source of at least one earth alkali metal cation, e.g. fresh hard water.

21. The method of any one of the preceding claims, wherein the at least one source of at least one earth alkali metal cation of step d) is fresh hard water having a hardness of from 5 to 130 °dH (0.89162 to 23.182 mmol/L), preferably from 10 to 60 °dH (1.7832 to 10.699 mmol/L), and most preferably from 14 to 50 °dH (2.4965 to 8.9162 mmol/L).

22. The method of any one of the preceding claims, wherein the at least one earth alkali metal cation of the at least one source of at least one earth alkali metal cation of step d) is selected from magnesium, calcium, strontium and mixtures thereof, preferably calcium.

23. The method of any one of the preceding claims, wherein the at least one source of at least one earth alkali metal cation of step d) comprises the at least one earth alkali metal cation in an amount from 0.1 to 200 mg/1, preferably from 0.5 to 150 mg/1, more preferably from 1 to 100 mg/1, even more preferably from 5 to 75 mg/1 and most preferably from 10 to 50 mg/1.

24. The method of any one of claims 6 to 23, wherein contacting step g) is carried out in that the at least one carbon dioxide-containing source of step b) is introduced into an aqueous solution obtained in step f).

25. The method according to claim 24, wherein the aqueous solution obtained step f) is further contacted with at least one catalyst for enhancing the hydratisation of carbon dioxide.

26. The method according to claim 25, wherein the at least one catalyst for enhancing the hydratisation of carbon dioxide is at least one enzyme, preferably carbonic anhydrase.

27. The method of any one of the preceding claims, wherein contacting step e) and/or separating step f) and/or contacting step g) and/or contacting step h)

is/are carried out at a temperature from 2°C to 80°C, preferably from 4°C to 60°C and most preferably from 5°C to 40°C.

28. The method of any one of the preceding claims, wherein contacting step e) and/or separating step f) and/or contacting step g) and/or contacting step h) is/are carried out at a pH of between 4 and 12, preferably between 5 and 11 and most preferably between 7 and 10.5.

29. The method of any one of the preceding claims, wherein contacting step g) is carried out under pressure of at least 100 Pa, more preferably at least 200 Pa and most preferably at least 300 Pa.

30. The method of any one of the preceding claims, wherein contacting step h) is carried out before and/or during and/or after contacting step g).

31. The method of any one of the preceding claims, wherein separating step f) is carried out by filtration, centrifugation, cycloning, sedimentation or a mixture thereof.

32. The method of any one of the preceding claims, wherein the method further comprises step k) of separating the carbonate salt of the at least one earth alkali metal cation obtained in step g).

33. The method of claim 32, wherein separating step k) is carried out by filtration, centrifugation, cycloning, concentrating, evaporation, sedimentation or a mixture thereof.

34. Use of a regeneratable ion exchange material as defined in any one of claims 1 to 10 for reducing the amount of CO_2 from a carbon dioxide-containing source.

35. The use of a regeneratable ion exchange material according to claim 34, wherein the regeneratable ion exchange material comprises bentonite.

Claims

1. A method for reducing the amount of CO_2 in a carbon dioxide-containing source by using a regeneratable ion exchange material, consisting of the following steps:
   a) providing at least one ion exchange material comprising at least one earth alkali metal cation,
   b) providing at least one carbon dioxide-containing source,
   c) providing at least one source of at least one cation which is capable of replacing the at least one earth alkali metal cation of the at least one ion exchange material,
   d) providing at least one source of at least one earth alkali metal cation,
   e) contacting the at least one ion exchange material of step a) with the at least one source of at least one cation of step c) such as to obtain a mixture comprising
      i) at least one ion exchange material, and
      ii) at least one earth alkali metal cation released from the at least one ion exchange material of step a),
   f) separating the at least one earth alkali metal cation of step ii) from the at least one ion exchange material of step i),
   g) contacting the at least one earth alkali metal cation obtained in step f) with the at least one carbon dioxide-containing source of step b) such as to obtain a carbonate salt of the at least one earth alkali metal cation, and
   h) contacting the at least one ion exchange material obtained in step f) with the at least one source of at least one earth alkali metal cation of step d) such as to regenerate the at least one ion exchange material of step a).

