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SPECIFICATION

Method of Manufacturing Crystalline Microporous
Material

5

[technical field]

10 The present invention relates to a method of
manufacturing crystalline microporous material, and
the invention relates more particularly to a method
suitable for manufacturing a variety of crystalline
microporous material under mild reaction conditions
and under safe working environmental conditions by
using simple installation. The crystalline
15 microporous materials obtained by the present
invention may be used as adsorbing agent, catalyst
carrier or the like.

[background art]

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Crystalline microporous material exist naturally
in many kinds such as mordenite, ferrierite. Further,
many kinds of artificial crystalline microporous
material are known such as Zeolite-A, Zeolite-X, ZSM-
25 Z5 (see Japanese patent Kokoku No. 46-10064), and ZSM-

11 (see Japanese patent Kokoku No. 53-23280) and so
on.

For manufacturing the artificial crystalline microporous material as mentioned above, there has
5 been employed a method commonly referred to as "hydrothermal synthesis method" which includes a mixing step for obtaining alkaline mixture liquid containing silicon dioxide (SiO_2), aluminum oxide, and organic ammonium salt, and a subsequent crystallizing
10 step for crystallizing crystalline microporous material in the inorganic material mixture liquid by means of high-pressure heating.

That is, according to the hydrothermal method, it has been believed that after the preparation of the
15 mixture liquid the crystallizing step by heating needs to be effected with the solid mixture component thereof being in the liquid. Thus, for obtaining the high-temperature and high-pressure conditions needed for the crystallization, it has been necessary to
20 place the mixture liquid in the form of liquid within a high-pressure heating container (autoclave) and then to heat it.

With the conventional hydrothermal synthesis method described above, the high-pressure heating
25 container is expensive. Also, since the inorganic

mixture liquid contains alkaline metal oxide or alkaline earth metal oxide as oxide or hydroxide component thereof, the liquid is strongly alkaline. Therefore, for preventing corrosion due to the strong alkaline, it has been necessary for the high-pressure heating container to be made of e.g. stainless steel or to be provided with fluorine resin surface treatment. In these manners, the method involves many factors which may increase the manufacturing costs in terms of the manufacturing installation. In addition, in handling of such strong alkaline mixture liquid as described above, it has been necessary to take some appropriate and sufficient measure for the safety of the worker engaged in this operation. Therefore, the method may be considered as a very expensive synthesis method from the view point of safety of the installation also.

Further, according to the hydrothermal synthesis method, the crystallizing step thereof requires severe reaction conditions of heating the mixture liquid at a high temperature condition normally at 70°C to 200°C or even higher in some cases for a long period extended over a few days or even more than 10 days. This too has contributed to further increase in the manufacturing costs.

Still further, in a small-scale research and development too, the use of the strong alkaline mixture liquid under such high-temperature, high-pressure conditions does not allow the use of ordinary glass container. So, there has been a demand for an improved method which allows inexpensive synthesis of crystalline microporous material under milder conditions.

In addition to the above, the crystalline microporous material obtained by the hydrothermal synthesis is in the form of fine particles, which needs to be molded depending on its application. Yet, the crystalline microporous material in the form of fine particles does not have caking force or property. Then, the molding must be effected by either sintering the material under an extremely high temperature or using a binder in combination. For this reason, the sintering under the very high temperature may cause melting of the surface layer of the crystal or the use of binder may cause blocking of the porous structure. Hence, in either case, there results decrease in the ratio of the crystalline microporous structure present in the molded material, i.e. the molded material will suffer decrease in the ratio of the porous structure per unit weight. Consequently, the resultant molded

material tends to suffer deterioration in such properties as adsorbent activity, catalyst activity afforded by the porous structure.

5 Taking the above-described state of the art into consideration, a primary object of the present invention is to provide an improved method which allows inexpensive synthesis of crystalline microporous material under milder reaction conditions. A further object is to provide an inexpensive
10 crystalline microporous material or crystalline microporous molded product obtained by the method. A still further object of the invention is to provide a crystalline microporous material which may achieve superior performance in a variety of applications.

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[disclosure of the invention]

For fulfilling the above object, a method of manufacturing crystalline microporous material,
20 according to the characterizing features of the present invention, comprises the steps of:

a mixing step for obtaining alkaline mixture liquid including: at least one kind of crystallization-modifier selected from the group consisting of
25 ammonium ion (R_4N^+ : R is at least one selected from

the group consisting of hydrogen, and alkyl group or
aryl group having carbon number of 10 or less),
phosphonium ion (R_4P^+ : R is at least one selected
from the group consisting of hydrogen and alkyl group
5 or aryl group having carbon number of 10 or less) and
amine; and canemite (ideal composition formula:
 $NaHSi_2O_5$) fine particles;

a solid-liquid separating step, subsequent to the
mixing step, for separating solid component of fine
10 particles deposited in the mixture liquid from this
inorganic material mixture liquid; and

a crystallizing step for crystallizing, by
heating, the solid component separated through the
solid-liquid separation (this method will be referred
15 to as 'manufacturing method A', hereinafter).

In the present invention, said crystallization
modifier preferably comprises at least one selected
from the group consisting of:

tetra-n-butylammonium ion ($(n-C_4H_9)_4N^+$),
20 tetra-n-propylammonium ion ($(n-C_3H_7)_4N^+$),
tetra-ethylammonium ion ($(C_2H_5)_4N^+$),
tetra-methylammonium ion ($(CH_3)_4N^+$),
n-propyltrimethylammonium ion ($(n-C_3H_7)(CH_3)_3N^+$),
benzyltrimethylammonium ion ($(C_7H_7)(CH_3)_3N^+$),
25 tetra-n-butylphosphonium ion ($(n-C_4H_9)_4P^+$),

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1, 4-dimethyl-1, 4-diazabicyclo [2, 2, 2] octane,
pyrrolidine,
n-propylamine ($n\text{-C}_3\text{H}_7\text{NH}_2$), and
methylquinuclidine.

