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System for removing ammonia from a freshwater environment

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Alcantar et al.

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(54) **SYSTEM FOR REMOVING AMMONIA FROM A FRESHWATER ENVIRONMENT**

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C02F 2201/006; A01K 63/04; A01K
63/045; B01J 39/02; B01J 39/14; B01J
49/53

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USPC 119/231, 259, 268
See application file for complete search history.

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Wen Zhao, Tampa, FL (US); **Sarina Joy Ergas**, Tampa, FL (US)

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(73) Assignee: **University of South Florida**, Tampa, FL (US)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 362 days.

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(21) Appl. No.: **14/997,793**

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(22) Filed: **Jan. 18, 2016**

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(Continued)

Related U.S. Application Data

(60) Provisional application No. 62/104,398, filed on Jan. 16, 2015.

Primary Examiner — Matthew O Savage

(51) **Int. Cl.**

(74) *Attorney, Agent, or Firm* — Michele L. Lawson; Smith & Hopen, P.A.

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C02F 1/66 (2006.01)
A01K 63/04 (2006.01)
B01J 39/14 (2006.01)
C02F 101/16 (2006.01)
C02F 103/20 (2006.01)

(57) **ABSTRACT**

(52) **U.S. Cl.**

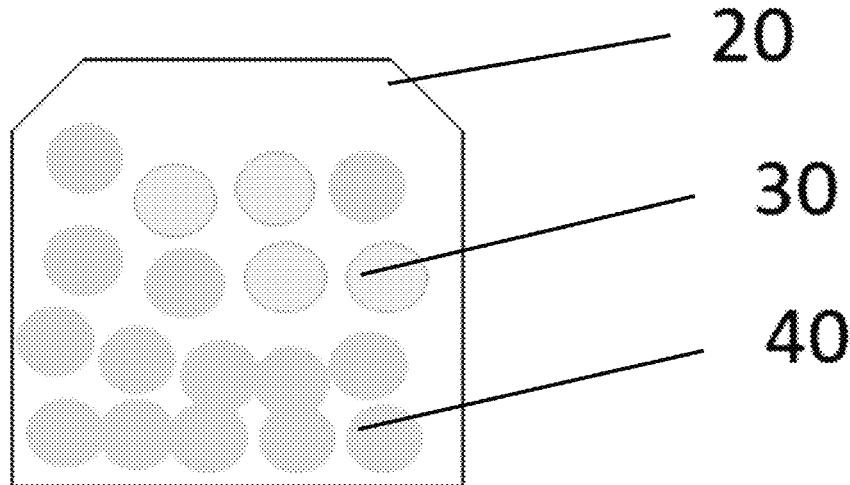
CPC **C02F 1/42** (2013.01); **A01K 63/04** (2013.01); **A01K 63/045** (2013.01); **B01J 39/14** (2013.01); **C02F 1/66** (2013.01); **C02F 2001/425** (2013.01); **C02F 2101/16** (2013.01); **C02F 2103/20** (2013.01); **C02F 2201/006** (2013.01)

An ammonia adsorption product is described which may be used for fresh caught fish and bait. The product may comprise functionalized tectosilicate compound and a buffer. High concentrations of ammonia produced by fish waste can be lethal, even though oxygen availability is rich enough to keep fish breathing. The product is a user-friendly, sustainable, affordable product which is able to extend the life of the fish by safely removing ammonia by an ion-exchange mechanism. This product can convert toxic ammonia into ammonium and uptake ammonium by releasing sodium ions in the water.

(58) **Field of Classification Search**

CPC .. C02F 1/42; C02F 2001/425; C02F 2101/16;

3 Claims, 12 Drawing Sheets



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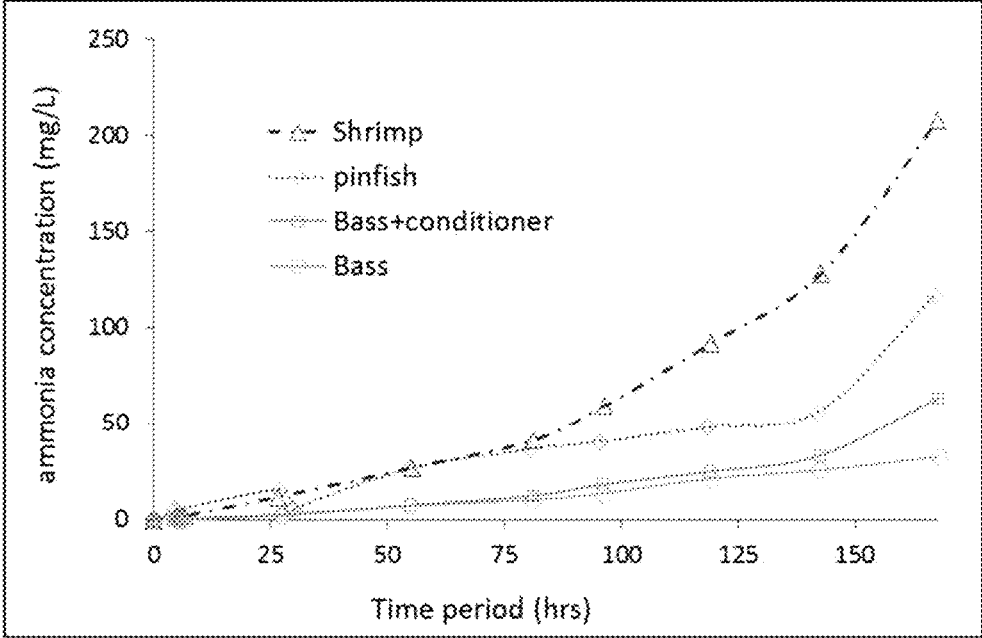


