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Clean-up and disposal process of polluted sediments from urban rivers

HE Pin-jing[1], SHAO Li-ming[1], GU Guo-wei[1], BIAN Cheng-lin[2], XU Chen[2]

(1. State Key Laboratory of Pollution Control and Resource Reuse School of Environmental Science and Engineering, Tongji University, Shanghai 200092, China. E-mail: yangbibiyang@etang.com; 2. Urban River Management Agency, Yangpu District, Shanghai 200093, China)

Abstract: In this paper, the discussion is concentrated on the properties of the polluted sediments and the combination of clean-up and disposal process for the upper layer heavily polluted sediments with good flowability. Based on the systematic analyses of various clean-up processes, a suitable engineering process has been evaluated and recommended. The process has been applied to the river reclamation in Yangpu District of Shanghai City, China. An improved centrifuge is used for dewatering the dredged sludge, which plays an important role in the combination of clean-up and disposal process. The assessment of the engineering process shows its environmental and technical economy feasibility, which is much better than that of traditional dredging-disposal processes.

Keywords: urban rivers; polluted sediments; clean-up; disposal; dredging; dewatering; feasibility analysis

Introduction

The urban river basins are generally located in constructed regions, easily influenced by human activities. Contaminants in effluents from industries and residential areas contribute to urban river pollution. Aquatic contaminants precipitate to the bottom of the rivers and produce polluted sediments (bottom sludge) through complex physical, chemical and biological processes. Moreover, the contaminants in the sediments are able to release into the water and result in water pollution. Therefore, clean-up and disposal of the polluted sediments is a necessary step in the reclamation process of urban rivers(He, 1997).

Different selection and combination of various clean-up and disposal processes for the polluted sediments influences the urban environments in different ways(Hauge, 1998). It is necessary to develop a suitable process combination in accordance with the pollution characteristics of the sediments and the site-specifics related to engineering conditions.

1 Engineering features for the clean-up and disposal of the polluted sediments in urban regions

1.1 Sediments properties

The physical-chemical analytical results of the typical polluted sediments in Shanghai are shown in Table 1. From the data, the polluted sediments from urban rivers have some special features:

(1) Pollution characteristics of the sediments. The pollution level of the sediments is closely related to the water quality of the rivers and the contaminants in the sediments are strongly influenced by the effluents that the river has received. Effluents with high levels of heavy metals and organic contents originating from the industrial and municipal pollution sources drain to the rivers and then cause heavily polluted sediments.

Table 1 Physico-chemical properties of the polluted sediments from urban rivers in Shanghai

Rivers	Water content, %	Organic content*, %	Element content*, mg/kg								
			TN	TP	Cr	Hg	Cd	Pb	Cu	Zn	Mn
Suzhou Creek	–	3 – 12	–	–	64.4	1.14	2.67	112.4	113.4	357.5	566.9
Zoumatang	72.0	12.0	2900	–	225	0.38	0.60	39.0	162	774.3	294
Yangpugang	–	15.9	3200	–	636	0.58	1.20	133.0	2526	4652	31

* Dry weight basis

(2) Settlement properties of the sediments. Compared with ordinary river bottom materials whose formation mechanisms differ from the polluted sediments, the latter has special settlement properties: high porosity and high water content (> 70 %), which lead to high flowability similar to that of water. The polluted sediments are mainly located in the upper layer of the bottom material (within 1.0m deep below the solid-liquid interface).

(3) Accumulation features of the sediments. Accumulation of the sediments from urban rivers is a continuous process. It occurs not only during the period that the river is being heavily polluted, but also during the period that the river has been reclaimed. During the latter period, even if the river receives only storm water, there are still many contaminants in urban runoff. It produces sediment accumulation based on both inorganic settlement and organic degradation processes. Thus it is necessary to clean-up the sediments regularly for the sustainable protection of urban rivers.

1.2 Features of clean-up process for the sediments in urban rivers

Generally speaking, urban rivers are located in urban regions. There are no conditions in the vicinity for the disposal of the dredged sediments. Both the urban traffic limits and possible secondary pollution requires reducing the volume of the dredged sediments as far as possible.