5 Further, the solid-liquid separating step may be
effected after a neutralizing step for neutralizing
the mixture liquid.

 An alternative method of manufacturing
crystalline microporous material, according to the
10 further characterizing features of the present
invention, comprises the steps of:

 a mixing step for obtaining alkaline inorganic
material mixture liquid including: at least one kind
of crystallization modifier selected from the group
15 consisting of ammonium ion (R_4N^+ : R is at least one
selected from the group consisting of hydrogen, and
alkyl group or aryl group having carbon number of 10
or less), phosphonium ion (R_4P^+ : R is at least one
selected from the group consisting of hydrogen and
20 alkyl group or aryl group having carbon number of 10
or less) and amine; and ~~silicon dioxide~~ (SiO_2);

 a solid-liquid separating step, subsequent to the
mixing step, for separating solid component of fine
particles deposited in the mixture liquid from this
25 inorganic material mixture liquid; and

a crystallizing step for crystallizing, by heating, the solid component separated through the solid-liquid separation (this method will be referred to as 'manufacturing method B', hereinafter).

5 The crystallization modifier used in the above may be the crystallization modifier described as being preferred in the manufacturing method A.

Further, in this method too, the solid-liquid separating step may be effected after a neutralizing
10 step for neutralizing the mixture liquid.

Moreover, as a still further manufacturing method preferred in the invention, there is proposed a method comprising the steps of:

15 a mixing step for obtaining alkaline inorganic material mixture liquid including silicon dioxide (SiO_2) component and aluminum salt; a solid-liquid separating step, subsequent to the mixing step, for separating solid component of fine particles deposited in the mixture liquid from this inorganic material
20 mixture liquid; and a crystallizing step for crystallizing, by heating, the solid component separated through the solid-liquid separation (this method will be referred to as 'manufacturing method C', hereinafter).

25 In any one of the above manufacturing methods A,

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B and C, the crystallization step may comprise a step of heating a sealed container into which the solid-liquid separated solid component has been introduced, or a step of supplying water vapor to the solid-liquid separated solid component. Further, the crystallization step may be provided after the solid-liquid separated solid component is molded.

Functions and effects of the invention will be described next.

In the case of the manufacturing methods A, B, when the canemite component or silicon dioxide component is caused to coexist with the crystallization modifier under the alkaline condition (mixing step), the inorganic material aggregates around the crystallization modifier to form fine particles of composite material. Thus, these fine particles of composite material may be collected separately as solid component. The present invention has been achieved based on a new finding that the separated composite solid component undergoes a phase change by the heating to be rendered into porous crystalline material.

More particularly, by heating the solid component to crystallize it (crystallizing step), the composite material is crystallized in such a form that the

inorganic material surrounds the crystallization modifier as a core. Consequently, from this crystal, simply by heating the composite material in the form of solid, there may be obtained a porous structure having a uniform pore diameter.

Further, the crystallization modifier may be at least one selected from the group consisting of;

ammonium ion (R_4N^+ : R is at least one selected from the group consisting of hydrogen, and alkyl group or aryl group having carbon number of 10 or less),

phosphonium ion (R_4P^+ : R is at least one selected from the group consisting of hydrogen and alkyl group or aryl group having carbon number of 10 or less), and

amine. In particular, the modifier preferably comprises at least one selected from the group consisting of:

tetra-n-butylammonium ion ($(n-C_4H_9)_4N^+$),
 tetra-n-propylammonium ion ($(n-C_3H_7)_4N^+$),
 tetra-ethylammonium ion ($(C_2H_5)_4N^+$),
 tetra-methylammonium ion ($(CH_3)_4N^+$),
 n-propyltrimethylammonium ion ($(n-C_3H_7)(CH_3)_3N^+$),
 benzyltrimethylammonium ion ($(C_7H_7)(CH_3)_3N^+$),
 tetra-n-butylphosphonium ion ($(n-C_4H_9)_4P^+$),
 1, 4-dimethyl-1, 4-diazabicyclo [2, 2, 2] octane,

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pyrrolidine,
n-propylamine ($n\text{-C}_3\text{H}_7\text{NH}_2$), and
methylquinuclidine.

5 But, other kinds of ammonium salt, phosphonium salts, amines may be also used.

Incidentally, if tetra-n-propylammonium salt is employed, there is obtained crystalline microporous material having MFI structure. And, if tetra-n-butylammonium is employed, there is obtained
10 crystalline microporous material having MEL structure. Accordingly, by selecting the organic ammonium salt depending on the structure to be synthesized, it is possible to obtain crystalline microporous material having a desired pore diameter.

15 Further, in the case of the manufacturing method A or B, if the solid-liquid separating step is provided after the neutralizing step for neutralizing the inorganic material mixture liquid, the composite material tends to be formed into fine particles and
20 the composite solid component tends to have caking property. Therefore, the material may be readily molded in advance by such simple operation as a pressurizing operation. Therefore, in this case, if the crystallizing step is effected after the composite
25 material is molded, there is obtained an advantage

that a molded product, even if having a complex shape, may be readily obtained.

