

STRUCTURE DIRECTING AGENT FOR IMPROVED SYNTHESIS OF ZEOLITES

Technical Field

The present invention relates to structure directing agents for synthesis of crystalline materials generally known as zeolites.

5 Background

Zeolites are important crystalline materials with a broad range of applications. There is an ongoing need for improved processes for manufacturing zeolites. In one aspect, it is desirable to decrease the time necessary for reaction and calcining of the materials used in manufacturing zeolites. In another aspect, it is desirable to increase
10 the degree of control of pore sizes in zeolites. In addition, it is desirable to better control the Si/Al ratio, and to obtain higher yields of the desired zeolite product.

U.S. Patent No. 5,958,370, entitled Zeolite SSZ-39, provides a detailed process for making zeolites using organic structure-directing agents, referred to therein as "templates". The disclosure of U.S. Patent No. 5,958,370 may be consulted for its
15 teachings relating to formation of zeolites generally and to formation of zeolite SSZ-39.

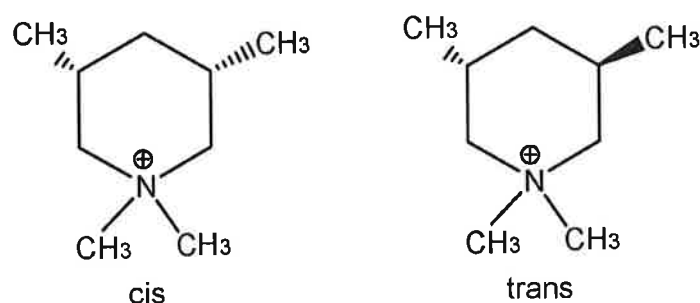
Summary

The zeolite SSZ-39 is a candidate for large-scale applications provided that the material can be synthesized efficiently. The synthesis is a common bottleneck hindering
20 the exploitation of many unique zeolite topologies. SSZ-39 has been synthesized using a variety of Organic Structure Directing Agents (OSDAs). Some of the proposed OSDAs share a common feature in their chemical structure, namely, the dimethylpiperidine (lupetidine) moiety. From an economic point of view, the 3,5-lupetidine is of interest, since its pyridine precursor, known as a lutidine, are among the most common,
25 commercially produced alkylpyridines, serving as precursors to drugs and specialty chemicals. The hydrogenation procedure (and especially the catalyst) used to convert

the lutidines determines the stereochemistry of the lupetidine products. The present invention is based on the discovery that significant economic advantages can be achieved using a mixture of these organic isomers having an enhanced *trans* content when used to synthesize SSZ-39. The present inventor has explored the influence of structural and diastereo-isomers of lupetidine-based OSDAs on the synthesis of SSZ-39

5 in order to exploit this discovery.

The 3,5-dimethyl-piperidine based SDA, referred to as 3,5-dimethyl-N,N-dimethylpiperidinium, has the following structures for the *cis* and *trans* isomers:



10 in which the two methyl groups on the six-membered ring may be oriented *cis* or *trans* to each other, as shown. It is noted that the six-membered ring is not a flat, two-dimensional ring, but has a three-dimensional structure of its own, as known in the art.

The zeolite Cu-SSZ-39 has been shown to be a promising catalyst for selective catalytic reduction (SCR) of nitrogen oxides in the tailpipes of diesel-fueled internal combustion engines. However, the parent zeolite H-SSZ-39 is difficult to synthesize and most of the reported recipes require many days and result in a relatively low yield of product. However the cost of its structure directing agent (SDA) is lower than the current industrially produced SCR catalyst (Cu-SSZ-13), and its thermal stability under SCR conditions is better. The cheapest and most widely available SDA for H-SSZ-39 is N,N-

15 dimethyl-3,5-lupetidinium hydroxide (lupetidine = dimethylpiperidine). It is derived from 3,5-lupetidine, and is commercially available as a 82/18 mixture of its *cis* and *trans*

20 isomers. The compound that is commercially available from other sources may have a

slightly different mixture of the *cis* and *trans* isomers. In one embodiment, the commercially available N,N-dimethyl-3,5-lupetidinium compound contains a ratio of the *trans* isomer to the *cis* isomer in the range from about 15:85 to about 25:75.

5 The present inventor has discovered that, in one embodiment, by selective use of the *trans* isomer of 3,5-dimethyl-N,N-dimethylpiperidinium hydroxide, or of a mixture of *cis* and *trans* isomers with an enhanced content of the *trans* isomer, the time required to form desirable zeolites can be significantly reduced. In one embodiment, an improved zeolite product can be obtained by selective use of the *trans* isomer of 3,5-dimethyl-N,N-dimethylpiperidinium hydroxide, or of a mixture of *cis* and *trans* isomers with an
10 enhanced content of the *trans* isomer. In addition, in another embodiment, by use of the *trans* isomer or a mixture of *cis* and *trans* isomer with an enhanced *trans* content, the desirable zeolites can be produced in a higher yield. In addition, in another embodiment, by use of the *trans* isomer or a mixture of *cis* and *trans* isomer with an enhanced *trans* content, the desirable zeolites can be produced with better control of the ratio of silicon
15 (Si) to aluminum (Al) in the zeolite. In other embodiments, combinations of these benefits are obtained together. I.e., in one embodiment both a reduced reaction time and a higher yield are obtained. In one embodiment, both a reduced reaction time and better control of the Si/Al ratio are obtained. In one embodiment, both a higher yield and better control of the Si/Al ratio are obtained. In one embodiment, all of a reduced
20 reaction time, a higher yield and better control of the Si/Al ratio are obtained.

Higher levels of the *trans* isomer can be produced at a modest increase in cost, by using specialized hydrogenation methods. In the following embodiment, it is demonstrated that H-SSZ-39 synthesis in the presence of enhanced concentrations of the *trans* isomer improve the kinetics and yield of H-SSZ-39, thereby reducing its cost of
25 manufacture. There is also evidence the Si/Al ratio of the product is increased, which imparts increased longevity as an SCR catalyst.

In one embodiment, the present invention relates to a method of preparing a zeolite, comprising:

providing a structure-directing agent comprising a first mixture of *cis* isomer and *trans* isomer of 3,5-dimethyl-N,N-dimethylpiperidinium cation;

5 treating the first mixture of the *cis* isomer and the *trans* isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation to obtain a second mixture of the *cis* isomer and the *trans* isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation having an increased content of the *trans* isomer;

10 contacting under crystallization conditions an intermediate mixture comprising sources of oxides of silicon and of aluminum and a structure-directing agent comprising the second mixture of the *cis* isomer and the *trans* isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation; and

calcining the intermediate mixture to form a zeolite.

In another embodiment, the present invention relates to a method of preparing a crystalline material comprising oxides of silicon and of aluminum and having, after calcination, a zeolite structure, said method comprising:

15 providing a structure-directing agent comprising a first mixture of *cis* isomer and *trans* isomer of 3,5-dimethyl-N,N-dimethylpiperidinium cation;

20 treating the first mixture of the *cis* isomer and the *trans* isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation to obtain a second mixture of the *cis* isomer and the *trans* isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation having an enhanced content of the *trans* isomer;

contacting under crystallization conditions an intermediate mixture of the sources of oxides of silicon and of aluminum and a structure-directing agent comprising the second mixture of the *cis* isomer and the *trans* isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation; and

25 calcining the intermediate mixture to form the crystalline material having a zeolite structure.

In one embodiment, the present invention relates to a method of preparing a zeolite, comprising:

5 contacting under crystallization conditions an intermediate mixture of sources of oxides of silicon and of aluminum and a structure-directing agent comprising a mixture of *cis* isomer and *trans* isomer of 3,5-dimethyl-N,N-dimethylpiperidinium cation wherein the mixture comprises an increased content of the *trans* isomer relative to a commercially available mixture of the *cis* isomer and the *trans* isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation,

10 wherein the commercially available mixture contains a ratio of the *trans* isomer to the *cis* isomer in the range from about 15:85 to about 25:75; and

 calcining the intermediate mixture to form a zeolite.

In another embodiment, the present invention relates to a method of preparing a crystalline material comprising oxides of silicon and of aluminum and having, after calcination, a zeolite structure, said method comprising:

15 contacting under crystallization conditions an intermediate mixture of sources of said oxides and an organic structure-directing agent comprising a mixture of *cis* isomer and *trans* isomer of 3,5-dimethyl-N,N-dimethylpiperidinium cation wherein the mixture comprises an increased content of the *trans* isomer relative to a commercially available mixture of the *cis* isomer and the *trans* isomer of the 3,5-dimethyl-N,N-
20 dimethylpiperidinium cation,

 wherein the commercially available mixture contains a ratio of the *trans* isomer to the *cis* isomer in the range from about 15:85 to about 25:75; and

 calcining the intermediate mixture to form the crystalline material having a zeolite structure.