2. The method of claim 1, wherein the at least one ion exchange material of step a) is selected from a natural ion exchange material, a modified ion exchange material, a synthetic ion exchange material, and mixtures thereof.

3. The method of claim 1 or 2, wherein the at least one ion exchange material of step a) comprises a natural ion exchange material selected from the group comprising phyllosilicates, zeolite, mica, montmorillonite, mauritzite and mixtures thereof and/or a synthetic ion exchange material selected from the group comprising EDTA, ion exchange resins and mixtures thereof, preferably phyllosilicates.

4. The method of any one of the preceding claims, wherein the at least one ion exchange material of step a) comprises at least one earth alkali metal cation selected from the group comprising magnesium, calcium, strontium and mixtures thereof, preferably calcium and/or magnesium.

5. The method of any one of the preceding claims, wherein the at least one ion exchange material of step a) is provided in form of a solid or an aqueous suspension or an emulsion or a filter material or a fluidized bed.

6. The method of any one of the preceding claims, wherein the at least one ion exchange material of step a) is provided in form of an aqueous suspension having an ion exchange material content of from 2 to 50 wt.-%, preferably from 5 to 40 wt.-%, more preferably from 7.5 to 30 wt.-% and most preferably from 10 to 20 wt.-%, based on the total weight of the aqueous suspension.

7. The method of any one of the preceding claims, wherein the at least one ion exchange material of step a) consists of bentonite comprising various clay minerals selected from the group comprising montmorillonites and concomitant minerals such as quartz, mica, kaolinite, feldspar, pyrite, calcite, cristobalite and mixtures thereof.

8. The method of any one of the preceding claims, wherein the at least one ion exchange material of step a) consists of bentonite having a montmorillonite content of at least 60 wt.-%, preferably of at least 80 wt.-%, e.g. between 85 and 95 wt.-%, based on the total weight of the bentonite.

9. The method of any one of the preceding claims, wherein the ion exchange material of step a) consists of bentonite whose interlayer spaces are occupied primarily with calcium and/or magnesium ions.

10. The method of any one of the preceding claims, wherein the at least one ion exchange material of step a) consists of bentonite having a weight median particle size d_{50} from 0.02 to 100 μm, from 0.075 to 50 μm, or from 0.1 to 5 μm, preferably from 0.2 to 3 μm.

11. The method of any one of the preceding claims, wherein the at least one carbon dioxide-containing source of step b) is selected from a gas, liquid, solid, complex, ion exchange material and mixtures thereof, preferably a gas.

12. The method of any one of the preceding claims, wherein the at least one carbon dioxide-containing source of step b) is selected from air, industrial exhaust gas streams, waste gas streams, volcanic outgassing and mixtures thereof.

13. The method of any one of the preceding claims, wherein the at least one carbon dioxide-containing source of step b) comprises carbon dioxide providing a partial pressure of at least 0.02 Pa, preferably of at least 0.05 Pa, more preferably at least 0.1 Pa, even more preferably at least 0.15 Pa and most preferably at least 0.2 Pa.

14. The method of any one of the preceding claims, wherein the at least one source of at least one cation of step c) and/or the at least one source of at least one earth alkali metal cation of step d) is an aqueous solution, preferably an aqueous solution comprising at least 50 wt.-%, more preferably at least 75 wt.-% and most preferably at least 90 wt.-%, based on the total weight of the aqueous solution, of water.

15. The method of any one of the preceding claims, wherein the at least one source of at least one cation of step c) is a naturally occurring source of at least one monovalent and/or divalent cation capable of replacing the at least one earth alkali metal cation of the at least one ion exchange material, preferably a naturally occurring source of at least one monovalent cation capable of replacing the at least one earth alkali metal cation of the at least one ion exchange material.

16. The method of any one of the preceding claims, wherein the at least one source of at least one cation of step c) is sea water.