In the case of the manufacturing method C, the mixture liquid containing the silicon dioxide component is caused to contain aluminum salt to be rendered alkaline (mixing step), composite material including aluminum tends to be formed in the inorganic material mixture liquid containing the aluminum salt. Then, it has been found out that for this composite material also, if the solid-liquid separating step for separating between solid component and liquid component in the inorganic material mixture liquid and the crystallizing step for crystallization under heating are provided, the porous material undergoes a phase change in its structure to be crystallized into porous crystal. Accordingly, with this method too, like the manufacturing methods A, B, crystalline microporous material may be obtained. Therefore, by the simple operation of just heating the solid material, crystalline microporous material may be obtained.

Further, since the solid component of the composite material of the invention tends to have caking property, the material may be readily molded in advance by such simple operation as a pressurizing

operation. Therefore, if the crystallizing step is effected after the composite material is molded, there is obtained an advantage that a molded product, even if having a complex shape, may be readily obtained.

5 Further, the crystallization step may comprise a step of heating a sealed container into which the the solid-liquid separated solid component has been introduced, or a step of supplying water vapor to the solid-liquid separated solid component. Further, the
10 crystallization step may be provided after the solid-liquid separated solid component is molded. With these heating methods, there is no necessity of heating to a high temperature under a high pressure condition. And, if necessary, the heating may be
15 effected by using water vapor under a normal pressure. Consequently, the handling of the material may be facilitated and the manufacturing costs may be reduced as well.

 As described above, according to the present
20 invention, the crystallization of the microporous material may be effected by the simple operation of heating solid component. There is no necessity of the hydrothermal synthesis method using a high-pressure heating container. As the material may be handled in
25 the form of solid, the handling is easier than that in

the hydrothermal synthesis method in which the material is handled in the form of mixture liquid. Moreover, there is no necessity of providing the heating container with such measure as the anti-alkaline corrosion treatment, so that the manufacturing costs may be reduced in terms of the installation costs also. And, a more simple safety measure may suffice for the purpose. Furthermore, since the heating crystallizing conditions may be milder than those required by the convention (for instance, in embodiments to be described later, conditions of 180 °C for 8 hours may be sufficient), so that the manufacturing costs may be reduced in terms of the reaction condition needed for the manufacture. With the above-described effects combined, the methods according to the present invention achieve significant improvement over the conventional method with respect to the economy and safety. Further, in the case of e.g. a small-scale research and development activity, the synthesis is possible by using such a simple device as an ordinary glass container. Therefore, these methods will prove useful in e.g. development/manufacture of crystalline microporous material in small amounts and in a great variety.

The method of the present invention may be considered as a synthesis method based on phase change occurring in the structure of inorganic compound regulated by solvation cluster of organic ammonium ion. Accordingly, when the performances required of crystalline microporous material are being more and more distinguished and differentiated from one another in a variety of industries, the method of the invention will prove to be greatly useful in structural designing with higher molecular level precision.

Further, according to the present invention, there may be obtained crystalline microporous material having strong caking force, which may be readily pre-molded into a molded product having a complicated shape. Therefore, in comparison with the molded product made of the conventional crystalline microporous material obtained by pre-molding the raw material using a binder and then sintering this pre-molded material, the molded product obtained by the method of the present invention may achieve superior performance attributable to the porous structure, such as increase in the ratio of the porous structure per unit weight. As a result, this material may prove to find new applications in those technical fields that

used to deny the use of the conventionally molded products because of their poor performance.

Moreover, if the solid component of the composite material alone is molded and then crystallized, the resultant molded product will have improved dimension stability over a molded product obtained by high-temperature sintering operation. So that, the yield of the molded product will be improved and the manufacturing costs may be reduced in this respect as well.

The solid component of the composite material obtained by the method of the invention may be used as a binder. Then, if crystalline microporous material such as natural zeolite or material manufactured by a method different from the method of the invention is molded with using the solid component obtained by the method of the present invention as a binder, the resultant molded product will be formed entirely of the crystalline microporous material.

Further, by exposing the crystalline microporous material to aluminum chloride vapor or by introducing aluminum ion into the material, aluminum element may be introduced into the crystal structure. And, the crystalline microporous material provided with such treatment as above may be used as catalyst for use in

the manufacture of ethylbenzene or praraxylene.

[best modes for embodying the invention]

5 Next, embodiments of the invention will be described. Yet, the present invention is not limited to these embodiments.

 Incidentally, as raw materials, those having the following compositions were employed (all % notations
10 are wt.%)

 water glass No. 3: analyzed values: SiO_2 : 29.17%, Na_2O : 9.82% (T silicate soda No. 3, manufactured by Nippon Chemical Industries Co., Ltd.);

 silica powder (high purity silica powder
15 manufactured by Tama Chemical Industries Co., Ltd.);

 tetra-n-propylammonium bromide $((\text{n-C}_3\text{H}_7)_4\text{NBr})$:
(manufactured by Tokyo Kasei Industries Co., Ltd.);

 tetra-n-butylammonium bromide $((\text{n-C}_4\text{H}_9)_4\text{NBr})$
(manufactured by Tokyo Kasei Industries Co.,
20 Ltd.);

 aluminum chloride ($\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$): (manufactured by Kishida Chemical Co., Ltd.)

 benzyltrimethylammonium chloride $((\text{C}_7\text{H}_7)(\text{CH}_3)_3\text{NCl})$:
(manufactured by Tokyo Kasei Industries Co.,
25 Ltd.):

tetra-n-propylammonium hydroxide $((n-C_3H_9)_4NOH)$
 water solution: 20-25% (manufactured by Tokyo Kasei
 Industries Co., Ltd.)