25 In one embodiment, the present invention relates to a method of preparing a zeolite, comprising:

providing a precursor to 3,5-dimethyl-N,N-dimethylpiperidinium cation;

treating the precursor to provide an intermediate that, when subsequently treated to form the 3,5-dimethyl-N,N-dimethylpiperidinium cation, has a content of *trans* isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation in a ratio of about 1:3 or higher to
5 *cis* isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation;

contacting under crystallization conditions an intermediate mixture of sources of oxides of silicon and of aluminum and a structure-directing agent comprising the 3,5-dimethyl-N,N-dimethylpiperidinium cation having the content of the *trans* isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation in the ratio of about 1:3 or higher to the *cis*
10 isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation; and

calcining the intermediate mixture to form a zeolite.

In another embodiment, the present invention relates to a method of preparing a crystalline material comprising oxides of silicon and of aluminum and having, after calcination, a zeolite structure, said method comprising:

15 providing a precursor to 3,5-dimethyl-N,N-dimethylpiperidinium cation;

treating the precursor to provide an intermediate that, when subsequently treated to form the 3,5-dimethyl-N,N-dimethylpiperidinium cation, has a content of *trans* isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation in a ratio of about 1:3 or higher to
cis isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation;

20 contacting under crystallization conditions an intermediate mixture of the sources of oxides of silicon and of aluminum and a structure-directing agent comprising the 3,5-dimethyl-N,N-dimethylpiperidinium cation having a content of the *trans* isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation in a ratio of about 1:3 or higher to the *cis* isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation; and

25 calcining the intermediate mixture to form the crystalline material having a zeolite structure.

In one embodiment, the zeolite is SSZ-39. In one embodiment, the crystalline material is SSZ-39.

In one embodiment, the treating comprises separating the *cis* isomer and the *trans* isomer.

5 In one embodiment, the 3,5-dimethyl-N,N-dimethylpiperidinium cation is paired with a hydroxide anion.

In one embodiment, the precursor is 3,5-dimethyl pyridine, or N-methyl-3,5-dimethylpiperidene, or 3,5-dimethylpiperidine.

10 In one embodiment, the treating comprises one or more of chemical reduction, non-catalytic hydrogenation (e.g., using NaH, NaBH₄, formic acid, etc.), catalytic hydrogenation in the absence of water, selective crystallization, and distillation.

The commercially available 3,5-dimethyl-N,N-dimethylpiperidinium hydroxide or salt contains about 80% *cis* isomer.

15 In one embodiment the ratio of the *trans* isomer to the *cis* isomer in the *trans*-enhanced material is at least 30:70. In one embodiment, the ratio of the *trans* isomer to the *cis* isomer in the *trans*-enhanced material is at least 40:60. In one embodiment, the ratio of the *trans* isomer to the *cis* isomer in the *trans*-enhanced material in the *trans*-enhanced material is at least 60:40. In one embodiment, the ratio of the *trans* isomer to the *cis* isomer in the *trans*-enhanced material is about 77:23, in one embodiment, about
20 80:20, and in another embodiment, the ratio of the *trans* isomer to the *cis* isomer in the *trans*-enhanced material is in the range from about 50:50 to about 80:20. In general, the higher the *trans* content, the faster the reaction proceeds, the higher the yield of zeolite product, e.g., SSZ-39, and the better the control of the content of aluminum in the zeolite product.

Brief Description of the Drawings

FIG. 1 is an X-ray diffraction scan for a product made in accordance with an embodiment of the present invention containing about 77% *trans* isomer of the OSDA.

5 FIG. 2 is an X-ray diffraction scan for a product made in accordance with an embodiment of the present invention containing about 28% *trans* isomer of the OSDA.

FIG. 3 is an X-ray diffraction scan for a product made in accordance with the prior art, containing about 14% *trans* isomer of the OSDA.

10 FIG. 4 is a series of PXRD scans of Si/Al=15 derived zeolites containing both SSZ-39 as the major phase, and a trace of the aluminosilicate gismondine, as that zeolite is washed with acid to remove the gismondine phase.

FIG. 5 is a ^{13}C CP-MAS solid state NMR on as-made samples of SSZ-39 that can distinguish the *cis* from the *trans* isomer occluded in the cages of the SSZ-39.

FIG. 6 is a graph showing the kinetics of SSZ-39 synthesis with different OSDA isomer ratios, based on the FAU reagent and AEI product reflections in PXRD.

15 FIG. 7A is the ^{27}Al MAS NMR of calcined SSZ-39s made with different isomer OSDA mixtures.

FIG. 7B shows the N_2 -physisorption isotherms and micropore volume from t-plot analyses (H^+ -form).

20 It should be appreciated that the process steps and structures described herein may not provide a complete system or process flow for carrying out a process for preparing a zeolite or crystalline material containing oxides of silicon and aluminum and having, after calcination, a zeolite structure, such as would be used in a commercial process for making these products. The present invention may be practiced in conjunction with techniques and apparatus currently used in the art, and only so much

of the commonly practiced materials, apparatus and process steps are included as are necessary for an understanding of the present invention.

Detailed Description

5 In accordance with the present invention, a method of preparing a crystalline material having a zeolite structure, i.e., a zeolite, is provided, in which as a result of the organic structure-directing agent prepared in accordance with the present invention, the method is improved in one or more of speed, cost, efficiency, product yield, control of aluminum content and/or the Al/Si ratio, and selectability of pore size of the resulting
10 zeolite. In various embodiments, each one of these improved characteristics is found, alone or in any combination.

 In one embodiment, separation of *trans* and *cis* isomers can be done on the final product salt, the secondary amine or the tertiary amine intermediate: N-methyl-3,5-dimethylpiperidine. In one embodiment, the separation is carried out by distillation and
15 in another embodiment, by crystallization. Any known method for separating *trans* and *cis* isomers may be suitable, including but not limited to those briefly discussed below. In one embodiment the tertiary amine intermediate may be purchased from commercial sources, rather than starting with 3,5 dimethyl piperidene.

 In one embodiment, the hydrogenation of 3,5-dimethylpyridine is carried out in
20 the absence of water, with a suitable catalyst that favors formation of the *trans* isomer. It is considered that the presence of water favors formation of the *cis* isomer. In one embodiment, the reduction of 3,5-dimethylpyridine is carried out chemically, e.g., by use of sodium borohydride, lithium aluminum hydride, sodium hydride or formic acid. It is considered that use of a heterogeneous catalyst may result in formation of more of the
25 *cis* isomer, contrary to the intent of the present invention.

 In one embodiment, the ratio of the *cis* and *trans* isomers of the 3,5-dimethyl-N,N-dimethylpiperidinium cation is controlled by selective precipitation of one of the

isomers, and preferential isolation and purification of the *trans* isomer, or of a composition containing an increased content of the *trans* isomer, which is subsequently paired with a hydroxide anion.

In one embodiment, the ratio of the *cis* and *trans* isomers of the 3,5-dimethyl-N,N-dimethylpiperidinium cation is controlled by selective isolation of 3,5-piperidene following hydrogenation of 3,5-pyridine, and subsequent methylation of the 3,5-piperidene to form the 3,5-dimethyl-N,N-dimethylpiperidinium cation, which is subsequently paired with a hydroxide anion.

Methods of separating the *cis* and *trans* isomers are set forth in the following, which is adapted from Ireland Patent No. IE20040197.

The methods disclosed in the art for separating a compound from the mixture of its isomers include preferential salt formation, but this can be expensive and time consuming. It is therefore, important to devise a method for separating *trans*-3,5-dimethylpiperidine from a mixture of its geometrical isomers in an economical and time-efficient manner.

In one embodiment, separation of *trans*-3,5-dimethylpiperidine from commercially available 4:1 mixture of *cis:trans*-3,5-dimethylpiperidine involves a multi-step process that includes heating, filtration, extraction, crystallization and drying.

In one embodiment, a process is provided having a single step and highly selective process for the separation of *trans*-3,5-dimethylpiperidine from a mixture of *cis:trans*-3,5-dimethylpiperidine.

