Influence of Dredge Reamer Operating Parameters on Pollutant Diffusion in Reservoir Dredging

Deyi Tang\textsuperscript{1,2}, Haoxuan Weng\textsuperscript{1,2}, Xuewei Ye\textsuperscript{3}*  
\textsuperscript{1} Zhejiang Guangchuan Engineering Consulting Co., Ltd, Hangzhou 310000, China  
\textsuperscript{2} Zhejiang Provincial Key Lab of Water Conservancy Disaster Prevention and Reduction, Hangzhou 310000, China  
\textsuperscript{3} Shulan International Medical College, Zhejiang Shuren University, Hangzhou 310000, China  
*Corresponding author’s e-mail: 578305363@qq.com

Abstract: In order to study the influence of pollutant diffusion in the process of reservoir environmental dredging, this paper took the Tongji-bridge reservoir environmental dredging project as an example to analyze the relationship among the reamer rotating speed, traverse speed and slurry absorption concentration, and thus determined the optimal reamer operation parameters. Besides, this paper also monitored and analyzed the impact of pollutant diffusion dispersion in environmental dredging under the condition of the optimal reamer operating parameters. The results turn out: (1) When the reamer rotating speed and traverse speed were set to 15 r/min and 15~20 m/min, the slurry absorption concentration was higher and the efficiency of dredging was optimal at the moment. (2) Under the optimal reamer operation parameters condition, the pollutant diffusion in the horizontal direction was obviously affected by water depths. The horizontal diffusion distance was about 20m when the water depth was 15m to 20m and the horizontal was increased to be 40m in the depth of 10m to 15m. (3) Under the optimal reamer operation parameters condition, the pollutant diffusion in the vertical direction was little affected by different water depths. The peak of pollutant concentration from high to low was 1.0m above the bottom, intermediate water depth and 1.0m below the water surface.

1. Introduction  
Environmental dredging method is aim to improve the water environment with high precision dredging and less pollutants diffusion\cite{1,2}. This method can remove sediments clearly and safely, and it has been one of the most effective water environment pollution treatment measures\cite{3,4}. The most widely used environmental dredging equipment is the environmental cutter suction dredger with an environmental reamer which is equipped with slurry baffle, seal cover and reamer horizontal controller. The seal cover can effectively cover the suspended sediments within the reamer disturbance range in the process of reservoir dredging\cite{5,6}.

In recent years, environmental cutter suction dredger has been widely used in lake environmental dredging project in southern China\cite{7-10}, however, the application in reservoir environmental dredging project is almost blank at present. Compared with lake environmental dredging, the reservoir environmental dredging has the characteristic of larger water depth, higher water pressure, faster flow velocity. The sediments at the bottom of reservoir are composed of small clay particles such as clay.
particles and powder particles, and the pollutants adsorbed on these small clay particles could be easily disturbed and dispersed into the water causing secondary pollution during dredging\cite{11,12}.

The slurry absorption concentration is mainly related to the dredge reamer operating parameters, such as the reamer rotating speed and traverse speed\cite{13,14}, and how to set the optimal reamer operating parameters is the key to realizing higher slurry absorption concentration and lower secondary pollution in the process of environmental dredging. Therefore, this paper conducts the environmental dredging experiments in Tongji-bridge reservoir to analyze the relationship among the reamer rotating speed, traverse speed and slurry absorption concentration and determine the optimal reamer operation parameters, which will have a good reference value for similar reservoir environmental dredging projects.

2. Materials and methods

2.1. Dredge reamer operating parameters settings

The field experiment was conducted in the middle area of Tongji-bridge reservoir with water depth ranged from 30 to 50m. The sediments accumulation in Tongji-bridge reservoir was $258\times10^4$ m$^3$ and water content was 90%~300% according to investigation and physical and chemical analysis. The sediments were mainly floating mud and flow mud composed of colloidal particles, clay particles and powder particles.

