A System of dehydration, purification, and reduction for dredged soil – Release inhibition of nutrient salts from bed mud using natural zeolite

Un système de déshydratation, d'épuration et de réduction de sols dragués - Prévention du relâchement de sels nutritifs des lits de boue à l'aide d'une zéolithe naturelle

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ABSTRACT: In a closed water body such as a lake, many nutrient salts such as nitrogen and phosphorus are contained in bed mud deposited on the bottom. Their release is one of the causes of eutrophication. We propose a zero-emission system to preserve the ecosystem in a closed water body. Applying the system obviates landfill sites for dredged soil and reduces countermeasure costs. In the system, the bed mud is dredged and then reduced to the bottom after dehydration and purification treatments that reduce their volume and absorb nutrient salts. To realize a suitable bottom environment, reclaimed soil requires moderate flexibility. Consolidation tests were conducted on the bed mud with natural zeolite powder as absorbent, and column tests were also conducted for release inhibition of nutrient salts on the treated soil and lake water. Based on test results, the effectiveness of dehydration and purification was investigated. Main conclusions are as follows: Applying about 30 kPa of low consolidation pressure, water contents approach the liquid limit and the volume decreases to about two-thirds. For simulating the proposed system, the release of nutrient salts is inhibited and development of algae is prevented.

RÉSUMÉ : Dans un plan d'eau fermé tel qu'un lac, le lit de boue déposé au fond contient des sels nutritifs tels que l'azote et le phosphore. Leur libération est l'une des causes de l'eutrophisation. Nous proposons un dispositif sans émission pour préserver ce type d'écosystème. Le système permet d'éviter la mise en décharge de ces sols dragués et réduit les coûts économiques. Dans ce principe, le lit de boue est dragué puis redéposé au fond après déshydratation et purification pour en réduire son volume et absorber les sels nutritifs. Pour réaliser un environnement convenable au fond du plan d'eau, le sol récupéré exige une souplesse modérée. Des tests de consolidation sur de la boue avec de la poudre de zéolithe naturelle comme absorbant ont été effectués, ainsi que des essais en colonne pour inhiber le relâchement de sels nutritifs dans le sol traité et l'eau du lac. L'efficacité de la déshydratation et de la purification ont été étudiées sur la base de ces résultats. Les principales conclusions sont que l'application d'une pression de consolidation faible d'environ 30 kPa permet d'approcher la limite de liquidité des sols dont le volume diminue d'environ deux tiers. L'avantage du système proposé est de prévenir le relâchement de sels nutritifs et le développement d'algues.

KEYWORDS: closed water body, eutrophication, nutrient salts, bed mud, natural zeolite, consolidation, protection of ecosystem

1 INTRODUCTION

In a closed water body such as a lake, eutrophication is accelerated by nutrient salts such as nitrogen and phosphorus that inflow from rivers and which are released from bed mud deposited on the bottom. Many algae develop in the water, causing problems such as water pollution and offensive odors. Dredging of bed mud has been used as a countermeasure. However, dredging work is rarely conducted because of high transportation costs of dredged soil with high water content. Moreover, landfill sites are scarce.

As described herein, we propose a zero-emission system for ecosystem preservation in a closed water body. The system, as shown in Figure 1, dredges, dehydrates, purifies, and reduces bed mud. First, the system outline is discussed. Next, consolidation tests and column tests of bed mud simulating this system were conducted to verify the system effectiveness. Based on test results, dehydration, volume reduction, and release inhibition of nutrient salts from the treated soil were discussed.

2 A ZERO-EMISSION SYSTEM FOR ECOSYSTEM PROTECTION

Figure 1 shows an outline of the proposed system, which has three processes: (a) dredging, (b) dehydration and purification, and (c) reduction. The system concept is the following.