U.S. Patent No. 4,138,399 to Holland et al., which may be referred to for more detailed information, beginning at column 11, line 55, discloses the preparation of *cis*-3,5-dimethylpiperidine hydrochloride from 3,5-lutidine by hydrogenation under 1000 psi hydrogen pressure in ethanol using 5% rhodium on carbon as catalyst at room temperature. In this method, organic solvents like hexane and chloroform are used for

the further extraction and purification of the product. The product contains approximately 78% *cis* and 22% *trans* isomers.

U.S. Patent No. 4,820,695 to Debono et al. and U.S. Patent No. 4,920,103 to Krist et al., which may be referred to for more information, disclose methods of purification of *cis*-3,5-dimethylpiperidine. In one method, in Example 39, the Debono patent discloses the addition of *o*-chlorobenzoyl chloride to a solution containing 3,5-dimethylpiperidine, triethylamine and dichloromethane. The use of hexane and dichloromethane is disclosed to further recrystallize the product to obtain pure *cis*-amide, and pure *cis*-3,5-dimethylpiperidine is obtained by further refluxing the amide in ethylene glycol and potassium hydroxide and then distilling and collecting the fraction boiling between 100°C and 195°C.

An alternate method of purification of *cis*-3,5-dimethylpiperidine described in the above-mentioned Krist patent, beginning at column 14, line 33, discloses the preparation of the hydrochloride salt by bubbling HCl gas through the solution of commercial grade 3,5-dimethylpiperidine and anhydrous ether. The salt is further treated, employing acetone and diethyl ether to yield *cis*-3, 5-dimethylpiperidine, contaminated with $\leq$ 5% of the *trans* isomer.

There are numerous prior art disclosures revealing the commercial use of *cis* 3,5-dimethylpiperidine, which include U.S. Patent No. 4,713,379; U.S. Patent No. 4,755,521, U.S. Patent No. 4,826,857, U.S. Patent No. 4,904,656, U.S. Patent No. 4,615,725, U.S. Patent No. 5,177,103, U.S. Patent No. 5,571,930, U.S. Patent No. 4,820,694 and U.S. Patent No. 6,187, 777, each of which may be consulted for additional information.

Although certain of the foregoing references provide for obtaining an enhanced or increased content of the *cis* isomer, it will be understood by those skilled in the art that by isolating one isomer, the other isomer is necessarily also separated and can be isolated. Thus, if one removes the *trans* isomer in an effort to obtain the *cis* isomer, one has necessarily separated the *trans* isomer. In the present invention, the *trans* isomer is

the sought isomer, and the invention relates to the use of an organic structure-directing agent containing an increased content of the *trans* isomer relative to the *cis* isomer, when compared to the commercially available material.

5 The present invention provides a method for separating a compound from a mixture of its geometrical isomers, wherein the compound being separated is *trans*-3,5-dimethylpiperidine and the mixture from which the compound being separated is a mixture of *cis:trans*-3,5-dimethylpiperidine.

10 In accordance with one embodiment of the present invention, disclosed herein is a single step process for separating *cis*-3,5-dimethylpiperidine from a mixture of *cis*- and *trans*-3,5-dimethylpiperidine wherein no organic solvent is used.

15 In accordance with another embodiment of the present invention, disclosed herein is a single step process for separating *cis*-3,5-dimethylpiperidine from a mixture of *cis*- and *trans*-3,5-dimethylpiperidine wherein the process comprises hydrogenation of 3,5-lutidine in the presence of water and 5% ruthenium on alumina catalyst at high temperature and pressure.

20 In accordance with yet another embodiment of the present invention, disclosed herein is a single step process for separating *cis*-3,5-dimethylpiperidine from a mixture of *cis*- and *trans*-3,5-dimethylpiperidine, wherein water present in the reaction process favors the *cis*-isomer formation and removes predominantly *trans*-isomer during the fractional separation.

25 In accordance with still another embodiment of the present invention, disclosed herein is a method of producing the pure form of *cis*-3,5-dimethylpiperidine wherein the method comprises a single step separation process to separate *cis*-3,5-dimethylpiperidine from a mixture of *cis*- and *trans*-3,5-dimethylpiperidine by hydrogenating 3,5-lutidine in the presence of water and 5% ruthenium on alumina catalyst at high temperature and pressure and decanting the crude product from the catalyst, recycling the catalyst in batches, carrying out fractional distillation of the crude mass to remove *trans*-isomer of 3,5-dimethylpiperidine as an azeotrope with water,

recycling the aqueous phase in the crude and distillation of pure *cis*-3,5-dimethylpiperidine.

In accordance with yet another embodiment of the present invention, disclosed herein is a single step process for separating *cis*-3,5-dimethylpiperidine from a mixture of *cis*- and *trans*-3,5-dimethylpiperidine, wherein the process comprises hydrogenation of 3,5-lutidine in the presence of water ranging from 10-60% by weight ratio of the base, at temperature ranging from 180-220°C, pressure ranging from 30 to 60 Kg/cm², decanting the crude product from the catalyst; recycling the catalyst in batches for 5 to 20 times, carrying out fractional distillation of the crude mass to remove *trans*-isomer of 3,5-dimethylpiperidine as an azeotrope with water, recycling the aqueous phase in the crude and distillation of pure *cis*-3,5-dimethylpiperidine with 5% *trans*-isomer.

In accordance with still another embodiment of the present invention, disclosed herein is a single step separation process for the separation of *cis*-3,5-dimethylpiperidine from a mixture of *cis*- and *trans*-3,5-dimethylpiperidine, wherein the process comprises, hydrogenation of 3,5-lutidine in the presence of water and ruthenium on alumina catalyst at 180 to 200°C.

In accordance with yet another embodiment of the present invention, disclosed herein is a single step separation process for the separation of *cis*-3,5-dimethylpiperidine from a mixture of *cis*- and *trans*-3,5-dimethylpiperidine, wherein the process comprises, hydrogenation of 3,5-lutidine in the presence of water and ruthenium on alumina catalyst, wherein the catalyst is about 0.3-2% with respect to 3,5-lutidine.

In accordance with still another embodiment of the present invention, disclosed herein is a single step separation process, wherein the process comprises, hydrogenation of 3,5-lutidine in the presence of water and ruthenium on alumina catalyst, wherein the catalyst is about 0.5-1% with respect to 3,5-lutidine.

In accordance with yet another embodiment of the present invention, disclosed herein is a single step separation process, wherein the process comprises,

hydrogenation of 3,5-lutidine in the presence of water and ruthenium on alumina catalyst, wherein the quantity of water is 10 to 60% of 3,5-lutidine.

In accordance with another embodiment of the present invention, disclosed herein is a single step separation process, wherein the process comprises,

5 hydrogenation of 3,5-lutidine in the presence of water and ruthenium on alumina catalyst, wherein the quantity of water is 20 to 50% of 3,5-lutidine.

In accordance with yet another embodiment of the present invention, disclosed herein is a single step separation process, wherein the process comprises,

10 hydrogenation of 3,5-lutidine in the presence of water and ruthenium on alumina catalyst, wherein the pressure is about 30 to 100 kg/cm², preferably 40 to 70 kg/cm².

In accordance with another embodiment of the present invention, disclosed herein is a process, wherein the process comprises hydrogenation of 3,5-lutidine in presence of a catalyst, wherein the catalyst can be recyclable for 5-20 times.

The disclosed embodiments deal with processes for the separation of *cis*-3,5-dimethylpiperidine from a mixture of *cis:trans*-3,5-dimethylpiperidine.

The present disclosure provides single step and highly selective process for the separation of *cis*-3,5-dimethylpiperidine from a mixture of *cis:trans*-3,5-dimethylpiperidine without employing any organic solvent.

The dimethylpiperidine containing an enhanced content of the *trans*- isomer, obtained by any of the foregoing methods, is first quaternized by the addition of two methyl groups to the ring N atom, then the resulting quaternary ammonium salt is converted to the quaternary ammonium hydroxide by an appropriate hydrolysis, electrolysis or ion exchange, and then this cyclic quaternary ammonium species is used as the OSDA in forming zeolites, such as that known as SSZ-39. As described in US
20 5958370, the OSDA of the present invention, i.e, dimethylpiperidine containing an
25 enhanced content of the *trans*- isomer, following its quaternization and conversion to

hydroxide form, is used as the cyclic quaternary ammonium cation crystallization template.