FIG. 1

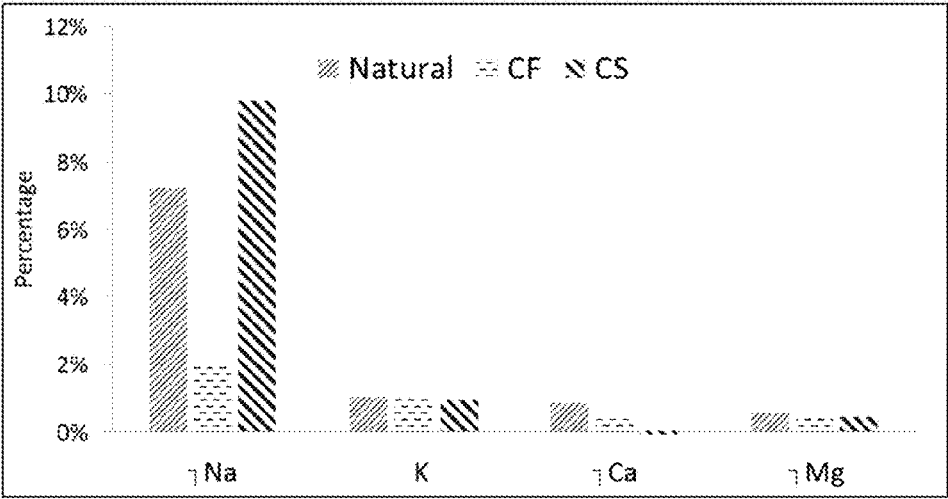
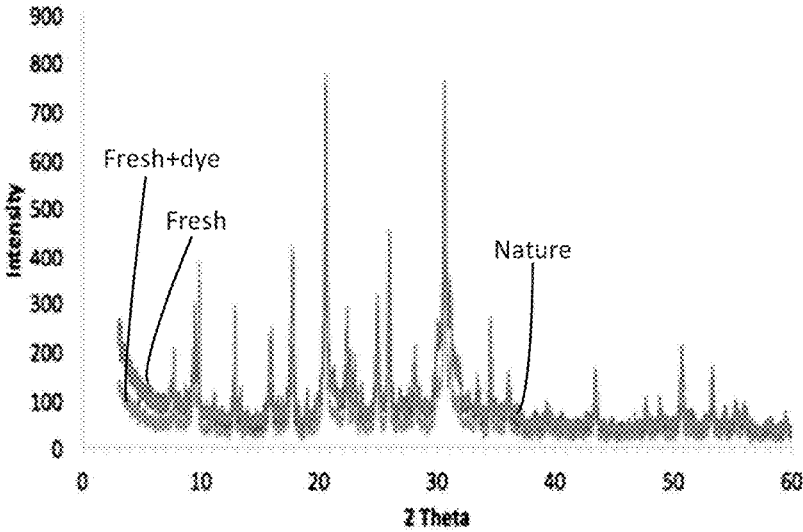
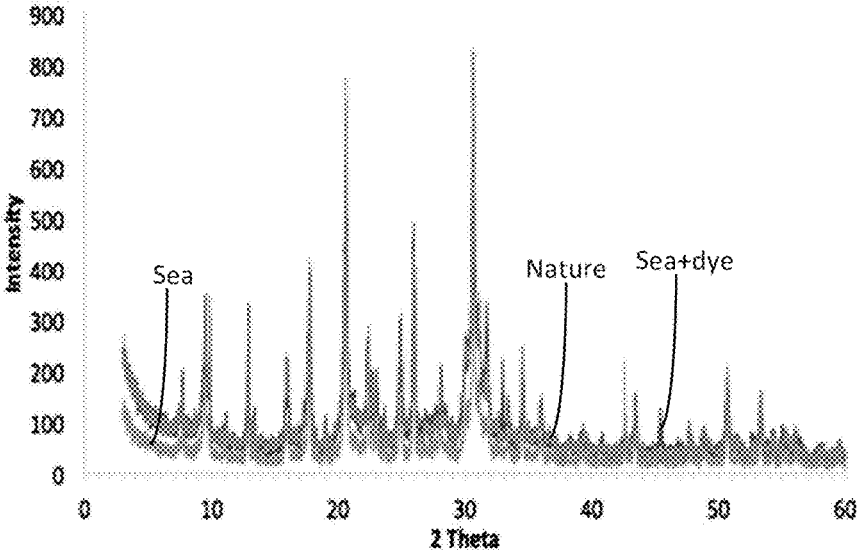