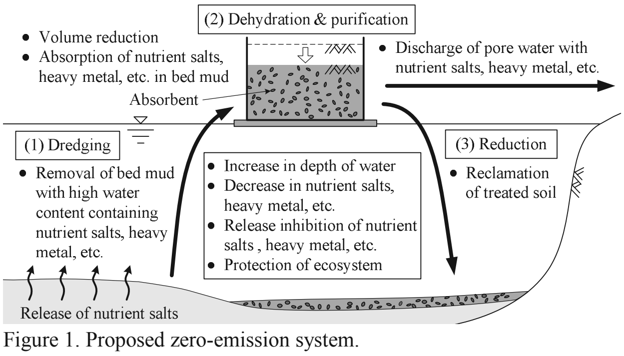
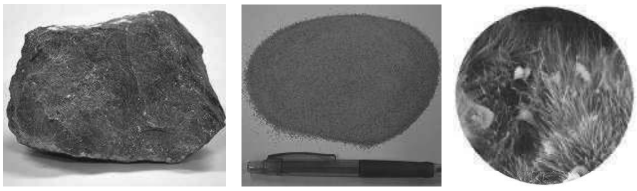


Figure 1. Proposed zero-emission system.

(1) To remove nutrient salts, heavy metals, etc. from the bed mud, the bed mud is dredged.
(2) By adding an environment-friendly adsorbent such as natural material to the bed mud, nutrient salts and heavy metals are adsorbed and immobilized.
(3) The volume of bed mud is reduced by dehydration, and nutrient salts and heavy metals are removed with drained water. After water quality analysis and suitable treatment, the drainage water is discharged.
(4) The treated soil is reclaimed to the bottom of the water and a zero-emission system is realized. The soil should be deformed flexibly with self-weight to avoid increasing the volume of reclaimed soil and release of nutrient salts from



(a) Natural zeolite consists primarily of mordenite (b) Natural zeolite powder (under 0.5 mm) (c) Electron micrograph (MINDECO, 2012)

Photo 1. Natural zeolite (Shimane Prefecture, Japan).

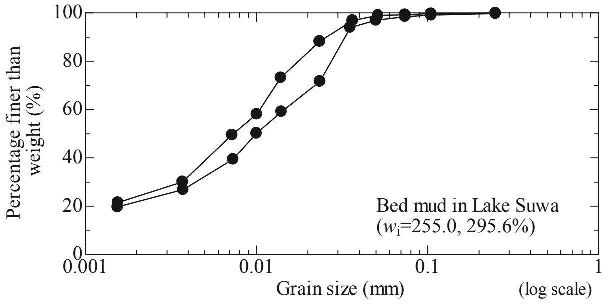


Figure 2. Grading curve of bed mud sampled in Lake Suwa.

Table 1. Physical properties of bed mud sampled in Lake Suwa.

w_i	255.0–295.6%	L_i	15.4–16.2%
ρ_s	2.520–2.582 g/cm^3	Clay fraction (%)	30–40%
w_L	155.0–165.0%	Silt fraction (%)	58–69%
w_P	102.0–104.2%	Sand fraction (%)	1–2%
I_P	53.0–61.3		

Table 2. Nutrient salt contents of dry bed mud.

Total nitrogen, T-N	3990–4200 mg/kg
Total phosphorus, T-P	1800–2000 mg/kg
Ammonia nitrogen, NH_4-N	248–258 mg/kg

Table 3. Nutrient salt contents of lake water.

Total nitrogen, T-N	0.48–0.52 mg/L
Total phosphorus, T-P	0.014–0.022 mg/L
Ammonia nitrogen, NH_4-N	0.03–0.09 mg/L
Chemical Oxygen Demand, COD	2.8–3.8 mg/L

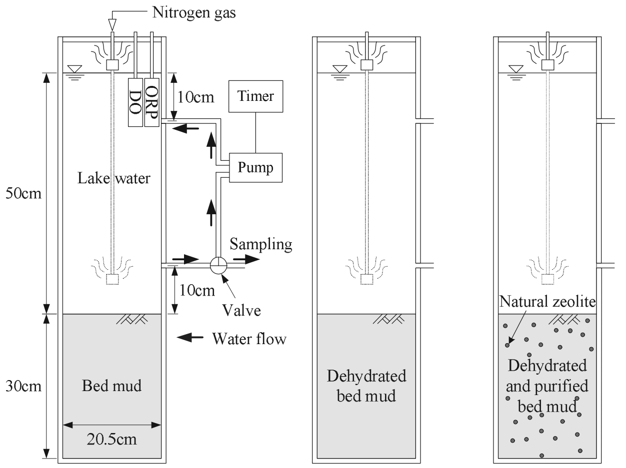
no dredged bed mud. Simultaneously, a suitable environment for living things on the bottom of water, such as plants, insect nymphs, and shellfish, is formed.