As known in the art, Cu containing zeolites with small pore sizes, such as SSZ-39 (AEI), are very active for the SCR of NO_x. Thus, in order to prepare these Cu-containing SSZ-39, Cu²⁺ species are introduced into calcined samples zeolites in the H form. Since Al species that remain in tetrahedral coordination after the calcination procedures generate negative charges in the zeolitic framework, Cu²⁺ species can be introduced by a post-synthesis cation exchange procedure to replace the H⁺ within the calcined SSZ-39 materials, using, for example, an aqueous solution of Cu(CH₃COO)₂. Chemical analyses indicate that the metal content introduced is about 4.7 wt.% for Cu-N-SSZ-39. As is also known in the art, Fe and V may be substituted for the Cu in the zeolite when used for SCR of NO_x.

EXPERIMENTAL SECTION

The organics are available from SACHEM Inc. in either chloride or hydroxide form. Hydroxide ion exchanges are performed using Dowex® Marathon A (OH-) exchange resin. Titrations are performed using a Mettler-Toledo® DL22 autotitrator using 0.01 M HCl as the titrant. ¹³C-CP solid state NMR spectra are recorded on a Bruker® 500 Mhz spectrometer with a 4 mm rotor at spinning rate of 10 kHz, referenced to adamantane as an external standard. Solid-state ²⁷Al MAS NMR spectra are acquired on a Bruker® AM 300 MHz spectrometer operated at 78.2 MHz using a 90° pulse length of 2 μs and a cycle delay time of 1 s. Samples are loaded in a 4 mm ZrO₂ rotor and spun at 12 kHz. Chemical shifts are referenced to 1 M aqueous aluminum nitrate solution. Before measurement, samples are hydrated overnight over a saturated KCl solution. Thermogravimetric analysis is performed on a Perkin Elmer® STA 6000 with a ramp of 10 °C.min⁻¹ to 900 °C under air atmosphere. Scanning electron microscopy (SEM) is performed on as-synthesized (washed and dried at 100 °C)

samples with a ZEISS® 1550 VP FESEM, equipped with an Oxford X-Max SDD X-ray Energy Dispersive Spectrometer (EDS) system for determining the Si/Al ratios of the samples. The calcination of SSZ-39 is performed in dry flowing air by heating to 150°C at 1 °C.min⁻¹; holding for 3 h at 150 °C, and then heated further to 580°C at 1°C.min⁻¹ and held for 6 h. All powder x-ray diffraction (PXRD) characterization is conducted on a Rigaku® MiniFlex II with Cu K α radiation. Elemental analysis of calcined zeolite samples is performed by Galbraith Labs (Knoxville, TN). All N₂ adsorption isotherms are performed at -196 °C with a Quantachrome® Autosorb iQ instrument. Prior to analysis, the samples are outgassed under vacuum at 350 °C. The t-plot method is used to calculate the micropore volumes on the adsorption branch. For analyzing the organic occluded in the zeolite, the latter is completely dissolved in a 50wt% HF solution. After neutralization with KOH (exothermic process, cooling required), the solution is dried under a stream of air to remove excess water and then the solids are dried under vacuum at room temperature. Then, CDCl₃ is added to dissolve the extracted organic and the isomers are analyzed by ¹H NMR (quantification) and ¹³C NMR.

A general procedure for hydroxide mediated zeolite syntheses is as follows. The organic SDA in its hydroxide form is combined with additional base (1N NaOH, RT Baker) and water in a 23 mL-Teflon Parr reactor. Then a silicon source is added (N^o Sodium silicate (PQ Corporation) or Ludox AS-40) as well as an aluminum source (for example, CBV500, a NH₄-USY zeolite with Si/Al of 2.6 from Zeolyst Corp.). The synthesis gel is then manually stirred with a spatula until a homogenous white gel is obtained. The Teflon Parr reactor is then sealed and placed in a rotating (spinning at 63 rpm) or static oven at temperatures ranging from 125 to 140°C. Alternatively, tetraethylorthosilicate (TEOS) is used as the source of silica. TEOS is combined with the additional base source (1N NaOH) in a 23 mL-Teflon Parr reactor, closed and stirred overnight at room temperature to allow for complete hydrolysis. The lid is then removed and the organic SDA in its hydroxide form as well as the aluminum source (CBV500) are added and stirred till a homogeneous gel is attained. The lid is then removed and ethanol and the appropriate amount of water are allowed to evaporate

under a stream of air. It is assumed that all the ethanol evaporates along with the water. Once the appropriate mass is reached, the Teflon Parr reactor is sealed and placed in a rotating oven at 140 °C. Aliquots of the synthesis gels are taken periodically as follows: quenching the reactor in water, opening the reactor, stirring its contents till

- 5 homogeneous, and finally removing enough material for PXRD. After washing the aliquots once with water and once with acetone, with intermittent centrifugation, they are left to dry in a 100°C oven before PXRD measurement. After total synthesis time, the zeolites are collected by centrifugation, washed 3 times with water and once with acetone, with intermittent centrifugation, and then left to dry overnight at 100 °C. The
- 10 yields are calculated as follows: the oven-dry zeolite weight obtained is corrected with the weight loss of organic SDA and water in TGA up to 900 °C (15 - 18% in a typical synthesis). This corrected weight is assumed to be pure aluminosilicate and is divided by the maximum theoretical oxide ($\text{SiO}_2 + \text{AlO}_2$) formation based on the input silicon and aluminum. The weight of sodium present in the samples is hereby neglected. The
- 15 weight loss in TGA between 300 and 900 °C is considered to be due to the loss of incorporated OSDA (amine form).

- Another method for forming the OSDA N, N-dimethyl-3, 5-dimethylpiperidinium is as follows. 10 g of 3,5-dimethylpiperidine having the desired enhanced *trans*- isomer content, is mixed with 140 mL of methanol and 19.51 g of potassium carbonate
- 20 (KHCO_3). While this mixture is stirred, 54 g of methyl iodide is added dropwise. The reaction is stirred for about 7 days. After this time, MeOH is partially removed under vacuum, and the iodide salt is precipitated by addition of diethyl ether. For its use in the synthesis of zeolites, the final product may be ion exchanged to the hydroxide form using a commercially available hydroxide ion exchange resin, e.g., Dowex® SBR.
- 25 Instead of ion exchange, electrolytic methods such as those used by Sachem, Inc. may be employed. See. e.g., U.S. Patent Nos. 5,389,211, 5,575,901, 5,753,097.

RESULTS AND DISCUSSION

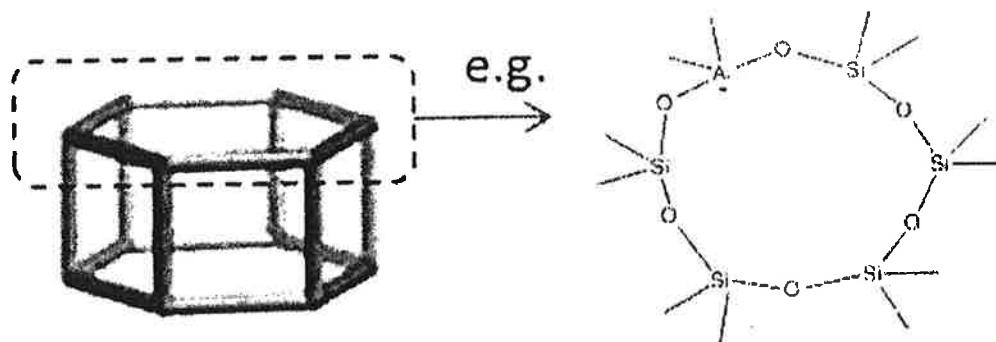
General SSZ-39 synthesis considerations

In order to assess the influence of the isomeric forms of the common lupetidines and the possibility of using mixtures of isomeric OSDAs, a standard SSZ-39 recipe was needed. Zones, in US 5958370, reported the first synthesis of SSZ-39 in hydroxide mediated syntheses. Procedures listed in the patent demonstrate the use of sodium silicate and a zeolite of the FAU topology (USY) as the respective silica and alumina sources. The reported results showed successful syntheses of SSZ-39 with 13 different OSDAs from gels with Si/Al ratios around 15. They also showed that a gel with Si/Al of 50 led to SSZ-39 (with Si/Al ratio of 25). Besides other FAU zeolites, no other sources were presented in this study. Later, Wagner *et al.* elucidated the structure of SSZ-39 and showed that it is the aluminosilicate analogue of SAPO-18 with the AEI framework topology. Wagner *et al.* reported successful SSZ-39 syntheses from gels with a Si/Al ratio of 15, in analogy to the original patent, whereas attempts to make SSZ-39 in gels with Si/Al ratios of 20 and higher resulted in other phases such as MFI and MTW.