FIG. 2



Chabazite Pretreated by Freshwater

FIG. 3



Chabazite Pretreated by Saltwater

FIG. 4

Linear Isotherm

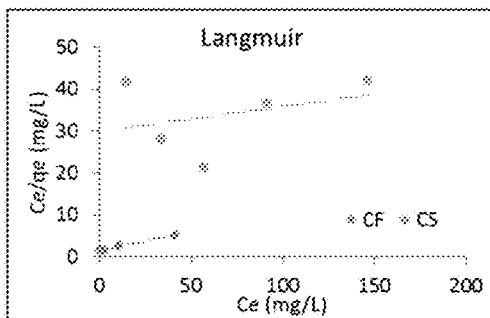


FIG. 5A

Non-Linear Isotherm

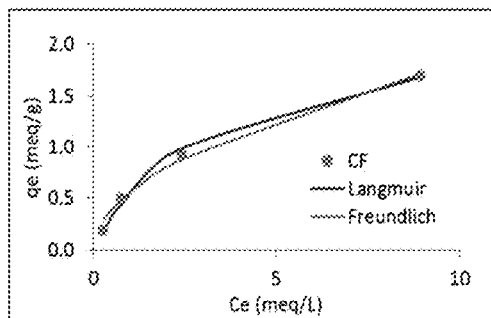


FIG. 5C

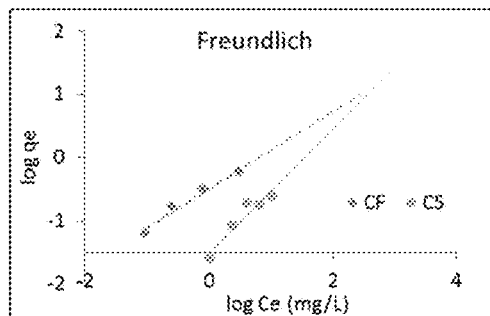


FIG. 5B

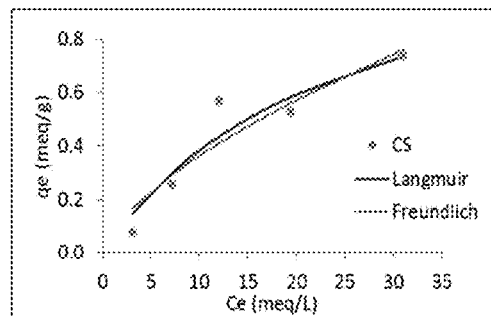


FIG. 5D

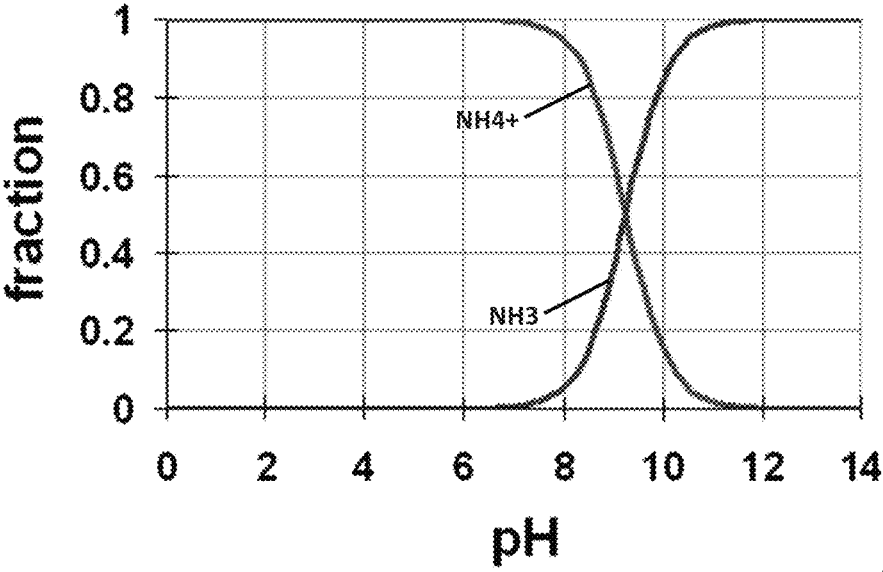


FIG. 6

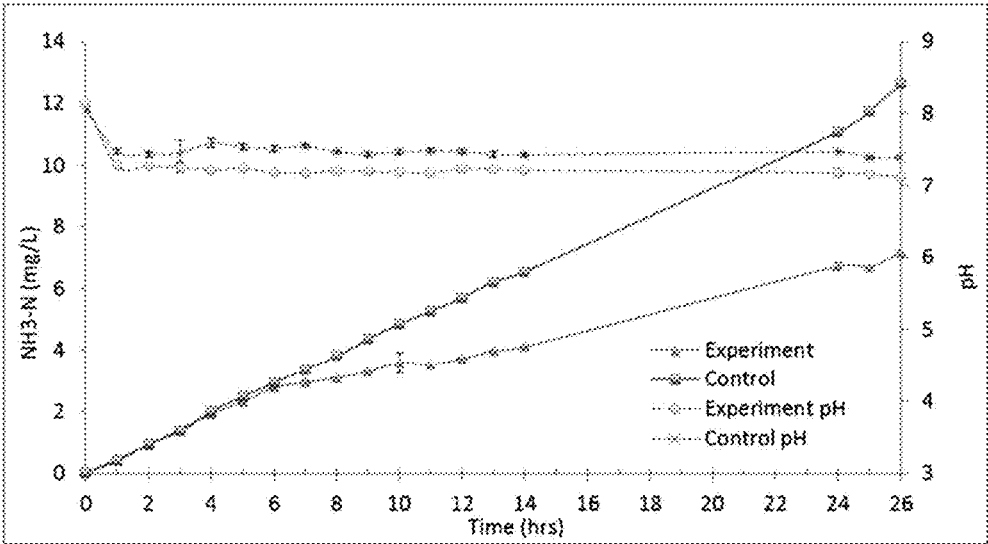