5 benzyltrimethylammonium hydroxide $((C_7H_7)(CH_3)_3NOH)$
 water solution: 40% (manufactured by Tokyo Kasei
 Industries Co., Ltd.)

aluminum-tri-sec-butoxide $(Al(O-(CH(CH_3)(C_2H_5))_3)$
 (manufactured by Tokyo Kasei Industries Co., Ltd.)

10 sodium alminate $(NaAlO_2)$: (manufactured by Wako
 Junyaku Co., Ltd.)

tetraethylorthosilicate ("TEOS", manufactured by
 Tokyo Kasei Industries Co., Ltd.)

15 tetra-n-butylammonium hydroxide $((n-C_4H_9)_4NOH)$
 aqueous solution: 40% ("TBAOH", manufactured by Tokyo
 Kasei Industries Co., Ltd.)

copper acetylacetate $(Cu(CH_3COCHCOCH_3)_2)$:
 (manufactured by Dozin Chemical Research Institute)

[embodiment 1]

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200g of water glass No. 3 was prepared in a 500
 ml beaker and 14g of sodium hydroxide was dissolved
 therein. Thereafter, the mixture was placed onto an
 evaporation plate made of ~~alumina~~. This plate was
 25 introduced into a thermostatic oven maintained at 150



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°C to evaporate the water content of the mixture. The resultant product obtained after the water content evaporation, together with the evaporation plate, was introduced into an electric furnace to be sintered therein at 700 °C for about 7 hours. Then, the sintered product was allowed to be cooled to room temperature, whereby a reaction product was obtained. This reaction product was submerged in 700 ml water in a beaker, whereby fine particle precipitation was obtained. The fine particle precipitation was collected by means of filtration under reduced pressure, rinsed with deionized water, and then naturally dried at room temperature, whereby about 60g of canemite (ideal composition formula: $\text{NaHSi}_2\text{O}_5 \cdot 3\text{H}_2\text{O}$) was obtained.

Tetra-n-propylammonium bromide 5.32 g was added with deionized water to obtain 200g of solution. Into this solution, 10g of the above-described canemite was dispersed and heated up to 70°C and left still for 3 hours (mixing step). Then, after naturally cooling the solution to room temperature, 2M (mol/l) of hydrochloric acid was added thereto to gradually lower the pH value of the mixture solution to 8 approximately, whereby there occurred sudden bulging in the volume of canemite (neutralizing step).

This phenomenon is believed to be attributable to an ion exchange reaction between sodium ion in canemite and tetra-n-propylammonium ion $((n-C_3H_7)_4N^+)$. Then, this bulged canemite was collected by means of filtration under reduced pressure, rinsed with deionized water, and then naturally dried at room temperature, whereby white powderly material was obtained (solid-liquid separating step). This white powderly material is believed to be composite material of canemite and tetra-n-propylammonium ion.

About 1g of the above-described composite material was placed on a small glass filter and this glass filter, together with about 7g of deionized water, was placed into a pressure-resistant container having an inner surface thereof coated with fluorine resin. Then, a heating operation was effected for eight hours by using steam at 130 °C without directly exposing the composite material to the water, whereby reaction product was obtained (crystallizing step). A powder X-ray diffraction spectrum analysis effected on this reaction product revealed that the product was crystalline microporous material comprised of silicalite-1 having the MFI structure.

[embodiment 2]

6.44g of tetra-n-butylammonium bromide was added with deionized water to prepare 200g of solution. And, 10g of canemite manufactured in the embodiment 1 was dispersed in the solution and heated to 70 °C and then allowed to cool to room temperature. Thereafter, 2 mol/l of hydrochloric acid was added thereto to gradually lower the pH value to 8 approximately (composite material forming step and neutralizing step). In this case too, like the embodiment 1, sudden bulging in the volume of canemite was observed. Then, this bulged canemite was collected by means of filtration under reduced pressure, rinsed with deionized water, and then naturally dried at room temperature, whereby white powderly material was obtained (solid-liquid separating step). This white powderly material is believed to be composite material of canemite and tetra-n-butylammonium ion ((n-C₄H₉)₄N⁺).

Like the embodiment 1, on this composite material, a heating operation was effected by exposing the material to steam at 130 °C for 24 hours, whereby reaction product was obtained (crystallizing step). A powder X-ray diffraction spectrum analysis effected on this reaction product revealed that the product was

crystalline microporous material comprised of silicalite-2 having the MEL structure.

[embodiment 3]

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The powderly composite material manufactured by the same method as the embodiment 1 was placed into a test tube made of hard glass and this test tube was sealed in the air by melting. Then, the test tube was heated for 20 hours in a thermostatic oven maintained at 130 °C and then allowed to cool to room temperature, whereby reaction product was obtained (crystallizing step). The reaction product was taken out of the test tube, and a powder X-ray diffraction spectrum analysis of this reaction product revealed that the product was crystalline microporous material comprised of silicalite-1 like that of the embodiment 1.

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[embodiment 4]

The powderly composite material manufactured by the same method as the embodiment 1 was subjected to a uniaxial compression at 500 MPa by using a hydraulic press, whereby molded product was obtained. Then,

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this molded product was placed into a test tube made of hard glass and the test tube was sealed in the air by melting. Then, this test tube was heated for 20 hours in a thermostatic oven maintained at 130 °C (crystallizing step). Incidentally, after the cooling to room temperature, the reaction product was taken out of the test tube and the product was checked whether it exhibited any deformation or not. But, no deformation was found. The reaction product was taken out of the tube and a powder X-ray diffraction spectrum analysis effected on this reaction product revealed that the product was crystalline microporous material comprised of silicalite-1 like that of the embodiment 1.