Recently, Moliner *et al.* reported similar results, confirming the fact that sodium silicate (Na_2SiO_3) and FAU precursors in gels with Si/Al ratios 15 and 30 lead to SSZ-39, whereas other sources of inorganics do not lead to SSZ-39. The OSDA used in the latter study was N,N-dimethyl-3,5-lupetidinium, but the *cis:trans* ratio of the organic was not reported. In addition to these hydroxide syntheses, Cao *et al.* disclosed a fluoride-mediated route towards high-silica SSZ-39. Using N,N-diethyl-2,6-lupetidinium as the SDA, these low-water syntheses are reported to produce SSZ-39 with Si/Al ratios of over 50.

Based on this literature overview, a wide screening of common procedures and sources of inorganics was carried out using *cis*-N,N-dimethyl-3,5-lupetidinium (*cis*-3,5) as the SDA over a range of Si/Al ratios. In line with literature data, initially only sodium silicate and FAU as inorganic sources yielded SSZ-39. Other recipes, consistent with those reported by Wagner *et al.*, led to SSZ-36 or pentasil type zeolites (e.g., MFI). Sodium silicate is a monomolecular Si source, unlike colloidal Si gels and aerosils. To see whether a monomolecular source of Si is vital, TEOS and colloidal Si were used instead of sodium silicate with the FAU aluminum source. From the results, it is clear

that SSZ-39 can be prepared using monomolecular TEOS and colloidal Si as well, but the latter led to the co-formation of a major impurity, analcime (ANA). The FAU Al source on the other hand is more crucial, as no synthesis was found successful without its presence. Remarkably, both AEI and FAU frameworks can be entirely built using
 5 only the double six-ring composite building unit d6r, shown here:



Interestingly, a hydrothermal *transformation* of FAU into AEI zeolites was recently reported, using tetraethylphosphonium cations. In general, an optimal gel compositional range was found to be $1\text{Si}:0.033\text{-}0.066\text{Al}:0.07\text{-}0.14\text{OSDA}:0.65\text{-}0.71\text{OH}^-:0.51\text{-}$

10 $0.58\text{Na}^+:20\text{-}30\text{H}_2\text{O}$, with OH^- being the sum of the NaOH and OSDA(OH^-) contents.

Another method of synthesizing SSZ-39 zeolite, reported by N. Martin, et al., Chem. Comm., 2015, 51, 11030-11033 (published 02 June 2015), is as follows. First the OSDA N,N-dimethyl-3,5-dimethylpiperidinium hydroxide is mixed with a 20% wt aqueous solution of sodium hydroxide. Then, the crystals of USY zeolite (CBV-720 with
 15 $\text{SiO}_2/\text{Al}_2\text{O}_3=21$) are introduced in this solution. The mixture is stirred until complete homogenization of the gel. The chemical composition of the synthesis gel is about $\text{SiO}_2/0.045\text{Al}_2\text{O}_3/0.2\text{NaOH}/0.2\text{OSDA}/15\text{H}_2\text{O}$. The resultant gel was transferred into a stainless steel autoclave with a Teflon liner. The crystallization is then conducted at 135°C for 7 days under static conditions. The solid product is filtered, washed with water
 20 and dried at 100°C . Finally, the sample is calcined in air at 550°C for 4h.

The following information on a process for forming SSZ-39 is taken from U.S. Patent No. 5,958,370.

Typical sources of aluminum oxide for the reaction mixture include aluminates, alumina, aluminum colloids, aluminum oxide coated on silica sol, hydrated alumina gels
5 such as $\text{Al}(\text{OH})_3$ and aluminum compounds such as AlCl_3 and $\text{Al}_2(\text{SO}_4)_3$.

Typical sources of silicon oxide include silicates, silica hydrogel, silicic acid, fumed silica, colloidal silica, tetra-alkyl orthosilicates, and silica hydroxides. Boron, as well as gallium, germanium, titanium, indium, vanadium and iron, can be added in forms corresponding to their aluminum and silicon counterparts. However, SSZ-39 contains
10 only Si and Al.

Typically, an alkali metal hydroxide and/or an alkaline earth metal hydroxide, such as the hydroxide of sodium, potassium, lithium, cesium, rubidium, calcium, and magnesium, is used in the reaction mixture; however, this component can be omitted so long as the equivalent basicity is maintained. In one embodiment, the alkali metal or
15 alkaline earth metal hydroxides may be replaced by an organic base, such as tetramethyl ammonium hydroxide, or another tetra-alkyl ammonium hydroxide known in the art. The OSDA may be used to provide hydroxide ion. Thus, it may be beneficial to ion exchange, for example, the halide for hydroxide ion, thereby reducing or eliminating the alkali metal hydroxide quantity required. When the alkali metal hydroxide and/or the
20 alkaline earth metal hydroxide is used, the alkali metal cation or alkaline earth cation may be part of the as-synthesized crystalline oxide material, in order to balance valence electron charges therein. This can be replaced by either H or, for example, Cu^{2+} , to form the desired product Cu-SSZ-39.

The reaction mixture is maintained at an elevated temperature until the crystals
25 of the SSZ-39 zeolite are formed, using mild stirring or agitation. The hydrothermal crystallization is usually conducted under autogenous pressure, at a temperature between 100°C . and 200°C ., preferably between 135°C . and 160°C . The crystallization period is typically about 3 days. However, as noted herein, one of the benefits of the

present invention is that by use of the enhanced *trans*- content the reaction time can be significantly reduced, e.g., from 3 days to 2 days, which is a very significant improvement.

During the hydrothermal crystallization step, the SSZ-39 crystals can be allowed
5 to nucleate spontaneously from the reaction mixture. The use of SSZ-39 crystals as seed material can be advantageous in decreasing the time necessary for complete crystallization to occur. In addition, seeding can lead to an increased purity of the product obtained by promoting the nucleation and/or formation of SSZ-39 over any undesired phases. When used as seeds, SSZ-39 crystals are added in an amount
10 between 0.1 and 10% of the weight of silica used in the reaction mixture.

Once the zeolite crystals have formed, the solid product is separated from the reaction mixture by standard mechanical separation techniques such as filtration. The crystals are water-washed and then dried, e.g., at 90°C. to 150°C. for from 8 to 24 hours, to obtain the as-synthesized SSZ-39 zeolite crystals. The drying step can be
15 performed at atmospheric pressure or under vacuum.

Influence of *cis/trans* isomer

The hydrogenation of the commercially relevant 3,5-lutidine leads to diastereomeric 3,5-lupetidine mixtures containing both the *cis* and *trans*-form depending on the catalysts used. Using metallic Pt and H₂ will lead to a product mixture with an
20 80/20 *cis/trans* isomer ratio, whereas under certain conditions, Raney Nickel catalysts produce mixtures of 25/75 *cis/trans* composition. If the amine is methylated before hydrogenation, pure *cis*-N-methyl-3,5-lupetidine can be synthesized with Pt catalysts. By preparing a nearly pure *cis*-3,5 isomer, along with an equimolar mixture, the isomeric range between 48/52 and 98/2 (*cis*-3,5/*trans*-3,5) could be assessed. This range is in
25 line with the production of these isomers, as it is very difficult to produce the pure *trans*-isomer. The influence of diastereo-isomer ratio on the synthesis of SSZ-39 is illustrated by the data shown in Table I where different isomeric mixtures of quaternized N,N-

dimethyl-3,5-lupetidinium hydroxide are employed OSDAs in two sets of gels with different Si/Al ratios (15 and 30).