(5) Increased water depth, release control of the nutrient salts, and immobilization of heavy metals are realized, and an ecosystem is preserved.

3 SAMPLES AND TEST PROCEDURES

3.1 *Natural zeolite*

Natural zeolite powder with particles smaller than 0.5 mm produced in Shimane Prefecture, Japan was used as an environment-friendly adsorbent (see Photo 1). The main mineral composition is mordenite (see Photo 1(a)), a light green, natural, inexpensive, and safe mineral produced from a mine. Zeolite, which contains large cavities and channels of angstrom scale (JSPS, 2006), exhibits characteristics of ion exchange and gas adsorption within its structural space. For the natural zeolite used for this study, the cavity size was 6.7–7.0Å (Photo 1(c), (MINDECO, 2012)) and the cation exchange capacity is CEC = 120–180 meq/100 g. The main application is soil improvement, water quality purification, etc., and it is useful to absorb ammonia, hydrogen sulfide, and nitrous acid from water, which cause bad odors (MINDECO, 2012). Moreover zeolite is effective as a bacteria carrier to resolve nutrient salts in the water (e.g. Popovici et al., 2011).



(a) Case A: Bed mud without treatment (b) Case B: Dehydrated bed mud (c) Case C: Dehydrated and Purified bed mud

Figure 3. Column test apparatus and test conditions.

Table 4. Conditions of column tests.

Case	Test conditions
Case A	Bed mud without treatment (water content, w_i=255.0%)
Case B	Bed mud (w_0=160.3%) dehydrated by consolidation
Case C	Bed mud (w_0=152.0%), to which was added 10% of natural zeolite powder for dry mass and dehydrated by consolidation

3.2 *Bed mud and lake water*

Bed mud was dredged using a grab type sampler at Lake Suwa in Nagano Prefecture, Japan. Lake water was sampled at the lakefront of Lake Suwa. The particle size distribution and physical properties of bed mud and content of the nutrient salts in bed mud and lake water are presented, respectively, in Figure 2 and Tables 1–3. In that figure and tables, w_i stands for the initial water content at dredging, ρ_s signifies the density of soil particle, w_L denotes the liquid limit, w_P represents the plasticity limit, I_P is the plasticity index, and L_i is the ignition loss. Tables 2 and 3 show contents of nutrient salts in bed mud as 3000–150,000 times greater than those in lake water. To improve eutrophication, countermeasures against bed mud are required.

3.3 *Consolidation test*

Two cases of the consolidation test of bed mud were conducted with and without natural zeolite powder. In one case, consolidation was conducted without natural zeolite (Case B in column test). In another case, 10% of natural zeolite powder (see Photo 1(b)), of which particle size is less than 0.5 mm, for the dry mass of bed mud was added and consolidation was conducted (Case C in column test). Consolidation pressure was increased step by step and the loading was continued until the water content calculated using drainage mass became w_L. Water quality analysis of the drainage water was conducted after consolidation. Analytical items are the total nitrogen (T-N), total phosphorus (T-P), ammonia nitrogen (NH_4-N), and chemical oxygen demand (COD). The analytical method followed Japanese Industrial Standards (JIS).

3.4 *Column test for release of nutrient salts*

Three column tests were conducted in reference to a manual of the Japan Sediments Management Association (2003). The outline and conditions of the test are presented in Figure 3 and Table 4. The bed mud was filled to 30 cm height into the acrylic cylinder with 20.5 cm inner diameter and 100 cm height. Moreover, lake water was poured carefully to 50 cm on the bed mud. A dissolved oxygen amount (DO) meter and oxidation reduction potential (ORP) meter were installed, and the top of the column was covered with a lid. Then, by the aeration of nitrogen gas near the bottom, lake water became an anaerobic condition (DO<1 mg/L), in which nutrient salts were released easily from bed mud. During the test, discharge of a slight amount of nitrogen gas was continued near the water surface to maintain an anaerobic condition. Circulation of lake water was performed. Tests were continued through 80 days. To verify the release inhibition effect, water quality analysis was conducted during a fixed period. All tests were conducted in a thermostatic chamber with room air temperature of 23±1°C in which the fluorescent light was illuminated continuously.