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[embodiment 5]

The powderly composite material manufactured by the same method as the embodiment 1 was exposed to steam at 130 °C under the normal pressure for 20 hours, whereby reaction product was obtained (crystallizing step). A powder X-ray diffraction spectrum analysis effected on this reaction product revealed that the product was crystalline microporous material comprised of silicalite-1 like that of the

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embodiment 1.

[embodiment 6]

5 Tetrapropylammonium bromide 5.32 g was added with
deionized water to obtain 200g of solution. Into
this solution, 10g of the canemite manufactured in the
embodiment 1 was dispersed and heated up to 70°C and
left still for 3 hours (mixing step). Then, this
10 mixture solution was added with 20g solution prepared
by adding deionized water to 0.97g of aluminum
chloride and added further with hydrochloric acid so
as to adjust its pH value to 8 (neutralizing step).
In the above, 3.64g of 2N hydrochloric acid was
15 necessary.

 The neutralized mixture solution was filtered
under reduced pressure and rinsed with deionized
water. Thereafter, the solution was dried naturally
at room temperature, whereby powderly material was
20 obtained (solid-liquid separating step). This
powderly material is believed to be composite material
of canemite and tetra-n-propylammonium ion.

 The above-described powderly material was placed
into a test tube made of hard glass and this test tube
25 was sealed in the air by melting. Then, the test tube

was heated for 53 hours in a thermostatic oven maintained at 130 °C, whereby reaction product was obtained (crystallizing step). A powder X-ray diffraction spectrum analysis and analysis using Al-NMR were effected on this reaction product. Then, 4 coordinated aluminum was confirmed and the product was found to be crystalline microporous material comprised of ZSM-5.

10 [embodiment 7]

Benzyltrimethylammonium chloride 1.81 g was added with deionized water to obtain 40g of solution. Into this solution, 10g of the canemite manufactured in the
15 embodiment 1 was dispersed and heated up to 70°C and left still for 3 hours (mixing step). Then, this mixture solution was added with 30g solution prepared by adding deionized water to 2.45g of aluminum chloride. This solution had pH value of about 9.
20 This mixture liquid was filtered under reduced pressure and collected. Thereafter, the solution was naturally dried at room temperature, whereby powderly material was obtained (solid-liquid separating step). A fluorescence X-ray spectrum analysis effected on
25 this powderly material showed that the material had

Si/Al element ratio of 97 : 7. This material is believed to be composite material of canemite, aluminum ion and benzyltrimethylammonium ion $((C_7H_7)(CH_3)_3N^+)$.

5 The above-described powderly material was placed into a test tube made of hard glass and this test tube was sealed in the air by melting. Then, this test tube was heated for 600 hours in a thermostatic oven maintained at 150 °C, whereby reaction product was
10 obtained (crystallizing step). A powder X-ray diffraction spectrum analysis effected on this reaction product revealed that the product comprised crystalline microporous material comprised of mordenite having MOR structure.

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[comparison example 1]

 About 1g of canemite manufactured in the embodiment 1 was directly placed onto a small glass
20 filter, and this glass filter, together with about 7g of deionized water, was introduced into a pressure-resistant container having an inner surface thereof coated with fluorine resin and heated by exposing it to water vapor at 130 °C for 8 hours without exposing
25 canemite directly to the water. However, canemite

deliquesced due to the steam and nothing was left on the glass filter. No crystallization was made. Incidentally, the solution remaining in the pressure-resistant container showed a strong alkaline property exceeding pH 10.

[embodiment 8]

100g of water glass No. 3 was added with 100g of deionized water to be diluted thereby, to which 13g of tetra-propylammonium bromide was added and the mixture solution was stirred well, whereby inorganic material mixture liquid in the form of soft gel was obtained (mixing step). With addition thereto of about 18g of strong hydrochloric acid, the soft gel was rendered into harder gel. Supernatant liquid of this gel was found to have a pH value of 8 approximately. After this hard gel was rinsed sufficiently with deionized water, the gel was collected by means of filtration under reduced pressure and then dried naturally at room temperature, whereby white powderly material was obtained (solid-liquid separating step). This powderly material is believed to comprise composite material of water glass and tetra-n-propylammonium ion.

The above-described powderly material was placed into a test tube made of hard glass and this test tube was sealed in the air by melting. Then, the test tube was heated for 24 hours in a thermostatic oven maintained at 150 °C, whereby reaction product was obtained (crystallizing step).

A powder X-ray diffraction spectrum analysis effected on this reaction product revealed that the product comprised crystalline microporous material comprised of silicalite-1 having the MFI structure.

[embodiment 9]

100g of water glass No. 3 was added with 100g of deionized water to be diluted thereby, to which 13g of tetra-n-propylammonium bromide and 2.3g of aluminum chloride were added and the mixture solution was stirred well, whereby inorganic material mixture liquid in the form of soft gel was obtained (mixing step). With addition thereto of about 16g of conc. hydrochloric acid, the soft gel was rendered into harder gel. Supernatant liquid of this gel was found to have a pH value of 8 approximately. After this hard gel was rinsed sufficiently with deionized water, the gel was collected by means of filtration under

reduced pressure and then dried naturally at room temperature, whereby white powderly material was obtained (solid-liquid separating step). This powderly material is believed to comprise composite material of water glass, tetra-n-propylammonium ion and aluminum chloride.

