Experimental research on river and lake silts adjusted by a low alkaline silt modifier using as planting soils for greening

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Abstract. To solve the high pH problem of the filter and the dewatered silt cake during the treatment and disposal of the river and lake silt, a low alkaline silt modifier was employed in this research. To contrast the performance, PAC, PAM and together with the fly ash, conventional silt modifier, and the low alkaline silt modifier were added in the silt sample. The silt was dewatered using a pilot-scale plate and frame filter press. It is found that the filter and the dewatered silt cake with the low alkaline silt modifier were weakly alkaline, TN and TP are also lower than the other groups. The internal mechanism and feasibility of the dewatered silt cake were analyzed and demonstrated by micro-tests (e.g. XRD and SEM). The results indicated the steel slag, phosphogypsum and cement in the low alkaline silt modifier can provide mineral framework, increase the porosity of the silt cake and improve the dewatering performance of silt as the fly ash and the conventional modifier, while the steel slag, phosphogypsum in the low alkaline silt modifier could improve the distribution of phosphorus in the dewatered cake, promote the transformation of bioavailable phosphorus, and improve soil fertility.

1. Introduction

Dredging is an effective way to improve the water quality and rebuild the ecology, after the pollutant source gets under certain control. With the increasing dredging numbers of dredging projects, the treatment and disposal of the silt which contain nutrient salt and other pollutants has become an important task of pollution control of rivers and lakes. Plate-and-frame pressure filtration is the most common treatment method for the silt, while the high pH of dewatered silt cake which resulted from the conventional silt modification agent restricts the subsequent resource utilization of the dewatered silt cake[1]. The secondary pollution and pollution by the pollutants in dewatered silt cake is of great concern in the utilization of dewatered silt cake, due to the dewatered silt cake may involve nutrients, heavy metals, and refractory organics[2].

Phosphorus is an important essential nutrient for plant growth, and phosphorus has become the bottleneck to solve the world food problems[2,3]. Approximately 1/3~1/2 of the cultivated soil in China is short of phosphorus, and the dewatered silt cake usually contains a considerable amount of phosphorus. It is of great significance to research the forms of phosphorus in dewatered silt cake for land use[4]. The forms of phosphorus in silt are of different classification according to the characteristics and research directions, this research adopted the widely used SMT method to analysing the phosphorus in sediment considered its simple operation and preferable repetition. The SMT sequential extraction method comprises 5 steps i.e. NaOH-extractable P (P bound to Al, Fe and
Mn oxides and hydroxides), HCl-extractable P (P associated with Ca), organic P, inorganic P, and concentrated HCl-extractable P (total P) [5,6].

This research investigated the pollutants in the dehydration water and the dewatered silt cake, the forms of phosphorus, and the fertilizer efficiency of the silt sampled from a river in Zaoyang China which is modified by a low-alkaline silt modifier. The research aims to support the resource utilization of dredging bottom sludge.

2. Materials and methods

2.1. Sediment

The sediment used in this research was collected from the urban section of Sha-he River in the city of Zaoyang, China, and the sediment was sampled from the surface layer about 0.5 m. The sediment were screened to remove debris such as stones, branches and leaves, and passed through a 2 mm sieve. The moisture content of the resulting raw sediment (RS) was 64.6 wt%, the organic matter content was 2.8 wt%, the pH was 7.4, the total nitrogen (TN) content was 40g~2280mg/kg, and the total phosphorus (TP) content was 232~1770mg/kg. The TN and TP in Shahe River is heavily polluted, according to the classification standards formulated by EPA. The concentration of heavy metals in the sediment did not exceed the control standard of soil environmental quality risk control standard for soil contamination of agricultural land GB 15618—2018 in China.

2.2. Sediment conditioning and dewatering

According to previous experiments, the concentrations of poly-aluminium chloride (PAC) and polyacrylamide (PAM) solutions used for silt conditioning were 10 wt% and 0.25 wt%, respectively, and the conditioning dosages were 3.3 wt% DS and 0.1 wt% DS, respectively. The low alkaline silt modifier, fly ash, and the conventional silt modification agent were added in solid form, respectively. Four group of experiments were carried out to research the dewatering characteristics of sludge by plate and frame filter under the conditioning of four agents. The specific experimental conditions are as follows the content is mass percentage, all chemicals used in this research were of analytical grade:

1) Group CK, acted as the blank group, was used to regulate the mud without any chemicals;
2) Group A, the dosage of PAC, PAM and the conventional sludge modifier were 0.5%, 0.12‰, and 0.5% respectively;
3) Group B, the dosage of PAC, PAM and fly ash were 0.12 ‰, 0.3% and 0.5%, respectively;
4) Group C, the dosage of PAC, PAM and the low alkaline silt modifier were 0.12 ‰, 0.3%, and 0.5% respectively.