4 TEST RESULTS AND DISCUSSIONS

4.1 *Volume reduction and removal of nutrient salts through dehydration*

The relation of the water content w and the consolidation pressure p obtained from the consolidation tests is shown in Figure 4. A normal consolidation line was also obtained from the consolidation test using incremental loading. Initial water contents of the bed mud, w_i, were about 300% (Cases A and B). Furthermore, it is a slime-like condition as shown in Photo 2(a). The water content after adding natural zeolite powder, w_i^*, decreases slightly (Case C). However in Cases B and C, by application of 30 kPa of low consolidation pressure, the relation between w and p is almost identical. The volume decreased to about two-thirds and the water content becomes about w_L. The bed mud condition changes to a moderate consistency with flexibility by self-weight (see Photo 2(b)). The bed mud with w_L has workability for reclamation. Furthermore, it is expected that a suitable environment for living things on the bottom and realize inhibition of nutrient salts (see 2(3) and 2(4)). If 200 kPa of consolidation pressure is applied, then the water content becomes about w_P. The condition with w_P is hard and flexibility passes away. The consolidation pressure of the filter press, which is generally used to dehydration work, is too high. Using a simple dehydration machine, the countermeasure cost can be curtailed.

Figures 5(a)–5(d) show contents of T-N, T-P, NH_4-N, and COD in the drainage water and lake water. In Case B without natural zeolite, these contents are 28, 62, 4.2, and 2.4 times of lake water respectively, the nutrient salts in bed mud can be removed with drainage water. For Case C with natural zeolite powder, they are, respectively, 7.9, 11, 6.8, and 3.9 times. The contents of T-N and NH_4-N decrease to about one-fourth and one-sixth of Case B because of the adsorption effect of natural zeolite. The values of T-N, T-P, and COD are larger than those of water quality standards for lakes in Japan. However, the contents of all cases are much smaller than in original bed mud (Table 2). The values of contents in bed mud for Cases B and C differ only slightly from the initial value.

4.2 *Release inhibition of nutrient salts from bed mud*

The conditions of lake water at the initial stage and after 40 days are presented in Photos 3(a)–3(d). The lake water at the beginning of test is almost clear (Photo 3(a)). In Cases A and B without natural zeolite powder, the lake water gradually becomes turbid (Photos 3(b) and 3(c)). In Case A with no treatment, algae begin to increase in the lake water after about 20 days; the color becomes green. After 40 days, the luxuriance of algae reaches a peak, with adhesion of algae on the inner surface of container (Photo 3(b)). The algae in the column are cyanobacteria, which generate oxygen by photosynthesis because of increase in DO from 30 days, which is not shown. After about 60 days, the green water gradually pales. In Case B,

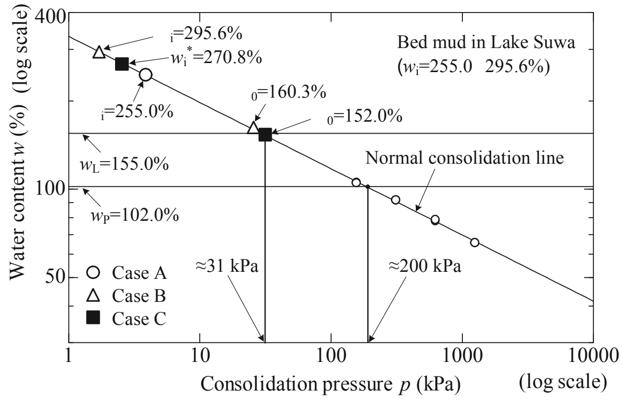
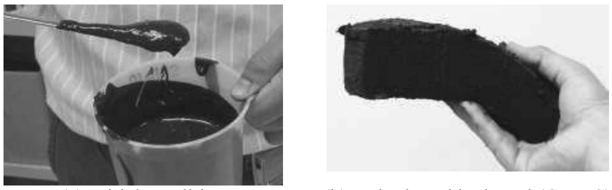


Figure 4. Relation between water content and consolidation pressure.