FIG. 7

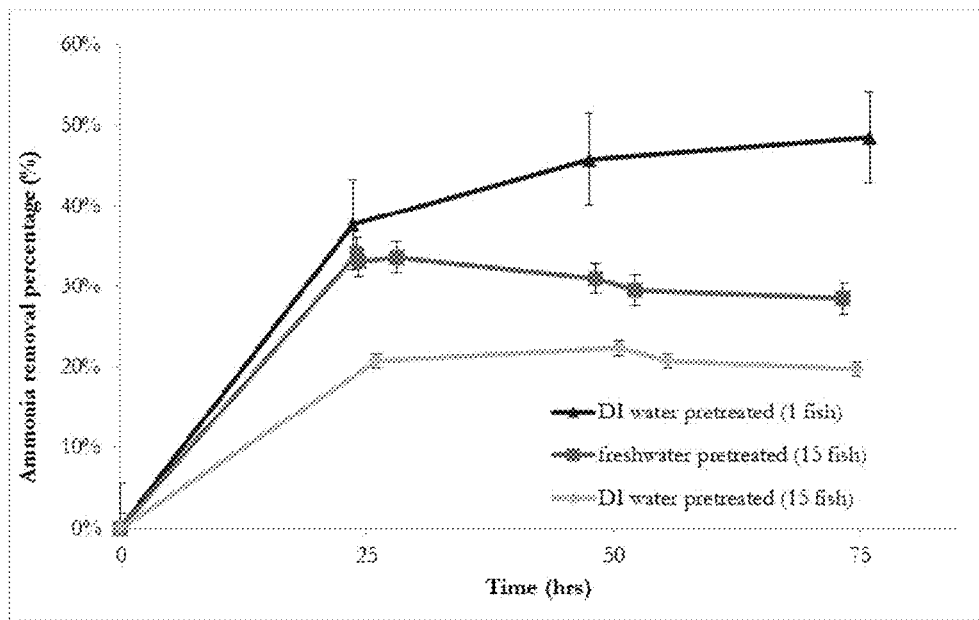


FIG. 8

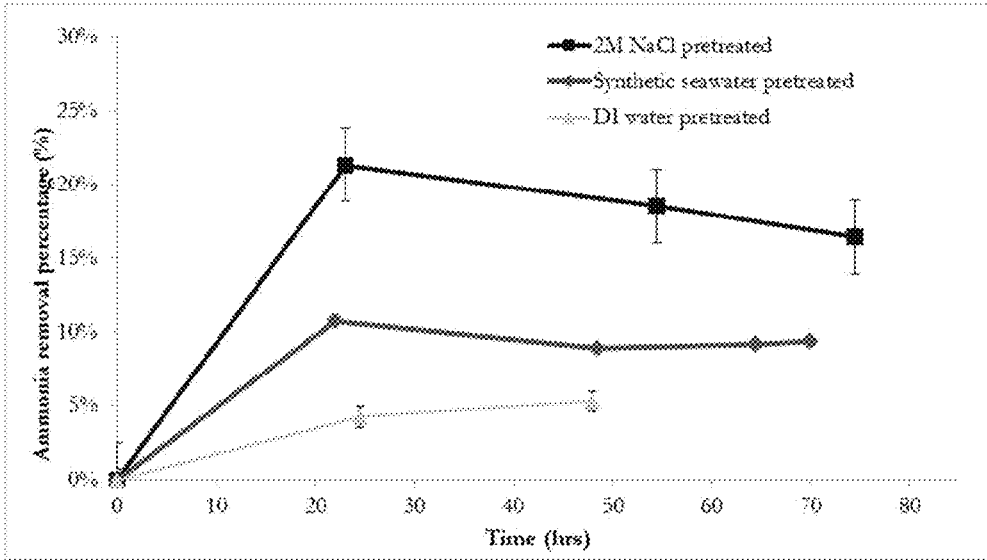


FIG. 9

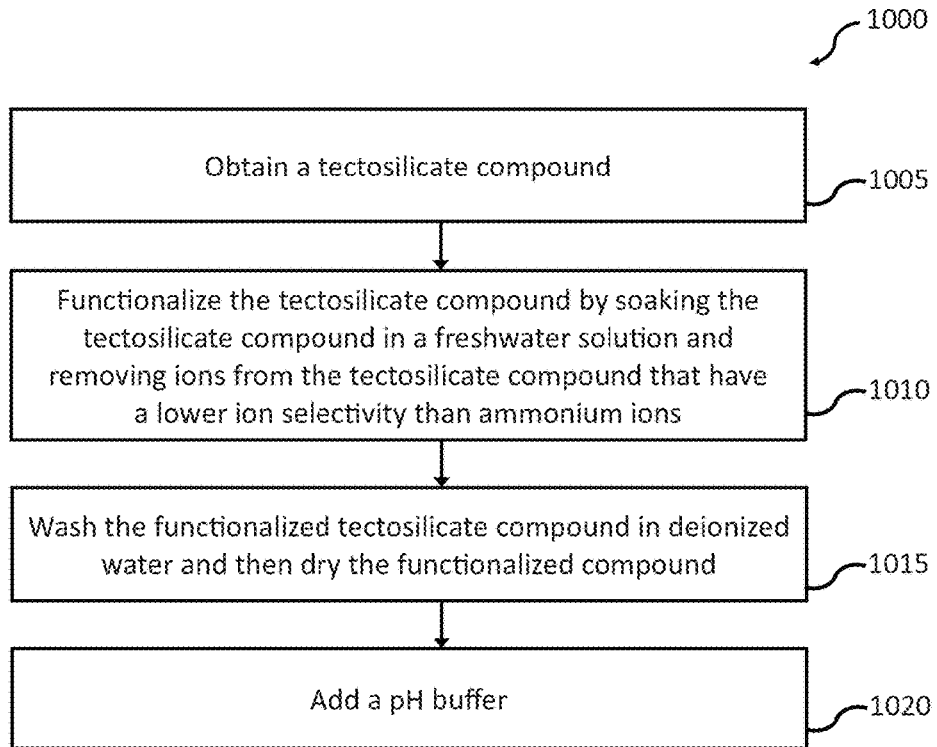


FIG. 10

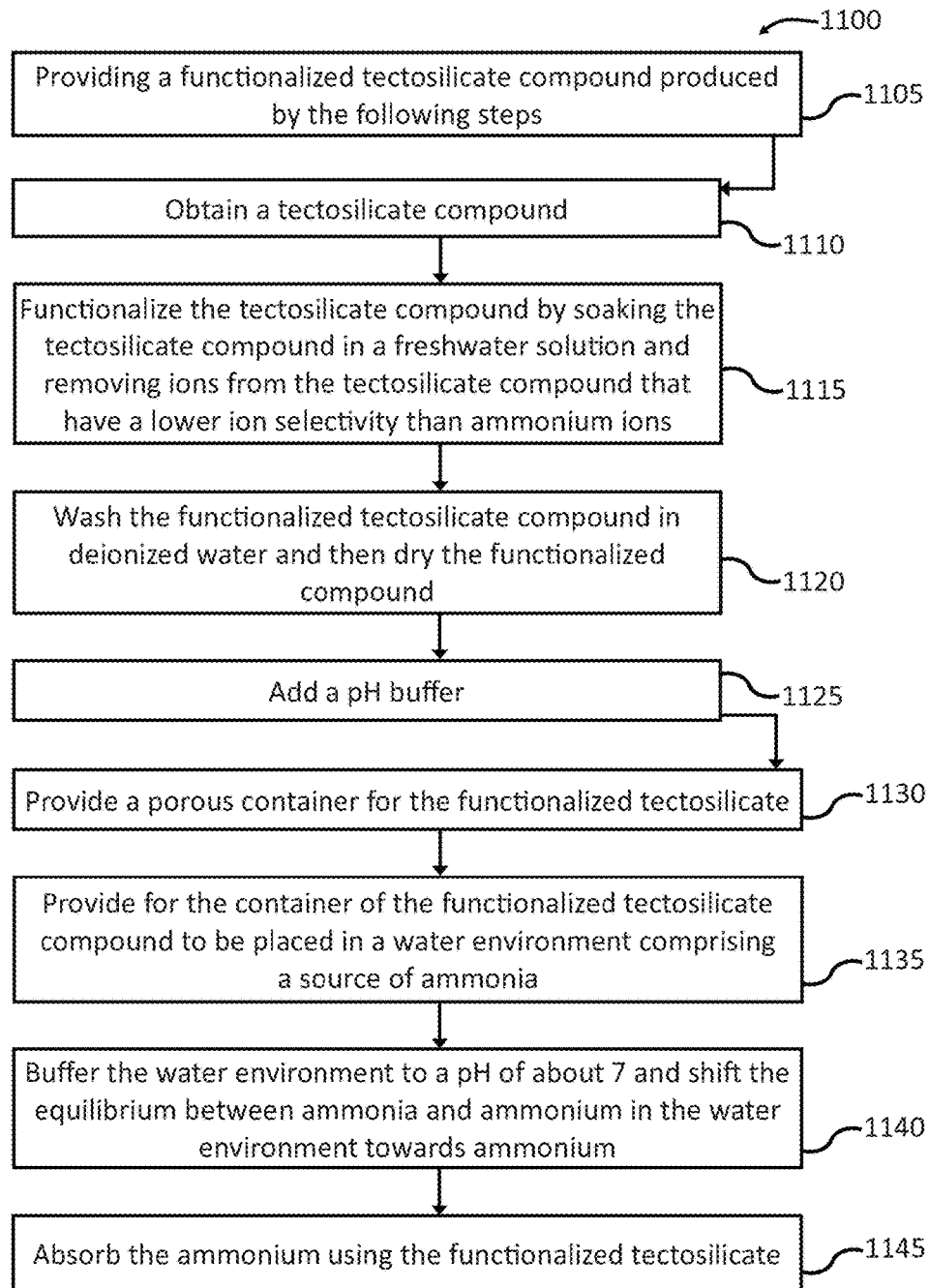


FIG. 11

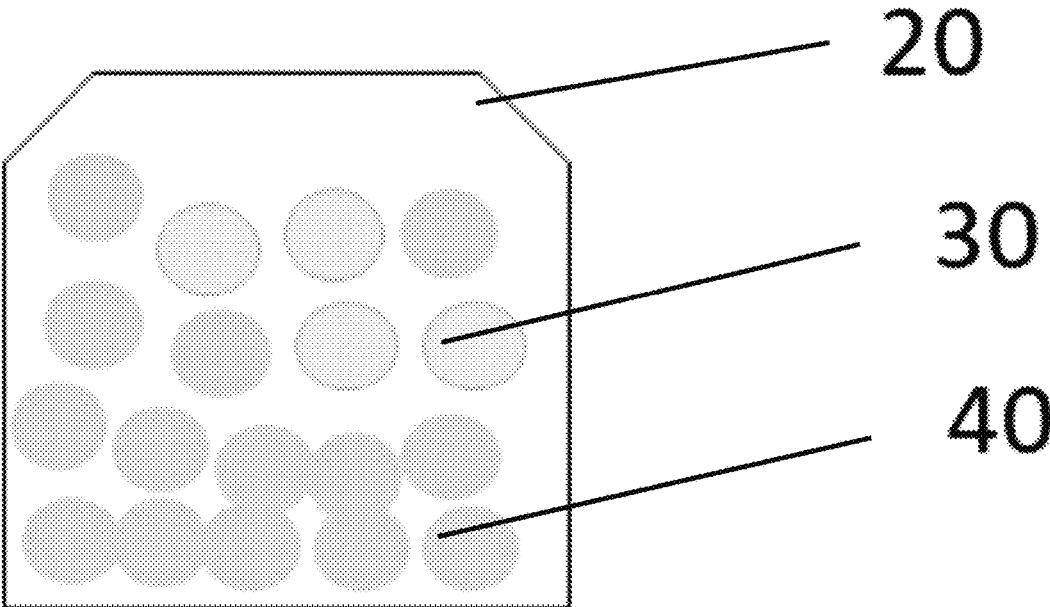


FIG. 12

SYSTEM FOR REMOVING AMMONIA FROM A FRESHWATER ENVIRONMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority to provisional U.S. Patent Application Ser. No. 62/104,398, filed on Jan. 16, 2015, titled "Ammonia Removal in Freshwater and Saltwater Systems," which is hereby incorporated by reference in its entirety.

FIELD OF THE INVENTION

This invention relates to removal of contaminants from water, and more specifically to systems and methods for removing ammonia from freshwater and saltwater environments to extend the life expectancy of stored fish.