On the other hand, the selection of dredging process should base on the sediment settlement properties, which means that it must focus on the clean-up of the upper layer heavily polluted sludge and be able to meet the needs of good flowability.

1.3 Key for the disposal of the dredged sediments

The inappropriate disposal of the dredged polluted sediments can produce secondary pollution to the surroundings. Therefore, the measures for secondary pollution control have to be considered firstly, then the cost of the sediments transport would be taken into account.

1.4 Relationship among the steps for an engineering project

The whole combination of clean-up and disposal for the polluted sediments from urban rivers consists of dredging, treatment in-situ, transport and final disposal, all of those steps interacting closely. Different dredging methods and treatment measures in-situ result in different dredged material properties, which affect the choices of transport and related costs as well as the disposal process. So, the combination of the whole process must base on the systematical analysis of all considerations above-mentioned.

2 Analysis on a clean-up and disposal project for the sediments from urban rivers

2.1 Alternatives of engineering methods

Some alternative methods for each step of the process are listed in Table 2(Roeters, 1998). Different combinations of those methods make up different clean-up and disposal processes.

Table 2 Alternatives of engineering steps

Dredging	Treatment in-situ	Transport	Disposal
Excavation	Dewatering	By pipe	Land disposal
Cutter-suction	Solidification	By river	Agricultural use
Vacuum-suction	Others	By road	Material use

2.2 Analysis of different choices

2.2.1 Dredging

Excavation dredging can not meet the requirements of the sediments clean-up with good flowability from urban rivers, so it is an unsuitable option. Suction dredging is able to clean up the upper layer heavily polluted sediments with good flowability. Compared with vacuum suction, the volume of the cutter-suction equipment is smaller. So cutter-suction is optimal in the situation of upper layer polluted sediments clean-up.

2.2.2 Treatment in-situ

Dewatering can effectively reduce the volume of the dredged material and make it solidified, thus cutting down the transport costs and preventing the secondary pollution. Therefore, dewatering in-situ is an essential engineering step.

2.2.3 Transport

The transport of the dredged sediments by pipe or river routes may not meet the needs of the restrictive conditions in urban areas. Sometimes, road transport is the only suitable choice.

2.2.4 Disposal

Land disposal known as landfill is favorable to pollution control. But the cost of long-distance transport of the dredged sediments has to be taken into account. Production of construction materials using the dredged sediments benefits both resource reuse and environmental protection. However, it needs huge investments. Urban green field use has most favorable economic features. But pollutant content limits have to be considered carefully.

Based on the above-mentioned, it is necessary to consider environmental, technical and economic factors comprehensively on choosing a suitable dredging plan. The most important factor among them is the pollutant compositions and relevant contents in the sediments.

2.3 Optimal clean-up process combination

The optimal clean-up process combination for the upper layer polluted sediments with good flowability from urban rivers is shown in Fig. 1.

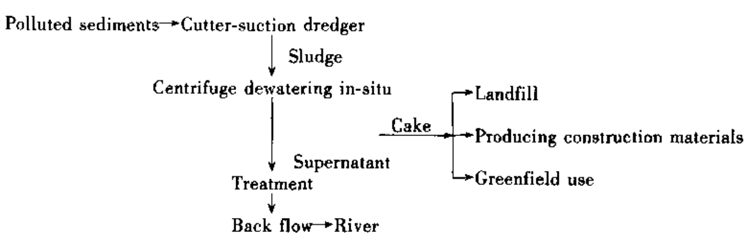

Fig.1 Flow sheet of recommended clean-up and disposal process combination

3 Technology development and application

3.1 Technology development

3.1.1 Subjects developed

To apply the process combination recommended, there are two lacunas in the chain of the process. One is dewatering, and the other is disposal method.

3.1.2 Developing of dewatering technology

The development of dewatering technology is arranged by three steps: gravity precipitation test, batch centrifugal settling test, and continuously centrifugal dewatering test.

(1) Gravity precipitation: After static precipitation for 24h, the volume of the dredged sludge can be concentrated to one quarter. It is evinced that the sludge can be dewatered by a precipitation process. But the separation factor should be increased considerably, to get the satisfactory dewatering level.