The rated power of the conventional environmental cutter suction dredger is 500kW and its production capacity is 250m$^3$/h. In order to observe the change of mud concentration and operating parameters of reamer more effectively, the sector and transverse dredging strip and the width was set to 40m with 1.5m lap between the banners. The vacuum pressure was controlled to be 0.2-0.3Mpa, meanwhile, the thickness of layered excavation was 30~50cm and the mud output velocity was 2.3-2.5m/s. In order to study the variation trend of mud concentration under different reamer rotating speed and traverse speed to realize high dredging efficiency and low secondary pollution in the process of environmental dredging, the reamer operating parameters settings scheme was listed in Table 1.

| Rotating speed | 10r/min | 15r/min | 20r/min | 25r/min | 30r/min | 35r/min |
|----------------|---------|---------|---------|---------|---------|---------|
| Traverse speed  | 5m/min  | 10m/min | 15m/min | 20m/min | 25m/min | 30m/min |

2.2 Experimental scheme

There were 6 scenarios conducted with different water depths and distances from the dredging source to further study and analyze the effect of the optimal reamer operating parameters on pollutants diffusion of dredging sediments. The monitoring scheme of pollutant diffusion is shown in Table 2.

| Scenarios | Monitoring sites | Water depth range |
|-----------|------------------|-------------------|
| A         | 1.0m above the bottom of the reservoir | 18~20m |
| B         | half the depth of the reservoir | 18~20m |
| C         | 1.0m below the surface of the reservoir | 18~20m |
| D         | 1.0m above the bottom of the reservoir | 10~12m |
| E         | half the depth of the reservoir | 10~12m |
| F         | 1.0m below the surface of the reservoir | 10~12m |

2.3. Pollutant detection

The samples were collected at different locations and the pollutant detection items and methods were listed in Table 3.
Table 3. Pollutant detection items and methods

| Pollutants          | Methods                                | Equipment                                      |
|---------------------|----------------------------------------|------------------------------------------------|
| Total phosphorus(TP)| Ammonium molybdate spectrophotometric method | UV-2250 full automatic spectrophotometer       |
| Total nitrogen(TN)  | Ultraviolet spectrophotometry of alkaline potassium persulfate digestion | UV-2250 full automatic spectrophotometer       |
| Permanganate index(COD$_{Mn}$) | Alkaline potassium permanganate method | CODMN-2AZ COD tester                           |
| Suspended material(SS) | gravimetric method                  | SS-1Z suspension tester                       |

3. Results and discussions

3.1. Effect of dredge reamer operating parameters on slurry absorption concentration

The variation trend of slurry absorption concentration under different reamer rotating speed and traverse speed in this experiment is shown in Figure 1. For the different reamer rotating speed situation, the slurry absorption concentration increased quickly as traverse speed increased from 5m/min to 15m/min firstly, and then the slurry absorption concentration increasing slowed down as traverse speed increased from 15m/min to 20m/min, and finally the slurry absorption concentration tended to stabilize or even decrease when the traverse speed exceeded 20m/min. Analogously, the slurry absorption concentration increased quickly as rotating speed increased from 10r/min to 15r/min, and then the slurry absorption concentration decreased to be stable as the traverse speed increased. It may be due to the reason that the reamer seal cover can effectively control the dispersion of suspended sediments caused by the dredging agitation when the traverse speed is lower, and the slurry absorption concentration increases with the increasing rotating speed. As the traverse speed continues increasing, the seal cover is not stable due to the influence of water flow and thus the slurry inside the seal cover is easy to leak to the outside of the seal cover, which reduces the slurry absorption concentration.

Therefore, the field test indicates that there is a certain internal relation between slurry absorption concentration, rotating speed and traverse speed. The highest slurry absorption concentration can be realized when the dredge reamer operating parameters are set to be 15r/min in rotating speed and 15-20m/min in traverse speed.

![Figure 1. The variation trend of slurry absorption concentration under different reamer rotating speed and traverse speed](image)

3.2. Analysis of pollutant diffusion under dredge reamer operating parameters

The variation trend of pollutants concentration at different distance to the dredging center under the optimal reamer operation parameters is shown in Figure 2. In the horizontal direction, the pollutants concentration in the dredging center was the highest when the water depth was between 18m and 20m, decreased rapidly with the distance to dredging center increasing, and then kept stable with the...
distance increasing to 20m. When the water depth was between 10m and 12m, the trend of pollutants diffusion was similar and the pollutants concentration tended to be stable with the distance increasing to 40m. This may be due to the sediments are susceptible to dredging disturbance when the water depth is smaller and the distance of pollutants diffusion is become relatively large. In the vertical direction, the peak value of pollutants concentration from large to small was successively 1.0m below the surface of the reservoir, half the depth of the reservoir and 1.0m above the bottom of the reservoir. This may be because the water temperature difference between the surface and the bottom of the reservoir is easy to form a thermocline, which hinders the vertical diffusion of pollutants at the bottom, which is basically consistent with the conclusion of Liu’s model test that temperature stratification has a certain blocking effect on the vertical diffusion of pollutant clouds[15].