Table I. Hydroxide syntheses with mixtures of *cis* and *trans*-N,N-dimethyl-3,5-lupetidinium hydroxide using sodium silicate as silica and NH₄-FAU as alumina sources. gel composition relative to Si1

Entry	Al	<i>cis</i> -3,5	<i>trans</i> -3,5	NaOH	<i>cis/trans</i> 2	time (days)	phase	Si/Al	TGA3	Yield
1	0.033	0.137	0.003	0.57	98/2	3	SSZ-39	7.6	19.2%	19%
2	0.033	0.067	0.073	0.57	48/52	3	SSZ-39	8.4	19.7%	19%

Entries 1 and 2 in Table I, for Si/Al ratios of 30, reveal no significant influence of the diastereo-isomer ratio of the 3,5-isomer on the preparation of SSZ-39: the produced-phase, pure SSZ-39, is identical in each run, as demonstrated by PXRD in Fig. 1 (Trace I.1 and II.2). Additionally, the phase, yield and synthesis time (kinetics) appear unaffected as well since both syntheses finished in 3 days (based on the absence of reflections of the FAU source in PXRD). Further characterizations of the produced solids were performed by TGA and SEM/EDS analyses. The Si/Al ratios of both SSZ-39 solids were found to be near 8, in line with Moliner et al., and the total amount of incorporated OSDAs were around 20% (ca. filling of 1 organic molecule per cage of the structure or 4 OSDA molecules per unit cell). The product Si/Al values (8) differ distinctly from the ratios in the gels (30). This result suggests an explanation for the low product yields (20%). Due to the formation of Al-rich SSZ-39, the gel becomes deficient in Al at some point in the synthesis, and a large fraction of dissolved Si remains unused. Additionally, the SSZ-39 morphologies are similar and closely resemble those reported previously. Some clear differences however exist between these syntheses and the ones with Si/Al ratios of 30 in the gel. First, the Si/Al ratios of the products from Si/Al=15 gels are found to be around 6. Although lower than the values obtained from more Al-deficient gels, the product ratios are diverging less from the ratio in the gels (6 to 15 versus 8 to 30) and explain the higher yields from Si/Al=15 gels. Secondly, a closer examination of the PXRDs of the Si/Al=15 derived zeolites reveals SSZ-39 as the major phase, but with a trace of the aluminosilicate gismondine

(GIS), e.g., the reflection at $2\theta = 12.4$. The origin of this impurity is attributed to the inorganic structure directing nature of the sodium- and hydroxide-rich gel. For catalytic applications, the presence of trace impurity phases can be a problem. In an effort to remove the impurities, we found that the as-synthesized SSZ-39 could be easily be

5 purified by contacting it with a 1 M HCl solution at 100 °C for only 1 h (no stirring, 10 gram of zeolite per liter). This conclusion is evidenced by data shown in FIG. 4 that are from the solids obtained before and after contacting with HCl. This simple treatment completely dissolves the GIS phase. To further verify this result and to estimate the amount of impurity in the as-made SSZ-39, we made a pure GIS zeolite in presence of

10 the *cis*-3,5 isomer by using sodium aluminate. The PXRD of this zeolite can be seen in FIG. 4. TGA analysis of the 8MR GIS zeolite confirmed that virtually no organic was incorporated ($< 2\%$). The PXRD patterns of physical mixtures of GIS and pure SSZ-39 (the as-made zeolite of Table I.1), shown in FIG. 4, allowed us to roughly estimate the level of impurity in Si/Al=15-derived SSZ-39s to be on the order of 5 wt.% (based on

15 intensities of the $2\theta = 12.4$ region). Since GIS phases usually have a low Si/Al ratio, the bulk Si/Al ratio of the HCl-treated zeolite rose (from 6.2) to 7.5 as determined by EDS and confirmed by elemental analysis below.

The TGA results in Table I demonstrate that the same total amount of organic is incorporated in the SSZ-39s made with different isomer ratios. However, the stereo-

20 chemistry of the occluded organics in these solids may be different. To address this issue, the occluded organic content was analyzed. Remarkably, ^{13}C CP-MAS solid state NMR on as-made samples was able to distinguish the *cis* from the *trans* isomer occluded in the cages of SSZ-39, as shown in FIG. 5. While the NMR trace of SSZ-39 made with pure *cis*-3,5 displayed the 6 characteristic resonances related to the *cis*-3,5-

25 standard (not shown), the spectra of the SSZ-39 made with the 73/27 and the 48/52 *cis/trans*-3,5 mixture displayed resonances of both *cis* and *trans* isomers in SSZ-39. The relative integration of the 27 versus 25 ppm peak hinted to a preferential uptake of the *trans* isomer with respect to the ratio of the gel. However, due to the non-quantitative nature of CP-MAS NMR, the isomer ratio inside SSZ-39 is verified by

dissolving the as-made materials in HF, extracting the SDAs in CDCl_3 and analyzing them by ^1H -NMR. These isomer ratios are shown in grey above the CP-MAS traces in FIG. 5 and corroborate the preferential incorporation of the *trans* isomer. The 48/52 gel, for instance, produced SSZ-39 with a 29/71 *cis/trans* ratio. The assignments of the
 5 chemical shifts for both isomers were verified using liquid phase NMR and ^1H - ^{13}C -HSQC.

Although there is a preference for the incorporation of the *trans*-3,5 isomer, both isomer mixtures as well as nearly-pure *cis*-3,5 are able to produce SSZ-39. To further investigate this phenomenon, the kinetics at the early stages of SSZ-39 syntheses were
 10 studied by taking intermediate samples of syntheses with 98/2 and 48/52 *cis/trans*-3,5 isomeric ratios after 12h, 24 h and 36 h. Because the starting FAU source is still present in these samples, and visible in PXRD, the kinetics of SSZ-39 formation can be assessed by relative comparison of the intensities of the major reflection of AEI (9.5° 2θ) and FAU (6.3° 2θ), as shown in FIG. 6. FIG. 6 is a graph showing the kinetics of
 15 SSZ-39 synthesis with different OSDA isomer ratios (based on the FAU reagent and AEI product reflections in PXRD), with the conditions shown in Table I. A clear difference in the kinetics of zeolite formation is noted between the 48/52 mixture and the near pure *cis*-3,5 isomer, with the high-in-*trans* synthesis notably faster. However, by 3 days of synthesis time, the results from these syntheses are the same (Table 1). These
 20 initial kinetic data, together with the observed preferential incorporation, point to the fact that the presence of the *trans* isomer is a positive (at least faster) for SSZ-39 synthesis.

Characterization of SSZ-39 samples

We selected three SSZ-39 samples made with different OSDA mixtures and/or
 25 gel recipes for characterization. After calcination for removal of the organic, Al MAS-NMR and full elemental analysis was performed, as well as SEM for analyzing the crystallite morphologies. Additionally, after NH_4 -exchange and calcination, the

microporosity of the H-SSZ-39 solid was analyzed. FIG. 7 and Table II display an overview of these results.

Table II

Full elemental analysis after calcination				
Sample	Na	Si	Al	Si/Al
II.2	1.1	4.0	36.9	9.1
II.3	5.1	4.6	36.3	7.9
I.5 HCl treated	0.7	5.2	37.8	7.2

- 5 The pure SSZ-39s obtained from Si/Al=30 gels were selected for study, as the latter represents a pure *cis*-3,5 synthesis. The third sample assessed is the acid-treated version from Table I, derived from a mixed diastereo-isomer (50/50 *cis/trans*-3,5) synthesis with preferred *trans* uptake in a Si/Al=15 gel. FIG. 7A is the ^{27}Al MAS NMR of calcined SSZ-39s made with different isomer OSDA mixtures. The numbers correspond
- 10 to the entries in Tables I and II. FIG. 7B shows the N_2 -physisorption isotherms and micropore volume from t-plot analyses (H⁺-form). The Al NMR traces in FIG. 7A with dominating bands at 57 ppm show that nearly all of the aluminum is incorporated tetrahedrally into the framework. The elemental analyses in Table II confirm the Si/Al ratios as measured by EDS. The Na/Al ratios are around 0.3 for both entries II.2 and
- 15 II.3, but much lower for the acid washed material.

This is caused by the HCl-mediated exchange of some of the Na cations for H⁺. The presence of Na cations in the calcined SSZ-39s explains the slightly lower Si/Al ratios than what theoretically could be expected for a complete filling of each cage with one OSDA. The Si/Al values for samples II.2 and II.3 respectively lead to 4.8 and 5.4 Al

20 atoms per unit cell. This tetrahedral Al should induce an equimolar amount of negative framework charge and is compensated by a maximum of 4 positively charged SDAs (in 4 cages) per unit cell. Combining TGA and elemental analysis, 3.9 OSDAs per unit cell were calculated for both materials. The charge deficit (*viz.* -0.9 and -1.5) is thus roughly

accounted for by the presence of respectively 1.3 and 1.75 Na⁺ per unit cell for II.2 and II.3 as measured by elemental analysis. The micropore volumes, shown in FIG. 7B, seem to differ to some extent, with the lowest value obtained for the acid-washed material (0.22 cc/g). This could be originating from the slightly higher Al content of this material. Generally, the pore volumes (and type of isotherm) are within the expected range for a highly crystalline microporous 3-dimensional 8MR molecular sieve with cages, and in line with SSZ-39 literature.