(a) Initial condition (b) Dehydrated bed mud (Case C)

Photo 2. Dehydration of bed mud by consolidation.

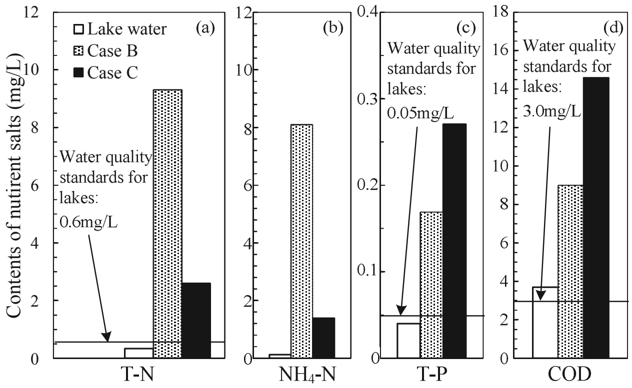
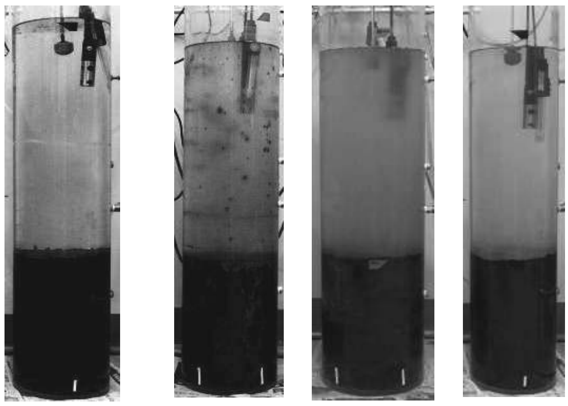


Figure 5. Nutrient salt contents in drainage water.



(a) Initial condition (b) Case A (c) Case B (d) Case C

Photo 3. Test results obtained after 40 days.

which was dehydrated by consolidation, algae regarded as cyanobacteria increase and the lake water color changes as well as Case A (Photo 3(c)). However algae are not observed on the container inner surface. In Case C, to which was added natural zeolite powder and dehydrated by consolidation, algae cannot be found in the lake water, and the lake water color changes only slightly (Photo 3(d)).

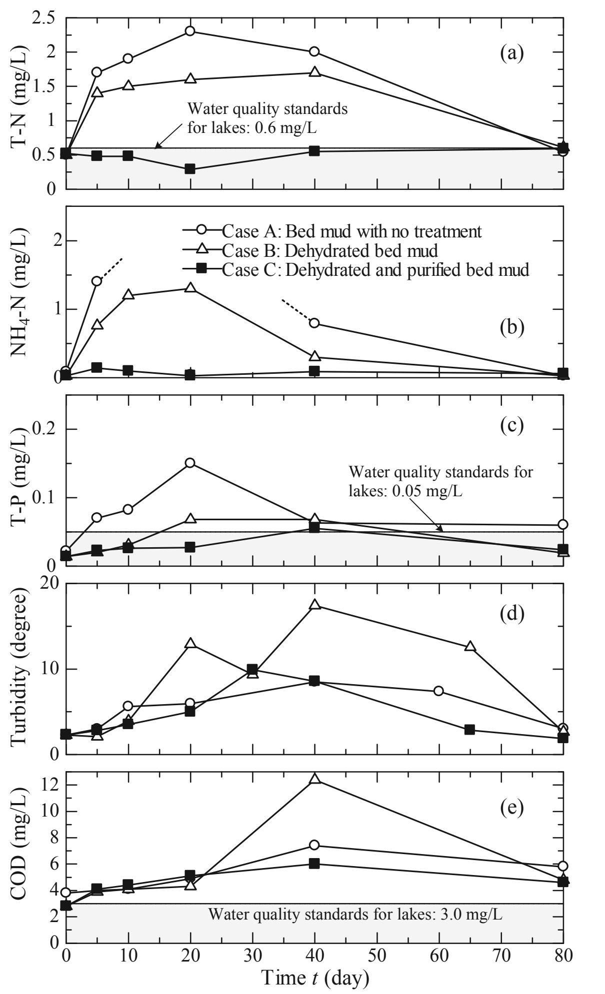


Figure 6. Analysis results of water quality.