(2) Batch centrifugal settling test: A centrifugal process can give larger separation factor proposed through the gravity precipitation process. In the batch centrifugal settling test, there are two different types of pumped samples: type A——solid content 23.1 %; type B——solid content 13.2 %. Experimental results are shown in Table 3.

Table 3 Experimental results of batch centrifugal precipitation of polluted sediments

Separation factor-z (- -)	887	1239	1595	1877	662	887	1239	1595
Separation time-t, min	3	3	3	3	5	5	5	5
Final solid content of type A, %	57.1	60.6	61.9	63.3	58.0	61.4	62.5	64.4
Final solid content of type B, %	45.6	47.5	48.9	50.4	46.1	47.9	49.3	51.1

Obviously the original solid content influences the centrifugal separation effect in that the thickness of sediment cakes in settling cup of the centrifuge has direct ratio relation with the original solid content. Since the unit weight of the sediment particles(2.65 g/cm^3) is much larger than that of water, in the centrifugal process the thicker of the sediment cakes is, the bigger the cohesive force on the sediment cakes is. Thus, the thicker bottom material relates to the better separation effect. According to the existing research results on the centrifugal process of sewage sludge from wastewater plants(He, 2000), there exists a following function:

$$S = a + b \times \lg (z^n \cdot t),$$

where, S is the solid content of the materials(%); z is the separation factor(- -); t is the separation time(min); a, b are the determined values by the regression of the experimental results.

When the experimental data are applied to the function, the pseudo-linearity of the line is best when $n = 1.5$. The regression values of a and b are 0.668 and 11.62 for type A samples, and 0.462 and 9.39 for type B samples respectively. Both of the regression coefficients are bigger than 0.99.

(3) Continuous centrifugal dewatering test. According to the results from the batch test, the parameters of the continuous test is determined.

The rotational speed of the centrifuge is 3000 r/min. The separation factor is about 1700 and the efficient separation time is about 30 seconds. The flowrate of the sediments is 1.0—2.7 m^3/h and the solid content of the sediments is 1%—15%.

The experimental results of full-scale centrifugal dewatering showed that when the original solid content is smaller than 5%, the solid content of the sediment cakes is smaller than 59%; while the original solid content is bigger than 5 %, the solid content of the sediment cakes is bigger than 64%.

The separation effects of the full-scale experiments are better than the values predicted by above-mentioned function. The possible reasons are: (1) the sediment cakes in rotating drum is thicker than that in the laboratory situation(only 1—2 mm); (2) there is a long-distance transport before the sediments dewatered, which may result in relatively lower water content of the sediment cake's surface. The ratio of the solid recovery of the full-scale tests in-situ is larger than 92 % and the solid content of the produced supernatant is 0.1%—0.8%.

3.1.3 Feasibility assessment of disposal method for dredged sludge

(1) Landfill: Landfill process requires that the wastes to be treated have enough structure stability. Considering landfill of sludge wastes, the essential related parameter is cohesive efficiency, which must be over 10 kPa^{-1}. The experiment has shown that there is a relationship between water content and cohesive efficiency of the dredged sludge: when water content of the dewatered sediment cakes is lower than 30%, the relevant cohesive efficiency can be more than 10 kPa^{-1}. The dewatering process decides the technical feasibility of sludge landfill.

(2) Green field use : The distribution of nitrogen in the aqueous solutions extracted from the polluted sediment cakes is NH_3-N/NO-N = 2:1, which means that considerable nitrate nitrogen has been produced. According to the research on the mature degree of sewage sludge composting, it is equal to the mature degree of more than 120 days. Thus the application of the dewatered sediment cakes to urban green fields will not do harm to the soil ecosystem. Heavy metal contents of the polluted sediment cakes should be lower than the control values of the national standard on sludge used in agriculture (GB4284 - 84, soil pH > 6.5).