BACKGROUND OF THE INVENTION

Freshwater and saltwater fishing are some of the most popular outdoor activities in the United States and throughout the world. Caught fish are often kept alive by placing the fish in a bucket, livewell, or other container or closed system. In addition, live bait is often used for fishing and must be kept in a similar container prior to use. Because the volume of water is limited in these closed systems, an aeration pump is often installed to replenish dissolved oxygen levels in the water. While aeration systems may maintain oxygen levels in the water to sustain the fish, other contaminants may build up in the closed system and poison the fish. For example, waste products discharged by the fish may increase ammonia concentration in the water and may build to levels that will kill the fish despite an adequate level of dissolved oxygen in the water. Traditional methods to control ammonia in these types of closed systems include lowering the pH of the water or introducing new water to the system (that is, diluting the ammonia concentration).

Accordingly, what is needed in the art is a user friendly, sustainable, cost-effective, and capable system and method for reducing the ammonia level in fresh and saltwater systems.

SUMMARY OF INVENTION

The present invention provides systems and methods for removing ammonia from freshwater and saltwater environments. Various embodiments may comprise a treated, functionalized zeolite compound with a high ammonium absorption capacity. Zeolites are microporous mineral compounds commercially used as adsorbents. The porous structure can accommodate a wide variety of cations such as Na⁺, Ca⁺, K⁺, and Mg⁺. In addition, once these cations are adsorbed by the zeolite, they can be exchanged for other cations when the zeolite is in contact with a solution containing the other cations. While there are a large number of available zeolites, various embodiments comprise chabazite because it is inexpensive, readily available from many areas of the world, and has a cation-exchange capacity.

An exemplary method for producing an ammonia removal agent for water environments may comprise obtaining a tectosilicate compound. The tectosilicate compound may be functionalized by soaking the tectosilicate compound in a freshwater solution and removing ions from the tectosilicate compound that have a lower ion selectivity than ammonium ions. The functionalized tectosilicate compound may be

washed in deionized water and then dried. A pH buffer may be added to the functionalized tectosilicate compound.

An exemplary method for controlling an ammonia level in a water environment may comprise providing a functionalized tectosilicate compound. The functionalized tectosilicate compound may be produced by first obtaining a tectosilicate compound. The tectosilicate compound may be functionalized by soaking the tectosilicate compound in a freshwater solution and removing ions from the tectosilicate compound that have a lower ion selectivity than ammonium ions. The functionalized tectosilicate compound may be washed in deionized water and then dried. A pH buffer may be added to the functionalized tectosilicate compound. A porous container that allows liquid to flow through the container may be provided for the functionalized tectosilicate compound. The container of functionalized tectosilicate compound may be placed in a water environment comprising a source of ammonia. The pH buffer may buffer the pH of the system to about 7 and shift an equilibrium between ammonia and ammonium in the water environment towards ammonium. The ammonium may be adsorbed by the functionalized tectosilicate.

An exemplary system for removing ammonia from a water environment may comprise a functionalized tectosilicate compound. The functionalized tectosilicate compound may be produced by first obtaining a tectosilicate compound. The tectosilicate compound may be functionalized by soaking the tectosilicate compound in a freshwater solution and removing ions from the tectosilicate compound that have a lower ion selectivity than ammonium ions. The functionalized tectosilicate compound may be washed in deionized water and then dried. A pH buffer may be added to the functionalized tectosilicate compound. The functionalized tectosilicate compound may be placed in a porous container that allows liquid to flow through the container such the buffer maintains a pH of about 7 in the water environment and shifts the equilibrium between ammonia and ammonium towards ammonium and the ammonium is adsorbed by the functionalized tectosilicate.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the invention, reference should be made to the following detailed description, taken in connection with the accompanying drawings, in which:

FIG. 1 is a graph of ammonia buildup in a closed aquatic system for a variety of fish.

FIG. 2 is a graph of the composition of chabazite before and after pretreatment.

FIG. 3 is an x-ray diffraction plot of chabazite pretreated using freshwater.

FIG. 4 is an x-ray diffraction plot of chabazite pretreated using 2M NaCl.

FIG. 5A is a graph of the ammonium adsorption linear isotherm using the Langmuir model.

FIG. 5B is a graph of the ammonium adsorption linear isotherm using the Freundlich model.

FIG. 5C is a graph of the ammonium adsorption non-linear isotherm using the Langmuir model for freshwater and saltwater environments.

FIG. 5D is a graph of the ammonium adsorption non-linear isotherm using the Freundlich model for freshwater and saltwater environments.

FIG. 6 illustrates the relationship of ammonia to ammonium concentration as a function of pH.

FIG. 7 is a graph of ammonia concentration for an in-vitro experiment.

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FIG. 8 is a graph of the ammonia removal rate of the functionalized chabazite in freshwater.

FIG. 9 is a graph of the ammonia removal rate of the functionalized chabazite in saltwater.

FIG. 10 is a flowchart of an exemplary method for producing an ammonia removal agent for water environments.

FIG. 11 is a flowchart of an exemplary method for controlling an ammonia level in a water environment.

FIG. 12 depicts the porous container holding the functionalized chabazite and phosphate buffer.

DETAILED DESCRIPTION OF THE INVENTION

Caught fish are often kept alive by placing the fish in a bucket, livewell, or other container or closed system. In addition, live bait is often used for fishing and must be kept in a similar container prior to use. Because the volume of water is limited in these close systems, an aeration pump is often installed to replenish dissolved oxygen levels in the water. While aeration systems may maintain oxygen levels in the water to sustain the fish, other contaminants may build up in the closed system and poison the fish. For example, waste products discharged by the fish may increase ammonia concentration in the water and may build to levels that will kill the fish despite an adequate level of dissolved oxygen in the water.