Figures 6(a)–6(e) present some analysis results of lake water. The initial T-N and T-P values are about 0.5 and 0.02 mg/L, which are below the water quality standards for a lake in Japan. The initial values of COD are 3–4 mg/L, that of Case A is slightly larger than the standard value.

In Cases A and B without natural zeolite powder, the values of T-N, NH_4-N, and T-P increase greatly with elapsed time until after about 20 days (Figures 6(a)–6(c)). Compared to the water quality standards for a lake in Japan, the values of T-N after 20 days are 3.8 and 2.7 times, and those of T-P after 20 days are 3 and 1.4 times, respectively. The release of nutrient salts from bed mud is great and no release inhibition effect by dehydration is observed. Subsequently, these values decrease gradually. The values of T-N and NH_4-N after 80 days decrease nearly to initial values and that of T-P decreases to the standard value after 40 days. The decrease in nutrient salts is thought to result from digestion of cyanobacteria. The turbidity and COD increase gradually and reach a peak after about 40 days; they decrease gradually thereafter (Figures 6(d) and 6(e)). These tendencies are likely related to cyanobacteria development.

However, in Case C with natural zeolite powder, the values of T-N and T-P are maintained as lower than the values of water quality standards, and that of NH_4-N is almost maintained initial value. The value of T-N after 20 days decreases to half the standard value (Figures 6(a)–6(c)). Algae do not grow in the lake water (Photo 3(d)). The release inhibition effect of natural zeolite is recognized. The absorption effect for nitrogen in the lake water is also recognized. However, the values of turbidity and COD increase gradually as well as Cases A and B (Figures 6(d) and 6(e)). The value of COD exceeds the standard value. It is probably the increase in dissolved organic matter in lake water. Therefore, additional countermeasures against COD are required.

5 CONCLUSIONS

A zero-emission system was proposed for preservation of the ecosystem in a closed water body. The system has three processes: (a) dredging, (b) dehydration and purification, and (c) reduction. Consolidation tests and column tests for bed mud and lake water sampled in Lake Suwa, Japan were conducted simulating this system. Natural zeolite powder was used as the absorbent for purification. Based on the test results, the effectiveness of the system was examined. Main conclusions are as follows.

(1) Applying about 30 kPa of low consolidation pressure, the volume of bed mud with high water content can be decreased to about two-thirds. The water content reaches the liquid limit, w_L. The bed mud condition changes to a moderate consistency and workability for reclamation is obtained. For reclaimed soil with w_L, a suitable environment for habitation of living things is formed at the bottom of the water. Moreover, reclaimed soil volume is reduced, because it can be deformed flexibly with self-weight.

(2) In the column test for bed mud with no treatment, total nitrogen (T-N), total phosphorus (T-P), and chemical oxygen demand (COD) surpass water quality standards for lakes in Japan. The release of nutrient salts from bed mud is clearly recognizable and many algae developed in the water. To inhibit eutrophication, it is necessary to control the release of the nutrient salts from bed mud.

(3) For bed mud dehydrated by 30 kPa, T-N, T-P, and COD in the lake increase as in the case with no treatment. Dehydration of bed mud alone is insufficient for release inhibition of nutrient salts.

(4) For bed mud dehydrated by 30 kPa and purified using natural zeolite powder, the contents of T-N and T-P meet water quality standards for lakes. Especially, total nitrogen decreases because of absorption of nitrogen in the water by natural zeolite. Algae do not grow. The release inhibition effect for nutrient salts of natural zeolite is recognized. However additional countermeasures against COD are required.

6 ACKNOWLEDGEMENTS

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