4. Conclusions
There is a certain qualitative law between the slurry absorption concentration, reamer rotating speed and traverse speed. The highest slurry absorption concentration can be realized when the dredge reamer operating parameters are set to be 15r/min in rotating speed and 15-20m/min in traverse speed.

The influence of water depth on pollutants diffusion in the horizontal direction is obvious, however, the influence in the vertical direction is not significant. The horizontal distance of pollutants diffusion is 40m when the water depth is between 10m and 12m and the horizontal distance of pollutants diffusion is 20m when the water depth is between 18m and 20m, which means the pollutants are more significantly affected by dredging disturbance when the water depth is smaller.

Figure 2. The variation trend of pollutants concentration at different distance to the dredging center under the optimal reamer operation parameters
Acknowledgments
This work is partially supported by Zhejiang Science and Technology Department Key Planning R&D Projects (2017C03008), Zhejiang Shuren University Young Dr Innovation Program(2019QC13) and Zhejiang Shuren University Teaching&Research Reform Project(2019JS1009).

References
[1] Zhong, JC., Fan, CX. (2007) Advance in the study on the effectiveness and environmental impact of sediment dredging. Journal of Lake Sciences, 19: 1-10.
[2] Yang, Y., Wang, N., Fan, JL. (2015) Ecological dredging of water sludge in Taigong Lake of Zibo City. China Water Resources, 20: 35-37.
[3] Dugopolski, R.A., Rydin, E., Brett, M.T. (2008) short-term Effect of Buffered Alum Treatment on Green Lake Sediment Phosphorus Speciation. Lake and Reservoir Management, 24: 181-189.
[4] Zhong, JC., Fan, CX., Zhang, L., et al. (2010) Significance of dredging on sediment denitrification in Meiliang Bay, China: A year long simulation study. Journal of Environmental Sciences, 22: 68-75.
[5] Wang, GZ., Fang, T., Tang, W., et al. (2014) Long-term effects of dredging on pollutant distribution in sediments of a heavily polluted inflow river. Journal of Lake Sciences, 26: 837-843.
[6] Wu, ZY., Yu, ZM., Shen, HY., et al. (2008) Ecological effects of the dredging in the West Lake, Hangzhou. Journal of Lake Sciences, 20: 277-284.
[7] Zhang, SY., Zhou, QH., Xu, D., et al. (2010) Effects of sediment dredging on water quality and zooplankton community structure in a shallow of eutrophic lake. Journal of Environmental Sciences, 22: 218-224.
[8] Fischer, J., Paukert, C., Daniels, M. (2012) Fish community response to habitat alteration: impacts of sand dredging in the Kansas River. Transactions of the American Fisheries Society, 141: 1532-1544.
[9] Jonge, M.D., Belpaire, C., Geeraerts, C., et al. (2012) Ecological impact assessment of sediment remediation in a metal-contaminated lowland river using translocated zebra mussels and resident macroinvertebrates. Environmental Pollution, 171: 99-108.
[10] Nayar, S., Miller, D., Hunt, A., et al. (2007) Environmental effects of dredging on sediment nutrients, carbon and granulometry in a tropical estuary. Environmental Monitoring and Assessment, 127: 1-13.
[11] Zhao, XM., Zhao, LP., Guo, XX., et al. (2014) Particle Component and Distribution Characteristics of Organic Carbon of Sediments in Water and Shore Soils. Journal of Soil and Water Conservation, 28: 304-308.
[12] Batayneh, A.T. (2012) Toxic( aluminum,beryllium,boron,chromium and zinc) in groundwater: health risk assessment. International Journal of Environmental Science and Technology, 9: 153-162.
[13] Jacob, B., Michael, A.A., Christopher, A. (2006) Influence of aging on phosphorus sorption to alum floc in lake water. Water Research, 5: 911-916.
[14] Keith, M.P., Brian, J.H., Patrick, L.B. (2007) A method for comparative evaluation of whole-lake and inflow alum treatment. Water research, 6: 1215-1224.
[15] Liu, CY., Chen, B., Luo, L. (2009) Influence of stratified temperature to vertical diffusion. In: The 9th national conference on hydrodynamics and the 12th Proceedings of the 2nd national symposium on hydrodynamics. Beijing. pp: 173-179.