The PAM used in this research is of anionic type, with molecular weight of 5-8 million and the content of alumina in PAC is 28%. The main raw material of the low alkaline silt modifier is low alkaline steel slag, phosphogypsum, and a small amount of cement. The steel slag used is from an iron and steel company in Wuhan City, China, with particle size less than 5 mm, density is 3470 kg / m³ and specific surface area is 435 m²/kg. The main chemical compositions of steel slag are CaO, SiO₂ and Fe₂O₃, which is shown in table 1. The main minerals of steel slag are C₃S, C₄S, C₄AF and C₁₂A₇, which is shown in Fig2. The fly ash used in this research are superfine fly ash floating beads produced in Rizhao, China. The physical properties are shown in table 2.

Table 1. The Chemical composition of steel slag

| Oxide   | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO  | MgO  | TiO₂ | SO₃ | P₂O₅ | MnO | Loss |
|---------|------|-------|-------|------|------|------|-----|------|-----|------|
| Steel slag (%) | 13.05 | 2.72  | 24.86 | 44.03 | 6.70 | 0.75 | 0.33| 1.50 | 1.45| 3.89 |

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Dewatering tests were performed using a pilot-scale plate and frame filter press with four diaphragm plates (870mm×870mm plates). After conditioning, the silt was pumped into a sealed storage tank. The internal pressure was controlled by the air compressor used to feed the sludge to the plate and frame filter press. The pressure of the feeding and filtrating stage was 0.7 MPa for 45min, and the diaphragm plates were injected with compressed water at 1.2 MPa for 10 min to squeeze the diaphragm plates for additional dewatering. After the pressure was released, the solid cakes in the chambers were removed and tested.

### 2.3 Analysis and testing

The water content (WC) of the dewatered cake and the silt were determined after the cake was dried at 105 °C for 24 h. The pH value of dewatered cake was determined by pH meter after extracted with 2.5 times of water. For the water samples, TP concentration was measured using Nessler’s reagent spectrophotometry (HJ535-2009) and molybdate spectrophotometry (GB/T 11893-1989). TN concentration was measured using ultraviolet spectroscopy method (HJ 636-2012) after digestion by alkali-line potassium persulfate. The surface morphology of the mud cake samples was obtained by field emission scanning electron microscope (Zeiss, sigma HD), and the elemental content of the samples was analysed by EDS. The silt cake was characterized by X - ray diffraction with 40 kV and 40 mA copper targets (Bruker AXS D8 focus, Germany). The SMT separation method developed under the framework of the European Committee for testing and standards is adopted for phosphorus speciation analysis in sediments[6,7].
3. Results and discussion

3.1. Properties of the cake
The SEM image of group CK dewatered silt cake (Figure 2a) shows that the original silt contains a lot of clay minerals, the particles are stacked and contacted, and the porosity is not obvious, which is not difficult for the internal water discharge. The internal particles of the dewatered silt cake regulated by fly ash, conventional sludge modifying agent and low alkaline silt modifier agglomerated gradually, and the pore development between particles increased, which is conducive to the internal water discharge. The analysis results of the EDS (Table 3) also show that the content of calcium and iron in dewatered silt increases significantly after adding low alkaline silt modifier, which is due to the iron and calcium in steel slag, phosphogypsum and other components of modifier.

![SEM images of the dewatered silt cake with different conditioners](image-url)

**Figure 2.** SEM images of the dewatered silt cake with different conditioners

| Elements | CK | A  | B  | C  |
|----------|----|----|----|----|
| Si       | 21.29 | 23.95 | 12.12 | 21.98 |
| Al       | 9.93  | 11.1 | 9.52  | 12.83 |
| Fe       | 4.84  | 4.8  | 4.64  | 13.44 |
| Ca       | 3.25  | 2.79 | 0.17  | 5.96  |

In order to explore the microcosmic solidification composition of the dewatered silt cake treated by different silt modifier, the cake samples dewatered after 28 days were analysed by XRD (Figure 3).
The results show that the low alkaline silt modifier can lead hydration reaction and form silicate mineral skeleton on the basis of flocculation. Meanwhile, the content of CHS hydrated calcium silicate in the dewatered silt cake by the low alkaline silt modifier is significantly lower than that of the solidified products of the fly ash group and the conventional silt modifier group[8,9]. CSH could fill the pores and cement soil particles, which promotes the development of solidified cake strength, thus explaining the mechanism of low pH of dewatered silt cake conditioned by low alkaline silt modifier at the micro level. Phosphogypsum played an obvious role in reducing the pH of dewatered silt cake. Previous studies have shown that the pH of the solidified body is significantly lower than that of cement if the cement paste tailings were replaced by the phosphogypsum based materials. Moreover, adding phosphogypsum to soil can adjust pH of the soil to neutral for a long time and improve soil properties [10,11].