The above-described powderly material was placed into a test tube made of hard glass and this test tube was sealed in the air by melting. Then, the test tube was heated for 24 hours in a thermostatic oven maintained at 150 °C and then allowed to cool to room temperature, whereby reaction product was obtained (crystallizing step).

A powder X-ray diffraction spectrum analysis effected on this reaction product revealed that the product comprised crystalline microporous material comprised of ZSM-5 having the MFI structure.

[embodiment 10]

100g of water glass No. 3 was added with 100g of deionized water to be diluted thereby, to which 16g of tetra-n-butylammonium bromide was added and the mixture solution was stirred well, whereby inorganic material mixture liquid in the form of soft gel was

obtained (mixing step). With addition thereto of about 12g of conc. hydrochloric acid, the soft gel was rendered into harder gel. Supernatant liquid of this gel was found to have a pH value of 8 approximately.

5 After this hard gel was rinsed sufficiently with deionized water, the gel was collected by means of filtration under reduced pressure and then dried naturally at room temperature, whereby white powdery material was obtained (solid-liquid separating step).

10 This powdery material is believed to comprise composite material of water glass and tetra-n-butylammonium ion $((n-C_4H_9)_4N^+)$.

The above-described powdery material was placed into a test tube made of hard glass and this test tube was sealed in the air by melting.

15 Then, this test tube was heated for 40 hours in a thermostatic oven maintained at 130 °C and then allowed to cool to room temperature, whereby reaction product was obtained out of the test tube (crystallizing step).

20 A powder X-ray diffraction spectrum analysis effected on this reaction product revealed that the product comprised crystalline microporous material comprised of silicalite-2 having the MEL structure.

25 [embodiment 11]

About 1g of the powderly composite material manufactured in the embodiment 1 was placed onto a small glass filter, and this glass filter, together with about 7g of deionized water, was introduced into a pressure-resistant container having an inner surface thereof coated with fluorine resin and heated by exposing it to water vapor at 130 °C for 8 hours without exposing canemite directly to the water (crystallizing step).

A powder X-ray diffraction spectrum analysis effected on this reaction product revealed that the product comprised crystalline microporous material comprised of silicalite-1 having the MFI structure.

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[embodiment 12]

The Powderly composite material manufactured in the embodiment 1 was subjected to a uniaxial compression at 500 MPa by using a hydraulic press, whereby molded product was obtained. Then, this molded product was placed into a test tube made of hard glass and the test tube was sealed in the air by melting. Then, this test tube was heated for 20 hours in a thermostatic oven maintained at 130 °C and then

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allowed to cool to room temperature, whereby reaction product was obtained (crystallizing step). Incidentally, the reaction product was taken out of the test tube and the product was checked whether it exhibited any deformation or not. No deformation was found.

A powder X-ray diffraction spectrum analysis effected of this reaction product revealed that the product was crystalline microporous material comprised of silicalite-1 having the MFI structure like that of the embodiment 1.

[embodiment 13]

About 1g of the powderly composite material manufactured in the embodiment 1 was placed onto a small glass filter, and this was heated by exposing it to steam at 130 °C for 20 hours, whereby reaction product was obtained (crystallizing step).

A powder X-ray diffraction spectrum analysis effected on this reaction product revealed that the product comprised crystalline microporous material comprised of silicalite-1 having the MFI structure like that of the embodiment 1.

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[embodiment 14]

5 60g of silica powder was left still for two weeks
at room temperature in 90g of water solution
containing tetra-n-propylammonium hydroxide, so that
the silica powder could be dispersed uniformly in the
solution, whereby inorganic material mixture solution
was obtained (mixing step). When this inorganic
material mixture solution was added with a large
10 amount of methanol, white precipitation product was
formed therein. This white precipitation product was
collected by filtration under reduced pressure and
naturally dried at room temperature, whereby white
powderly material was obtained (solid-liquid
15 separating step). This powderly material is believed
to comprise composite material of silica and tetra-n-
propylammonium ion.

The above-described powderly material was placed
into a test tube made of hard glass and this test tube
20 was sealed in the air by melting. Then, this test
tube was heated for 20 hours in a thermostatic oven
maintained at 150 °C and then allowed to cool to room
temperature, whereby reaction product was obtained out
of the test tube (crystallizing step).

25 A powder X-ray diffraction spectrum analysis

effected on this reaction product revealed that the product comprised crystalline microporous material comprised of silicalite-1 having the MFI structure.

5 [embodiment 15]

Solution prepared by diluting 100g of water glass No. 3 with 100g of deionized water and further solution prepared by dissolving 40g of sodium alminate
10 in 60g of deionized water were mixed and stirred well, whereby inorganic material mixture liquid in the form of gel was obtained (mixing step). Incidentally, supernatant liquid of this inorganic material mixture liquid was found to have a pH value of about 10. This
15 hard gel was sufficiently rinsed with deionized water and collected by filtration under reduced pressure and then dried naturally, whereby white powderly material was obtained (solid-liquid separating step). This
20 powderly material is believed to comprise composite material of water glass and aluminum oxide. A fluorescence X-ray spectrum analysis effected on this powderly material showed that the material had $\text{SiO}_2/\text{Al}_2\text{O}_3$ mol ratio of 5. 3.

The above-described powderly material was placed
25 into a test tube made of hard glass and this test tube

was sealed in the air by melting. Then, this test tube was heated for 24 hours in a thermostatic oven maintained at 130 °C and allowed to be cooled to room temperature, whereby reaction product was obtained (crystallizing step).