17. The method of any one of the preceding claims, wherein the at least one carbon dioxide-containing source of step b) and/or the at least one source of at least one cation which is capable of replacing the at least one earth alkali metal cation of the at least one ion exchange material of step c) and/or the at least one source of at least one earth alkali metal cation are provided in form of an aqueous solution, preferably an aqueous solution having a pH of between 5 and 12, preferably between 6 and 11 and most preferably between 7 and 10.5.

18. The method of any one of the preceding claims, wherein the at least one cation of the at least one source of at least one cation of step c) is selected from the group comprising lithium, sodium, potassium, magnesium, strontium and mixtures thereof, preferably sodium.

19. The method of any one of the preceding claims, wherein the at least one source of at least one cation of step c) comprises the at least one cation in an amount of from 0.1 to 150 g/l, preferably of from 1 to 100 g/l, more preferably of from 5 to 75 g/l and most preferably of from 10 to 50 g/l.

20. The method of any one of the preceding claims, wherein the at least one source of at least one earth alkali metal cation of step d) is a naturally

occurring source of at least one earth alkali metal cation, e.g. fresh hard water.

21. The method of any one of the preceding claims, wherein the at least one source of at least one earth alkali metal cation of step d) is fresh hard water having a hardness of from 5 to 130 °dH (0.89162 to 23.182 mmol/L), preferably from 10 to 60 °dH (1.7832 to 10.699 mmol/L), and most preferably from 14 to 50 °dH (2.4965 to 8.9162 mmol/L).

22. The method of any one of the preceding claims, wherein the at least one earth alkali metal cation of the at least one source of at least one earth alkali metal cation of step d) is selected from magnesium, calcium, strontium and mixtures thereof, preferably calcium.

23. The method of any one of the preceding claims, wherein the at least one source of at least one earth alkali metal cation of step d) comprises the at least one earth alkali metal cation in an amount from 0.1 to 200 mg/l, preferably from 0.5 to 150 mg/l, more preferably from 1 to 100 mg/l, even more preferably from 5 to 75 mg/l and most preferably from 10 to 50 mg/l.

24. The method of any one of claims 6 to 23, wherein contacting step g) is carried out in that the at least one carbon dioxide-containing source of step b) is introduced into an aqueous solution obtained in step f).

25. The method according to claim 24, wherein the aqueous solution obtained in step f) is further contacted with at least one catalyst for enhancing the hydratisation of carbon dioxide.

26. The method according to claim 25, wherein the at least one catalyst for enhancing the hydratisation of carbon dioxide is at least one enzyme, preferably carbonic anhydrase.

27. The method of any one of the preceding claims, wherein contacting step e) and/or separating step f) and/or contacting step g) and/or contacting step h) is/are carried out at a temperature from 2°C to 80°C, preferably from 4°C to 60°C and most preferably from 5°C to 40°C.

28. The method of any one of the preceding claims, wherein contacting step e) and/or separating step f) and/or contacting step g) and/or contacting step h) is/are carried out at a pH of between 4 and 12, preferably between 5 and 11 and most preferably between 7 and 10.5.

29. The method of any one of the preceding claims, wherein contacting step g) is carried out under pressure of at least 100 Pa, more preferably at least 200 Pa and most preferably at least 300 Pa.

30. The method of any one of the preceding claims, wherein contacting step h) is carried out before and/or during and/or after contacting step g).

31. The method of any one of the preceding claims, wherein separating step f) is carried out by filtration, centrifugation, cycloning, sedimentation or a mixture thereof.

32. The method of any one of the preceding claims, wherein the method further comprises step k) of separating the carbonate salt of the at least one earth alkali metal cation obtained in step g).

33. The method of claim 32, wherein separating step k) is carried out by filtration, centrifugation, cycloning, concentrating, evaporation, sedimentation or a mixture thereof.

34. Use of a regeneratable ion exchange material as defined in any one of claims 1 to 10 for reducing the amount of CO_2 from a carbon dioxide-containing source wherein the regeneratable ion exchange material comprises bentonite.