Various embodiments may comprise one or more treated, functionalized zeolite compounds with a high ammonium absorption capacity. Zeolites are microporous mineral compounds commercially used as adsorbents. The porous structure can accommodate a wide variety of cations such as Na⁺, Ca⁺, K⁺, and Mg⁺. In addition, once these cations are adsorbed by the zeolite, they can be exchanged for other cations when the zeolite is in contact with a solution containing the other cations. While there are a large number of available zeolites, various embodiments comprise chabazite because it is inexpensive, readily available from many areas of the world, and has a cation-exchange capacity. Chabazite (available from St. Cloud Mining Company) is a tectosilicate mineral with the formula (Ca,Na₂,K₂,Mg)Al₂Si₄O₁₂·6H₂O.

The ion selectivity series for chabazite is:

Ti⁺>K⁺>Rb⁺>NH₄⁺>Pb₂⁺>Na⁺>Ba₂⁺>Sr₂⁺>Ca₂⁺>Li⁺

Thus, chabazite that has been functionalized with a common and readily available ion such as Na⁺ will tend to give up the Na⁺ ion in favor of NH₄⁺ (ammonium). This property can be exploited to use Na⁺ functionalized chabazite to selectively remove ammonium from water.

Experimentation was conducted to determine the ammonia accumulation rate over time for closed systems of various volumes containing live fish in both freshwater and saltwater. These tests involved bass with a commercial water conditioner, bass without the conditioner, pinfish and blowfish, and shrimp. Ammonia concentration was determined using the salicylate method (HACH Method 10031) and the results are shown in FIG. 1. These tests indicated an ammonia accumulation rate of 1.13 mg HN₃-N/fish/hr for freshwater fish and 1.6 mg HN₃-N/fish/hr for saltwater fish.

Next, a procedure was developed to treat and functionalize chabazite pellets to maximize ammonium adsorption capacity. Chabazite pellets having a size range of 1-2 mm were washed in deionized (DI) water using a shaker table for 24 hours to remove small particles. The washed pellets were then oven dried at 100° C.

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Two pretreatment methods were used to develop products specific to freshwater and saltwater uses. For freshwater uses, the washed and dried chabazite was soaked in freshwater/synthetic freshwater for 24 hours to remove sodium ions, then washed with DI water and oven dried at 100° C. for 5 hours. The composition of the synthetic freshwater is provided in Table 1. For saltwater uses, the washed and dried chabazite was soaked in a 2M NaCl solution for 24 hours to uptake sodium ions, then washed with DI water and oven dried at 100° C. for 5 hours.

TABLE 1

Synthetic Freshwater Composition	
Ion	Freshwater (g/L)
Sodium (Na ⁺)	0.075
Potassium (K ⁺)	0.00312
Magnesium (Mg ²⁺)	0.024
Chloride (Cl ⁻)	0.193
Calcium (Ca ²⁺)	0.043
Bicarbonate (HCO ₃ ⁻)	0.0048
Sulfate (SO ₄ ²⁻)	0.096
Alkalinity	0.310

FIG. 2 shows the chemical composition of the chabazite before and after treatment. The Na⁺ composition decreased sharply for the treated freshwater chabazite (CF in FIG. 2) and a less sharp increase in Na⁺ composition for the saltwater chabazite (CS in FIG. 2). Approximately half of the Ca²⁺ ions were released from the freshwater chabazite and essentially all Ca²⁺ was released from the saltwater chabazite. There was no appreciable change in the K⁺ and Mg²⁺ composition.

The functionalized chabazite was then coated with an environmentally friendly blue dye (PSP0002 Lake and Pond Dye available from Outdoor Water Solutions).

FIGS. 3 and 4 illustrate that the crystalline structure of the freshwater chabazite and the saltwater chabazite, respectively, are unchanged after treatment. The additional peaks evident in FIG. 4 are due to the presence of the blue dye.

The ammonium adsorption isotherm using the Langmuir and Freundlich models were then determined for both the freshwater and saltwater chabazite. This testing was performed using the synthetic freshwater characterized in Table 1 and synthetic saltwater (available from Instant Ocean) characterized in Table 2. The ammonium adsorption isotherm results are presented in FIGS. 5A and 5B (linear isotherm) and FIGS. 5C and 5D (non-linear isotherm) and Table 3. The non-linear regression appears to better correlate with the experimental data, particularly for the saltwater chabazite.

TABLE 2

Synthetic Saltwater Composition	
Ion	Saltwater (g/L) ⁷
Sodium (Na ⁺)	10.780
Potassium (K ⁺)	0.42
Magnesium (Mg ²⁺)	1.32
Chloride (Cl ⁻)	19.290
Calcium (Ca ²⁺)	0.400
Bicarbonate (HCO ₃ ⁻)	0.200
Sulfate (SO ₄ ²⁻)	2.66
Alkalinity	0.241

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TABLE 3

Isotherm Constants for Ammonium Adsorption in Both Freshwater and Saltwater							
		Langmuir			Freundlich		
		q_0	b	R^2	K	1/n	R^2
		(meq/g)	(L/meq)				
Linear	Freshwater	2.24	0.34	0.992	0.50	0.61	0.969
	Saltwater	3.61	0.01	0.114	0.03	0.99	0.900
Non-linear	Freshwater	2.29	0.31	0.993	0.55	0.52	0.991
	Saltwater	1.32	0.04	0.899	0.08	0.66	0.867

Proper pH control may be used to affect the ammonia chemistry according to the equation $\text{NH}_3 + \text{H}^+ \leftrightarrow \text{NH}_4 + \text{H}_2\text{O}$. The higher the pH, the more the equilibrium moves to the left, favoring ammonia formation. The lower the pH, the more the equilibrium is shifted to the right, favoring ammonium formation. As shown in FIG. 6, a pH of about 7 favors essentially 100 percent formation of ammonium. To achieve a pH of 7, a buffer comprising K_2HPO_4 and KH_2PO_4 were added to both the freshwater and saltwater chabazite.