Finally, the crystal morphologies of all calcined materials are similar (square - rectangular) and size in the range of 0.5 – 1 µm, although the material made with pure *cis*-3,5 is slightly smaller (II.3). From these characterizations, it can be concluded that all SSZ-39 samples, although prepared with different isomer mixtures, are typical SSZ-39 materials. However, only the processes using the OSDA with the enhanced *trans*-content, in accordance with the present invention, provided the benefits of faster reaction time, higher yield and/or better control of Si/Al ratios in the SSZ-39 product.

CONCLUSIONS

The objective of this study was to investigate whether the synthesis of SSZ-39 could be accomplished with mixtures of isomers that occur in the production of dimethylpyridine-based organic structure directing agents. The influence of both diastereo-isomers as well as structural isomers of quaternized (N,N-dimethyl) lupetidines was assessed. We found that: *i*) pure SSZ-39 can be made with either of the *cis*-3,5 or *trans*-3,5 isomers and mixtures thereof; *ii*) a relative rate-of-SSZ-39-formation exists as follows: *trans*-3,5 > *cis*-3,5; *iii*) when presented in competition, a preferential incorporation of the *trans*-3,5 over the *cis*-3,5 isomer exists; *iv*) GIS is a common impurity in synthesis from Al-rich gels, but it can be removed by a simple HCl-treatment that preserves the OSDA-stabilized SSZ-39; and *v*) SSZ-39s from different isomer origins possess similar physicochemical properties.

The following examples are provided to illustrate obtention of a preferred isomer.

Isomer Example 1

880gm 3,5-lutidine and 220gm water are charged in a 2 liter autoclave. To this solution 4.4 gm ruthenium on alumina (5% Ru) is charged. The autoclave is boxed up and flushed with nitrogen gas thrice followed with the flushing by hydrogen gas twice.

- 5 The autoclave is pressurized with hydrogen gas and the mass is heated to 190 to 200°C. After achieving 190 to 200°C, the hydrogen pressure is increased to 45 to 55 kg/cm² and pressure is continued till the hydrogen consumption ends. The sample is checked for complete conversion of 3,5-lutidine and 1120 gm crude product is obtained. The G.C. analysis shows *cis*-81.12 area % and *trans*-17.99 area%. The crude mass is
- 10 decanted and the catalyst is recycled during hydrogenation.

The crude mass is charged for fractional distillation along with 75 gm of fresh or recycled water in a two meter, 1 inch diameter column, filled with Sulzer packings. The *trans* isomer is removed as the azeotrope and collected in decanter. The organic layer from the decanter, rich in *trans* isomer, is used for further isolation.

- 15 The aqueous phase is recycled in the same crude to draw out *trans*-isomer predominantly. *Trans*-3,5-dimethylpiperidine is enriched at the top leaving the *cis*-isomer predominantly at the bottom. After removal of water, once the *trans* isomer is removed as per the desired limit, *cis*-3,5-dimethylpiperidine is distilled out.

20

Isomer Example 2

880 gm 3,5-lutidine is charged in a 2 liter autoclave, then 4.4 gm ruthenium on alumina (5% Ru) is charged in autoclave. The autoclave is boxed up and flushed with nitrogen gas thrice followed with the flushing by hydrogen gas twice. The autoclave is pressurized with hydrogen gas and the mass is heated to 190 to 200°C. After achieving

25 190 to 200°C, the hydrogen pressure is increased to 45 to 55 kg/cm² and pressure is continued till the hydrogen consumption is complete. The sample is checked for complete conversion of 3,5-lutidine and 1120 gm crude product is obtained. The G.C.

analysis shows *cis* 68 area % and *trans* 31.2 area%. The crude mass is decanted and the catalyst is recycled during hydrogenation.

The crude mass is charged for fractional distillation along with 75 gm of water in a two meter, 1 inch diameter column, filled with Sulzer packings. The *trans* isomer is azeotroped and collected in a decanter. The organic layer from the decanter, rich in *trans* isomer, is removed for further isolation. The aqueous phase is recycled in the same crude to draw out *trans*-isomer predominantly. *Trans*-3,5-dimethylpiperidine is enriched at the top leaving the *cis*-isomer predominantly at the bottom.

10

Isomer Example 3

15

880gm 3,5-lutidine and 220gm water are charged in a 2 liter autoclave. To this solution 4.4 gm ruthenium on alumina (5% Ru) is charged. The autoclave is boxed up and flushed with nitrogen gas thrice followed with the flushing by hydrogen gas twice. The autoclave is pressurized with hydrogen gas and the mass is heated to 190 to 200°C. After achieving 190 to 200°C, the hydrogen pressure is increased to 45 to 55 kg/cm² and pressure is continued till the hydrogen consumption is complete. The sample is checked for complete conversion of 3,5-lutidine and 1120 gm crude product is obtained.

20

Zeolite Example #1 (Si/Al = 15)

25

To a 23 ml Teflon® jar is added: 3.835 g N grade sodium silicate (Na/Si ratio = 3.21, PQ Corporation), 0.4 ml 1 M/l sodium hydroxide), 2.5 ml 23/77 *cis/trans*-N,N-dimethyl, 3,5 dimethylpiperidinium hydroxide (20%, Sachem, Inc.), 0.335 faujasite (e.g., CBV-500 SiO₂/Al₂O₃ = 5.2, Zeolyst Corp.) and 8.88 ml DI H₂O. The mixture is stirred for 2 hours at ambient temperature, then the Teflon® jar is inserted into a sealed autoclave. The autoclave is placed in an oven at 140 C for 48 hours and rotated at 60

rpm. The autoclave is then removed from the oven and cooled to room temperature. The solids and mother liquors are then separated by centrifugation (or filtration). The solids are dried and weighed, and then characterized by X-ray diffraction (XRD)

The yield of the product zeolite SSZ-39 can be estimated by comparing the areas of the XRD peaks at $2\theta = 9.5$ (characteristic of SSZ-39) and 6.2 degrees (characteristic for faujasite), as shown in FIG. 1.

Zeolite Example #2 (Si/Al = 15)

To a 23 ml Teflon® jar is added: 3.835 g N grade sodium silicate (Na/Si ratio = 3.21, PQ Corporation), 0.4 ml 1 M/l sodium hydroxide), 2.5 ml 72/28 *cis/trans*-N,N-dimethyl, 3,5 dimethylpiperidinium hydroxide (20%, Sachem, Inc), 0.335 faujasite (e.g., CBV-500 SiO₂/Al₂O₃ = 5.2, Zeolyst Corp.) and 8.88 ml DI H₂O. The mixture is stirred for 2 hours at ambient temperature, then the Teflon® jar is inserted into a sealed autoclave. The autoclave is placed in an oven at 140 C for 48 hours and rotated at 60 rpm. The autoclave is then removed from the oven and cooled to room temperature. The solids and mother liquors are then separated by centrifugation (or filtration). The solids are dried and weighed, and then characterized by X-ray diffraction (XRD)

As in Zeolite Example 1, the yield of the product zeolite SSZ-39 can be estimated by comparing the areas of the XRD peaks at $2\theta = 9.5$ (characteristic of SSZ-39) and 6.2 degrees (characteristic for faujasite), as shown in FIG. 2.

Zeolite Example #3 (Si/Al = 15)

To a 23 ml Teflon® jar is added: 3.835 g N grade sodium silicate (Na/Si ratio = 3.21, PQ Corporation), 0.4 ml 1 M/l sodium hydroxide), 2.5 ml 86/14 *cis/trans*-N,N-dimethyl, 3,5 dimethylpiperidinium hydroxide (20%, Sachem, Inc.), 0.335 faujasite (e.g., CBV-500 SiO₂/Al₂O₃ = 5.2, Zeolyst Corp.) and 8.88 ml DI H₂O. The mixture is stirred

for 2 hours at ambient temperature, then the Teflon® jar is inserted into a sealed autoclave. The autoclave is placed in an oven at 140 C for 48 hours and rotated at 60 rpm. The autoclave is then removed from the oven and cooled to room temperature. The solids and mother liquors are then separated by centrifugation (or filtration). The solids are dried and weighed, and then characterized by X-ray diffraction (XRD).

As in Zeolite Examples 1 and 2, the yield of the product zeolite SSZ-39 can be estimated by comparing the areas of the XRD peaks at $2\theta = 9.5$ (characteristic of SSZ-39) and 6.2 degrees (characteristic for faujasite), as shown in FIG. 3.