(3)Producing construction materials : The results of the intensity experiments of the bricks, made from the dewatered sediment cakes mixed with ordinary clay by different ratios, indicate that when the mixing ratio is larger than 50%, the intensity (anti-pressure) of the experimented bricks is not lower than the required intensity of first-class bricks. The heavy metal contents of the 1:1 extracts of the bricks do not surpass GB5741-85 Drinking Water Standards of China. The contents of Hg and Cd in the dewatered sediment cakes should be limited by national soil environment quality standards (GB15618 - 1995, secondary-limiting values).

3.2 Technology application

3.2.1 Technological flow sheet

Based on the study results of technology development, the technological flow sheet in full scale is shown in Fig.2. The key equipment in this flow is a centrifuge used for sediment dewatering and relevant key parameters are shown in Table 4.

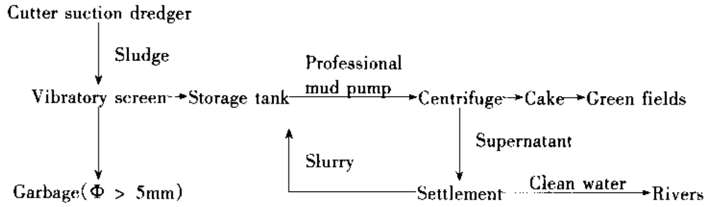

Fig.2 Flow sheet of the clean-up project process

Table 4 Key parameters of the centrifuge in full scale

Flow rate, m^3/h	Rotating drum size, mm	Rotating speed, r/m	Input power, kW
Separation factor - z(- -) ≥15	Φ450 × 1350	≥3000	37

3.2.2 Results of the application

The implemented river is called Zoumatang located in Yangpu District of Shanghai. Its bottom sludge composition is shown in Table 1. The results of the clean-up process are shown in Table 5 and the properties of the produced cakes are shown in Table 6.

The data in Table 5 and Table 6 have shown that the cakes have enough stability for using in urban green fields and the contaminant contents in the cakes are similar to the data showed in Table 1. It indicates that this process is feasible to clean-up upper layer heavily polluted bottom sludge purposefully. Moreover, the mean pollutant contents in the cakes do not surpass the limits of GB4284-84, which means that the cakes can be reused in urban green fields.

Table 5 Results of the implemented clean-up project

Influent to centrifuge, m^3/h	Solid content of the influent, %	Solid content in supernatant, %	Solid recovry ratio, %	Solid content of cakes, %	Dry solid flux, kg/h
12—15	5.5—25.2	0.012—0.014	> 99	70.5—75.9	~ 2400

Table 6 Analytical results of the cake properties

Dry density, g/m^3	Wet density, g/cm^3	Water content*, %	Plasticity index(- -)	Liquidity index(- -)	Cohesive force, kPa	Vertical leakage factor, cm/s
2.71	1.81	31.7	8.5	0.95	11.1	1.1×10^{-6}

* Dry weight basis

3.2.3 Assessment of the technology

(1) Environmental effect: The implementation of the clean-up process on the polluted sediments contributes to the reclamation of river water quality. In this process, the use of the technological system enables avoiding possible secondary pollution. But until now, it is difficult to describe the environmental effect quantitatively.

(2) Economic effect: The unit cost of the sediment clean-up and disposal process in Zoumatang is 7.4 $/$m^3$. Compared with the cost of traditional clean-up and disposal (excavating dredging, river transport and dumping the dredged sludge in suburb area), it can save expenses up to 80 %.

4 Conclusions

A suitable technological system for clean-up and disposal of polluted sediments (bottom sludge) is recommended. It is composed of cutter-suction dredging, dewatering in situ by an improved centrifuge, road transport of the dewatered cakes, and the dewatered cakes being used to produce construction materials, being used in urban green fields or disposed in landfill (according to contaminants composition and contents).

(2) The key step of the system is dewatering in situ, which makes the various disposals economically and technically feasible. Moreover, it can avoid possible secondary pollution caused by transport and reduce the transport cost greatly.

(3) The dry solid flux of the developed technological system is about 2.5 ton/h. The water content of the dewatered sludge cakes is less than 30%. The economic parameters surpass current clean-up processes.

(4) This technological system can focus on the upper layer heavily polluted sediments clean-up in urban rivers. Its practical environmental effect is much better than the current clean-up processes of river sediments.

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