A powder X-ray diffraction spectrum analysis effected on this reaction product revealed that the product comprised crystalline microporous material comprised of Na-Pl having GIS structure.

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[embodiment 16]

The powderly composite material manufactured in the embodiment 8 was placed into a test tube made of hard glass and sealed in the air by melting. This was then heated by being kept in a thermostatic oven maintained at 150 °C for 45 hours and then allowed to be cooled to room temperature, whereby reaction product was obtained (crystallizing step).

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A powder X-ray diffraction spectrum analysis effected on this reaction product revealed that the product comprised crystalline microporous material comprised of analcime having ANA structure.

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[embodiment 17]

5 62.5g of tetraethylorthosilicate, 19.5g of water
 solution of tetrabutylammonium hydroxide and 68.3g of
 deionized water were mixed together and heated for one
 hour at 80 °C, whereby inorganic material mixture
 liquid in the form of gel was obtained (mixing step).
 (This phenomenon is believed to be attributable to
 that tetraethylorthosilicate was hydrolyzed and
 condensed in association with elimination of ethanol
 10 therefrom.)

The inorganic material mixture liquid was
 filtered under reduced pressure to obtain solid
 component. And, this solid component was rinsed well
 with acetone and naturally dried, whereby powderly
 15 material was obtained (solid-separating step). This
 powderly material is believed to comprise composite
 material of amorphous silicon dioxide and tetra-n-
 butylammonium ion.

20 The powderly composite material was placed into a
 test tube made of hard glass and this test tube was
 sealed in the air by melting. Then, this test tube
 was heated for 71 hours in a thermostatic oven
 maintained at 150 °C and allowed to be cooled to room
 temperature, whereby reaction product was obtained
 25 (crystallizing step).

A powder X-ray diffraction spectrum analysis effected on this reaction product revealed that the product comprised crystalline microporous material comprised of silicalite-2 having MEL structure.

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[embodiment 18]

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83.3g of tetraethylorthoxylate, 36.2g of water solution of tetrapropylammonium hydroxide and 1g of copper acetylacetate were mixed together and heated for one hour at 80 °C, whereby inorganic material mixture liquid in the form of gel was obtained (mixing step). The inorganic material mixture liquid was filtered under reduced pressure to obtain solid component. And, this solid component was rinsed well with acetone and naturally dried, whereby green-colored powderly material was obtained (solid-separating step). This powderly material is believed to comprise composite material of amorphous silicon dioxide and tetra-n-propylammonium ion.

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The powderly composite material was placed into a test tube made of hard glass and this test tube was sealed in the air by melting. Then, the test tube was heated for 24 hours in a thermostatic oven maintained at 150 °C and allowed to be cooled to room

temperature, whereby reaction product was obtained (crystallizing step).

A powder X-ray diffraction spectrum analysis effected on this reaction product revealed that the product comprised crystalline microporous material comprised of silicalite-1 having MFI structure. It is believed that this crystalline microporous material includes copper acetylacetate and can be used as a catalyst for e.g. denitration reaction.

[embodiment 19]

83.3g of tetraethylorthosilicate, 16.7g of water solution of benzyltrimethylammonium hydroxide, 4.9g of aluminum-tri-sec-butoxide ($\text{Al}(\text{O}-(\text{CH}(\text{CH}_3)(\text{C}_2\text{H}_5))_3)$), and 20g of ethanol were mixed together and heated for one hour at 80 °C, whereby inorganic material mixture liquid in the form of gel was obtained (mixing step). The inorganic material mixture liquid was filtered under reduced pressure and rinsed well and then dried naturally, whereby white powderly material was obtained (solid-separating step).

A fluorescence X-ray spectrum analysis effected on this powderly material showed that the material had Si/Al element ratio of 95 : 5. Therefore, this

material is believed to be composite material of amorphous silicon dioxide, aluminum oxide and benzyltrimethylammonium ion ($(C_7H_7)(CH_3)_3N^+$).

5 The powderly composite material was placed into a test tube made of hard glass and this test tube was sealed in the air by melting. Then, the test tube was heated for 530 hours in a thermostatic oven maintained at 150 °C and allowed to be cooled to room temperature, whereby a reaction product was obtained
10 (crystallizing step).

A powder X-ray diffraction spectrum analysis effected on this reaction product revealed that the product comprised crystalline microporous material comprised of mordenite having MOR structure.

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[industrial applicability]

The crystalline microporous material obtained by the present invention may be used as material for
20 adhesive agent, catalyst or separating material, more particularly, flon type cooling medium, drying agent for sulfur fluoride which is insulating medium for high-voltage electric appliances or for pneumatic brake of vehicles, or adsorbing/eliminating agent for
25 adsorbing/eliminating nitrogenous substances from

waste water or radioactive substances from radioactive waste water, or further as catalyst carrier for carrying various metal catalysts in the field of mainly e.g. petrochemical industries.

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[claims]

1. A method of manufacturing crystalline microporous material, which comprises the steps of:

5 a mixing step for obtaining alkaline mixture liquid including: at least one kind of crystallization modifier selected from the group consisting of ammonium ion (R_4N^+ : R is at least one selected from the group consisting of hydrogen, and alkyl group or
10 aryl group having carbon number of 10 or less), phosphonium ion (R_4P^+ : R is at least one selected from the group consisting of hydrogen and alkyl group or aryl group having carbon number of 10 or less) and amine; and kanemite (ideal composition formula:
15 $NaHSi_2O_5$) fine particles;

a solid-liquid separating step, subsequent to the mixing step, for separating solid component of fine particles deposited in the mixture liquid from this inorganic material mixture liquid; and

20 a crystallizing step for crystallizing, by heating, the solid component separated through the solid-liquid separation.