Zeolite Examples #4-7 (Si/Al = 30)

To four 23 ml Teflon® jars is added: 4.33 g N grade sodium silicate (Na/Si ratio = 3.21, PQ Corporation), 0.5 ml 1 M/l sodium hydroxide), 2.5 ml 98/2 *cis/trans*-N,N-dimethyl, 3,5 dimethylpiperidinium hydroxide (20%, Sachem, Inc.), 0.17 faujasite (e.g., CBV-500 SiO₂/Al₂O₃ = 5.2, Zeolyst Corp.) and 8.88 ml DI H₂O. Each of the mixtures are stirred for 2 hours at ambient temperature, then the Teflon® jars are inserted into sealed autoclaves. The autoclaves are placed in an oven at 140 C and rotated at 60 rpm. One autoclave is removed from the oven and cooled to room temperature after 12, 24, 36 and 72 hours. The solids and mother liquors are then separated by centrifugation (or filtration). The solids are dried and weighed, and then characterized by X-ray diffraction (XRD).

Zeolite Examples 8-11 (Si/Al = 30)

The same preparations are performed as described above for Example 4-7, except that a 48/52 ratio of *cis* and *trans* isomers of N,N-dimethyl, 3,5 dimethylpiperidinium hydroxide is used instead of 98% *cis* isomer. The yields of the desired products are compared to those produced using the 98% *cis* isomer (Examples

4-6) and in each case the ratio of AEI to FAU in the XRD pattern is higher when using the higher *trans* composition.

The Si/Al ratios of the solids formed after 72 hours are 7.6 and 8.4 for examples 8 and 11, respectively. So the higher *trans* isomer content of the zeolite gel improves the Si/Al ratio closer to the commercially desirable level.

Zeolite Examples 12 and 13

To two 23 ml Teflon® jars is added: 3.835 g N grade sodium silicate (Na/Si ratio = 3.21, PQ Corporation), 0.4 ml 1 M/l sodium hydroxide), 2.5 ml 71.8/28.2 *cis/trans*-N,N-dimethyl, 3,5 dimethylpiperidinium hydroxide (20%, Sachem, Inc.), 0.335 faujasite (e.g., CBV-500 SiO₂/Al₂O₃ = 5.2, Zeolyst Corp.) and 8.88 ml DI H₂O. The mixture is stirred for 2 hours at ambient temperature, then the Teflon® jar is inserted into a sealed autoclave. One autoclave is placed in an oven at 140 C for 23 hours and rotated at 25 rpm and then removed from the oven and cooled to room temperature. The other autoclave is placed in the oven for 41 hours. The solids and mother liquors are then separated by centrifugation (or filtration) and the mother liquors analyzed by HPLC to determine the isomeric ratios of the residual SDA present.

Zeolite Examples 14 and 15

To two 23 ml Teflon® jars is added: 3.835 g N grade sodium silicate (Na/Si ratio = 3.21, PQ Corporation), 0.4 ml 1 M/l sodium hydroxide), 2.5 ml 84.8/15.2 *cis/trans*-N,N-dimethyl, 3,5 dimethylpiperidinium hydroxide (20%, Sachem, Inc.), 0.335 faujasite (e.g., CBV-500 SiO₂/Al₂O₃ = 5.2, Zeolyst Corp.) and 8.88 ml DI H₂O. The mixture is stirred for 2 hours at ambient temperature, then the Teflon® jar is inserted into a sealed autoclave. One autoclave is placed in an oven at 140 C for 26 hours and rotated at 25 rpm and then removed from the oven and cooled to room temperature. The other

autoclave is placed in the oven for 42 hours. The solids and mother liquors are then separated by centrifugation (or filtration) and the mother liquors analyzed by HPLC to determine the isomeric ratios of the residual SDA present.

5 The results of examples 12-15 shown in Table 3 clearly show a preferential uptake of the *trans* isomer into the AEI zeolite product, resulting in a depletion of the *trans* isomer in the mother liquors. This is additional evidence for the favorability of the *trans* isomer in preparation of zeolites in accordance with the invention.

Table 3

hours	% <i>trans</i> in mother liquors	
	Examples 14-15	Examples 12-13
0	15.23	28.21
26	14.85	
42	14.1	
23		26.05
41		24.68

10 While the principles of the invention have been explained in relation to certain particular embodiments, which are provided for purposes of illustration, it is to be understood that various modifications thereof will become apparent to those skilled in the art upon reading the specification. Therefore, it is to be understood that the invention disclosed herein is intended to cover such modifications as fall within the scope of the appended claims. The scope of the invention is limited only by the scope of the appended claims.

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CLAIMS

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1. A method of preparing a SSZ-39 zeolite, comprising:
providing a precursor to 3,5-dimethyl-N,N-dimethylpiperidinium cation;
treating the precursor to provide an intermediate that, when subsequently
treated to form the 3,5-dimethyl-N,N-dimethylpiperidinium cation, has a content of trans
isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation to cis isomer of the 3,5-
dimethyl-N,N-dimethylpiperidinium cation in a ratio of 1:3 or higher;
contacting under crystallization conditions a mixture of sources of an oxide of
silicon and faujasite, one or more alkali metal hydroxide or alkaline earth metal
hydroxide, water, and a structure-directing agent comprising the 3,5-dimethyl-N,N-
dimethylpiperidinium cation having the content of the trans isomer of the 3,5-dimethyl-
N,N-dimethylpiperidinium cation to the cis isomer of the 3,5-dimethyl-N,N-
dimethylpiperidinium cation in the ratio of 1:3 or higher; and
calcining the mixture to form a SSZ-39 zeolite.
2. The method of claim 1 wherein the precursor is 3,5-dimethyl pyridine, or N-
methyl-3,5-dimethylpiperidine, or 3,5-dimethylpiperidine.
3. The method of claim 1 wherein the treating comprises one or more of chemical
reduction, non-catalytic hydrogenation, catalytic hydrogenation in the absence of water,
selective crystallization, and distillation.
4. The method of claim 1 wherein the ratio of the trans isomer to the cis isomer in
the 3,5-dimethyl-N,N-dimethylpiperidinium cation having an increased content of the
trans isomer is at least 40:60.
5. The method of claim 1 wherein the ratio of the cis and trans isomers of the 3,5-
dimethyl-N,N-dimethylpiperidinium cation is controlled by selective isolation of 3,5-
dimethylpiperidine following hydrogenation of 3,5-dimethylpyridine, and subsequent
methylation of the 3,5-dimethylpiperidine to form the 3,5-dimethyl-N,N-
dimethylpiperidinium cation, which is subsequently paired with a hydroxide anion.

6. The method of claim 1 wherein the oxide of silicon is one or a combination of two or more of a silicate, a silica hydrogel, silicic acid, fumed silica, colloidal silica, a tetra-alkyl orthosilicate, and a silica hydroxide.

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7. The method of claim 1 wherein the precursor is 3,5-dimethylpyridine, and the treating comprises a catalytic reduction to form a mixture of cis- and trans-3,5-dimethylpiperidine.

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8. The method of claim 7 wherein the treating further comprises distillation of the mixture to separate the cis-3,5-dimethylpiperidine from the trans-3,5-dimethylpiperidine, and isolation of a fraction substantially enhanced in the cis-3,5-dimethylpiperidine and a fraction substantially enhanced in the trans-3,5-dimethylpiperidine.

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9. The method of claim 8 wherein the treating further comprises methylation of the separated cis-3,5-dimethylpiperidine and the trans-3,5-dimethylpiperidine to form the cis isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation and the trans isomer of the 3,5-dimethyl-N,N-dimethylpiperidinium cation, paired with a suitable anion.

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10. The method of claim 1 wherein the combining under crystallization conditions comprises stirring the mixture at room temperature, and the calcining comprises heating the mixture to an elevated temperature.

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11. The method of claim 7 wherein the treating further comprises adding water to a mixture of the cis-3,5-dimethylpiperidine and the trans-3,5-dimethylpiperidine, followed by a step of azeotropic distillation of the mixture to separate the trans-3,5-dimethylpiperidine from the mixture.

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12. The method of any one of claims 1 to 3, or 5 to 11, wherein the ratio of the trans isomer to the cis isomer in the 3,5-dimethyl-N,N-dimethylpiperidinium cation ranges from 30:70 to 80:20.

13. A method of making Cu-SSZ-39 zeolite, comprising:
- (a) providing a SSZ-39 zeolite made according to any one of claims 1 to 12;
 - (b) replacing at least a portion of alkali metal cation or alkaline earth metal cation
- 5 remaining in the SSZ-39 zeolite with a Cu^{+2} cation, to form Cu-SSZ-39.