Product preparation steps are summarized as follows:

Freshwater Chabazite

1. Chabazite (30 g) pretreated by synthetic freshwater at for 24 hrs 40 (200 mL synthetic freshwater and 1 mL blue dye solution).

2. Wash by DI water and dry in the oven at 100° C. for 5 hours.

3. Mix with 2 g K_2HPO_4 and 2 g KH_2PO_4 .

4. Pack in a porous bag 20 (30 g per bag).

Saltwater Chabazite

1. Chabazite (30 g) pretreated by 2M NaCl for 24 hrs (200 mL 2M NaCl and 1 mL blue dye solution).

2. Wash by DI water and dry in the oven at 100° C. for 5 hours.

3. Mix with 2 g K_2HPO_4 and 2 g KH_2PO_4 .

4. Pack in a porous bag (30 g per bag).

Using the above preparation steps, porous containers of the freshwater chabazite were prepared and an in-vitro test was conducted using synthetic freshwater. A high performance ammonia ion selective electrode was used to measure ammonia concentration in a container with the freshwater chabazite in a porous bag and a control. Aeration was used in both. The experimental results are shown in FIG. 7. For the experimental specimen, $k_{\text{experimental}} = 2.5 \text{ mg NH}_3\text{—N/hr}$. For the control specimen, $k_{\text{control}} = 4.71 \text{ mg NH}_3\text{—N/hr}$.

In-vivo tests were then performed using live fish in an experimental container with the prepared chabazite and live fish in a container without chabazite as a control. Aeration was used in both. Testing was performed for both freshwater and saltwater systems. In freshwater, functionalized chabazite (30 g) removed $49.6 \pm 9.6\%$ of $\text{NH}_4^+\text{—N}$ for up to 4 days at high fish density (see FIG. 8). The same system removed $58.5 \pm 8\%$ of $\text{NH}_4^+\text{—N}$ for 4 days at low fish density. In seawater, functionalized chabazite (30 g) removed $49.2 \pm 13.9\%$ of $\text{NH}_4^+\text{—N}$ for up to 4 days at high fish density (see FIG. 9).

In various embodiments, spent chabazite may be regenerated by removing the adsorbed ammonium ions and replacing them with sodium ions (or other suitable ions).

Table 4 presents the cost of materials for the chabazite system. The total cost compares favorably to commercial water conditioners which range from \$4-10.

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TABLE 4

Material Costs for Chabazite, Dye, and Buffer	
Component	Cost/Day
Chabazite	\$0.84
Buffer	\$3.52
Bag	\$0.56
Other	\$1.00
TOTAL	\$5.92

Definition of Claim Terms

Ammonium: a positively charged polyatomic ion with the chemical formula NH_4 . It may be formed by the protonation of ammonia (NH_3).

Buffer: an aqueous solution consisting of a mixture of a weak acid and its conjugate base, or vice versa. Its pH changes very little when a small or moderate amount of strong acid or base is added to it and thus it may be used to prevent changes in the pH of a solution.

Chabazite: a tectosilicate mineral with the formula $(\text{Ca}, \text{Na}_2, \text{K}_2, \text{Mg})\text{Al}_2\text{Si}_4\text{O}_{12} \cdot 6\text{H}_2\text{O}$.

Functionalize: to change surface properties of a material by adding or removing functional groups.

Ion selectivity: the affinity a compound shows for reacting with different ions. An ion with a higher ion selectivity will tend to displace an ion in the compound that has a lower ion selectivity.

Tectosilicate compound: a silicates compound having a three-dimensional framework of silicate tetrahedra with SiO_2 or a 1:2 ratio.

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- [3] R. M. Durborow, D. M. Crosby and M. W. Brunso, "Ammonia in Fish Ponds," Southern Regional Aquaculture Center, 1992, No. 463.
- [4] S. S. Verma, "Wonders of Zeolite," Chemical Business, 2012, 26(2), pp. 10-12.

It will be seen that the advantages set forth above, and those made apparent from the foregoing description, are efficiently attained and since certain changes may be made in the above construction without departing from the scope of the invention, it is intended that all matters contained in the foregoing description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

What is claimed is:

1. A system for removing ammonia from a water environment, comprising:
 - a water environment containing ammonia;
 - a functionalized tectosilicate compound, the functionalized tectosilicate compound produced by the steps of:

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obtaining a tectosilicate compound wherein the tectosilicate compound is chabazite;
 functionalizing the tectosilicate compound, comprising soaking the tectosilicate compound in a synthetic freshwater solution and removing ions from the tectosilicate compound that have a lower ion selectivity than ammonium ions wherein the synthetic freshwater solution consists of:
 0.075 g/L of sodium;
 0.00312 g/L of potassium;
 0.024 g/L of magnesium;
 0.193 g/L of chloride
 0.043 g/L of calcium;
 0.0048 g/L of bicarbonate;
 0.096 g/L of sulfate; and
 0.310 g/L of alkalinity;
 washing the functionalized tectosilicate compound in deionized water and then drying the compound; and

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a pH buffer, wherein the pH buffer is K_2HPO_4 or KH_2PO_4 in a solid state wherein an amount of the pH buffer used is such that the pH buffer maintains a pH of 7 in the water environment; and
 a container holding the functionalized tectosilicate compound and the pH buffer, the container comprising a porous material to allow water to flow through the material;
 wherein the pH of 7 of the water environment shifts an equilibrium between ammonia and ammonium in the water environment towards ammonium, and the ammonium is adsorbed by the functionalized tectosilicate.
 2. The system of claim 1, wherein removing ions from the tectosilicate compound comprises removing sodium ions from the tectosilicate compound.
 3. The system of claim 2, wherein functionalizing the tectosilicate compound reduces a percentage of sodium in the compound by at least 50 percent.

* * * * *