![XRD analysis results of mud cake after different sludge conditioning](image)

**Figure 3.** XRD analysis results of mud cake after different sludge conditioning

### 3.2. Variations of the Phosphorus morphological

![Forms and distribution of phosphorus in silt cake conditioned with different chemicals](image)

**Figure 4.** Forms and distribution of phosphorus in silt cake conditioned with different chemicals

The morphic distribution of the phosphorus in the dewatered silt cake are shown in Figure 4. The total phosphorus in the dewatered silt cake varied little, and the proportion of exchangeable phosphorus in mud cake increased significantly after conditioning with low alkaline silt modifier. The PAC and PAM added into the silt may lead to the uniformity of total phosphorus in the dewatered silt cake, as the PAC and PAM which can remove the phosphorus in the water in the range of pH 6~8.5, and the pH value of each group is roughly consistent with the appropriate range[12]. The increase of the
proportion of Ex-p in the dewatered silt cake conditioned by low alkaline silt modifier could be connected to the steel slag and phosphogypsum, which may strengthen the adsorption of phosphorus. The HCl-p is the active portion of phosphorus forms, which can be biologically utilized. The NaOH-p is a relatively inert phosphorus form in the dewatered silt cake, and this form is relatively stable[6,7]. The HCl-p and NaOH-p in the dewatered silt cake regulated by the low alkaline silt modifier is relatively lower, these two forms may be transformed into the exchangeable Ex-p, while the specific mechanisation of the transformation needs further research. At the same time, the transformation is beneficial to improve the supply capacity of soil phosphorus and soil productivity for the land use of de dewatered silt cake.

3.3. Quality of the filtrate
Table 4 shows pH of the filtrate in the low alkaline silt modifier group was significantly lower than the group A, and also slightly lower than that in the fly ash group. Generally, fly ash is weakly alkaline, and pH of the filtrate rises[3]. The conventional silt modifier contains more alkaline substances, which leads to the high pH of the filtrate, and the alkalinity of the filtrate required to be reduced to meet the mission emission standards. TN and TP of the filtrate in the different groups varied little, and the filtrate of the low alkaline silt modifier is slightly lower than that of fly ash group and conventional silt modifier group, which may be resulted in the specific surface area and the adsorption characteristics of steel slag in the low alkaline silt modifier[13-17]. The steel slag has a high phosphorus adsorption capacity, and the characteristic is mainly owing to chemical precipitation and ligand exchange[14]. The calcium oxide in steel slag is abundant, which can easily form amorphous calcium phosphate, and more stable calcium hydroxy phosphate precipitation with the hydrogen phosphate ion in solution[7].

Table 4. The pH, TN, TP of the filtrate by different modifiers

| Sample            | river water | Group A | Group B | Group C |
|-------------------|-------------|---------|---------|---------|
| pH                | 7.24        | 9.98    | 7.98    | 7.62    |
| TN(mg/L)          | 4.99        | 5.96    | 7.21    | 4.13    |
| TP(mg/L)          | 0.430       | 0.413   | 0.438   | 0.302   |

3.4. Fertility of the cake
The fertility of the dewatered silt cake before and after modifier conditioning was tested to investigate the feasibility of employing the cake as planting soil, and evaluate the effect of low alkaline silt modifier on the nutrients. Table 2 shows that the pH of the dewatered silt cake treated by the low alkaline silt modifier is neutral, and the modification improves the soil permeability. In particular, the available potassium and magnesium in group C were significantly higher than those in the group A and B, while there was no significant difference in other fertility indexes. Lu et al. found that adding steel slag and biochar to red soil can increase the content of exchangeable cations and exchangeable magnesium[18,19]. If the dosage is well controlled, the soluble trace elements in the steel slag are helpful to improve soil fertility.

Table 5. Fertility analysis of the silt cake with and without modifier

| Sample                        | CK    | C     |
|-------------------------------|-------|-------|
| pH                            | 7.22  | 7.1   |
| Salt content ms/m             | 83.4  | 106.4 |
| Soil infiltration rate, mm/h  | 55    | 53    |
| Organic matter, g/kg          | 17.6  | 19.4  |
| Cation exchange capacity, cmol(+)/kg | 9.3  | 16    |
| Hydrolytic N, mg/kg           | 44.5  | 76.2  |
Available P, mg/kg | 30.9 | 33.8
Available K, mg/kg | 78  | 201
Available S, mg/kg | 8.5  | 13.8
Available Mg, mg/kg | 48.1 | 82.4
Available Ca, mg/kg | 512  | 920
Available Fe, mg/kg | 19.8 | 24.4
Available Mn, mg/kg | 5.8  | 8.6
Available Cu, mg/kg | 0.59 | 0.95
Available Zn, mg/kg | 1.7  | 2.2
Available Mo, mg/kg | 0.15 | 0.2
Soluble chlorine, mg/kg | 64  | 504

4. Conclusions
(1) The steel slag, phosphogypsum and cement in the low alkaline silt modifier can provide mineral framework, increase the porosity of the silt cake and improve the dewatering performance of silt.
(2) The content of TN and TP in the filtrate of the low alkaline silt modifier group is lower than that of fly ash and conventional silt modifier group, this improvement is helpful to reduce the internal pollution of the rivers and lakes.
(3) From the perspective of land use, the low alkaline silt modifier could improve the distribution of phosphorus in the dewatered cake, promote the transformation of bioavailable phosphorus, and improve soil fertility during land use.

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