2. A method of manufacturing crystalline
25 microporous material, as defined in claim 1, wherein



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said crystallization modifier preferably comprises at least one selected from the group consisting of:

- 5 tetra-n-butylammonium ion $((n-C_4H_9)_4N^+)$,
 tetra-n-propylammonium ion $((n-C_3H_7)_4N^+)$,
 tetra-ethylammonium ion $((C_2H_5)_4N^+)$,
 tetra-methylammonium ion $((CH_3)_4N^+)$,
 n-propyltrimethylammonium ion $((n-C_3H_7)(CH_3)_3N^+)$,
 benzyltrimethylammonium ion $((C_7H_7)(CH_3)_3N^+)$,
 tetra-n-butylphosphonium ion $((n-C_4H_9)_4P^+)$,
10 1, 4-dimethyl-1, 4-diazabicyclo [2, 2, 2] octane,
 pyrrolidine,
 n-propylamine $(n-C_3H_7NH_2)$, and
 methylquinuclidine.

15 3. A method of manufacturing crystalline microporous material, which comprises the steps of:

 a mixing step for obtaining alkaline inorganic material mixture liquid including: at least one kind of crystallization modifier selected from the group
20 consisting of ammonium ion (R_4N^+) : R is at least one selected from the group consisting of hydrogen, and alkyl group or aryl group having carbon number of 10 or less), phosphonium ion (R_4P^+) : R is at least one
 selected from the group consisting of hydrogen and
25 alkyl group or aryl group having carbon number of 10



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or less) and amine; and silicon dioxide (SiO_2);

a solid-liquid separating step, subsequent to the mixing step, for separating solid component of fine particles deposited in the mixture liquid from this inorganic material mixture liquid; and

a crystallizing step for crystallizing, by heating, the solid component separated through the solid-liquid separation.

4. A method of manufacturing crystalline microporous material, as defined in claim 3, wherein said crystallization modifier preferably comprises at least one selected from the group consisting of:

tetra-n-butylammonium ion $((\text{n-C}_4\text{H}_9)_4\text{N}^+)$,

tetra-n-propylammonium ion $((\text{n-C}_3\text{H}_7)_4\text{N}^+)$,

tetra-ethylammonium ion $((\text{C}_2\text{H}_5)_4\text{N}^+)$,

tetra-methylammonium ion $((\text{CH}_3)_4\text{N}^+)$,

n-propyltrimethylammonium ion $((\text{n-C}_3\text{H}_7)(\text{CH}_3)_3\text{N}^+)$,

benzyltrimethylammonium ion $((\text{C}_7\text{H}_7)(\text{CH}_3)_3\text{N}^+)$,

tetra-n-butylphosphonium ion $((\text{n-C}_4\text{H}_9)_4\text{P}^+)$,

1, 4-dimethyl-1, 4-diazabicyclo [2, 2, 2] octane, pyrrolidine,

n-propylamine $(\text{n-C}_3\text{H}_7\text{NH}_2)$, and

methylquinuclidine.



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5. A method of manufacturing crystalline microporous material, as defined in any one of claims 1 through 4, wherein said solid-liquid separating step is effected after a neutralizing step for neutralizing the mixture liquid.

6. A method of manufacturing crystalline microporous material, which comprises the steps of:

a mixing step for obtaining alkaline inorganic material mixture liquid including silicon dioxide (SiO_2) component and aluminum salt; a solid-liquid separating step, subsequent to the mixing step, for separating solid component of fine particles deposited in the mixture liquid from this inorganic material mixture liquid; and a crystallizing step for crystallizing, by heating, the solid component separated through the solid-liquid separation.

7. A method of manufacturing crystalline microporous material, as defined in any one of claims 1 through 6, wherein said crystallization step comprises a step of heating a sealed container into which the solid-liquid separated solid component has been introduced.



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8. A method of manufacturing crystalline microporous material, as defined in any one of claims 1 through 5, wherein said crystallization step comprises a step of supplying water vapor to the solid-liquid separated solid component for crystallizing it.

9. A method of manufacturing crystalline microporous material, as defined in any one of claims 1 through 6, wherein said crystallization step comprises a step of supplying water vapor to the solid-liquid separated solid component under normal pressure for crystallizing it.

10. A method of manufacturing crystalline microporous material, as defined in any one of claims 1 through 8, wherein said crystallization step is provided after the solid-liquid separated solid component is molded.

[abstract of the disclosure]

A method of manufacturing crystalline microporous material suitable for manufacturing a variety of crystalline microporous material under mild reaction conditions and under safe working environmental conditions by using simple installation. The crystalline microporous materials obtained by the present invention may be used as adsorbent agent, catalyst or separating material.

According to the characterizing features of the manufacturing method of the present invention, there are provided a method of using cation compound or amine as crystallizing modifier and using, in combination, raw material including canemite or silicon dioxide and a further method using raw material including silicon dioxide and aluminum salt. The method includes a step of mixing these components, a solid-liquid separating step for separating produced fine particles, and a crystallizing step for crystallizing the separated solid component. The invention achieves improvement in safety, economy and so on, in comparison with the coventionally practiced hydrothermal synthesis method which requires severe reaction conditions of high-temperature, high-pressure

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and strong alkaline. Further, the method allows freedom in adjustment of the pore diameter and allows a higher proportion of porous structure to be maintained in a product when the material is formed into a molded product.

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