A Review on the Physical Dewatering Methods of Sludge Pretreatment in Recent Ten Years

Zheng Zhen¹, Yi Jinxiang²*, Dai Renhui³

¹,³ School of Civil and Architectural Engineering, East China University of Technology, Nanchang 330013, China;
²State Key Laboratory of Nuclear Resources and Environment (East China University of Technology), Nanchang, Jiangxi, 330013 China
²*Corresponding author’s E-mail: yjxmx2662@sina.com

Abstract: Due to the increasingly tight land resources and the increasingly intensified ecological environment of pollution, sludge treatment has become an important subject of environmental protection research, among which sludge dewatering is the primary link of sludge treatment. Many researchers have used physical methods to improve the dewatering performance of sludge. Through the distribution of sludge water, this paper analyzes the influence of several important factors of sludge dewatering, and expounds several methods for sludge dewatering pretreatment such as electrolysis, freezing and thawing method, ultrasonic method and activated carbon adsorption method and corresponding dehydration mechanism such as change the sludge particle size, increase the sludge water channel, shatter extracellular polymers and change the charge distribution of sludge.

1 Introduction

With the improvement of people's living standards, the discharge of domestic sewage is increasing [1], and the sludge treatment capacity is also increasing. Sludge not only occupies a large amount of land resources, but also poses a potential threat to human health [2-3]. In the process of sludge reduction, the water content of sludge after mechanical dehydration is above 70% [4], which cannot meet the subsequent reuse of sludge. In order to improve the dewatering performance of sludge, some scholars have tried different methods to pre-treat the sludge before deep dewatering [5]. Sludge dewatering performance is mainly affected by such factors as sludge particle size, sludge surface charge, flocculent and extracellular polymer (EPS) [6-8]. EPS is mainly composed of proteins and polysaccharides [9], and the main components of hydrophilic groups in EPS are proteins [10], which have a strong hydrophilicity with the fluidoplasms formed by the flocculent sludge, and can bind a large number of water molecules in the sludge [11]. Therefore, reducing protein content in EPS is a feasible method to solve the problem of sludge dewatering. The degradation of EPS into low-molecular compounds can promote the decomposition of sludge flocs and the release of bound water [12-13], and also improve the water release capacity of sludge flocs [14]. Sludge regulation methods are mainly divided into biological method, chemical method and physical method [15]. Biological methods have been widely used to improve the dewatering performance of sludge. Biological enzymes are used to catalyze the degradation of proteins in sludge, cut off the molecular chains of macromolecular proteins, and promote the disintegration of sludge flocs [16]. Chemical method is to add flocculant to the sludge to make the sludge particles flocculate to improve its dewatering performance [17-19], or use surfactant, fenton reagent and advanced oxidant oxidation method to destroy EPS in the sludge to improve the dewatering performance.
of the sludge [20-22]. The physical method is to form a particle skeleton in the sludge to construct the drainage channel or change the particle size of the sludge, so as to improve the dewatering performance of the sludge [23]. This paper systematically introduces the principle of sludge dewatering, the application of physical methods in sludge dewatering and the research results of domestic and foreign scholars.

2 Principle of sludge dewatering

2.1 Classification of water in sludge

The water in the sludge can be divided into adsorbed water, interstice water, capillary water and internal water according to its existing form [24]. The adsorbed water is the water attached to the surface of the sludge particles. When the distance between the water molecules and the particle size is too small, the sludge particles will have an adsorption effect on the water, and the water molecules will be adsorbed on the surface of the sludge particles. Gap water mainly exists between sludge particles and microorganisms, which is one of the reasons why EPS is difficult to dehydrate. Capillary water exists in the pores of sludge, and most of the sludge dewatering is to remove capillary water. Internal water exists only inside the cell and can only be removed by destroying the cell wall or membrane [25].

2.2 Factors affecting sludge dewatering

Sludge dewatering is the primary process of sludge treatment, and there are many factors affecting sludge dewatering, among which extracellular polymer (EPS), particle size of sludge particles and the effect of electric charge have the strongest influence. Extracellular polymer is a kind of natural polymer secreted by microorganisms on the cell wall surface under certain environment. The main components of EPS are polysaccharides, proteins and other macromolecular substances, and it is generally believed that EPS content accounts for 50%-90% of the total organic mass in activated sludge [26-28]. The extracellular polymer adheres to the surface of the sludge particles and connects the sludge flocculent body [29], so that a large amount of sludge and water are closely combined and difficult to dehydrate [30]. Sludge belongs to the flow plastic body, its particle size is small, so it has a large viscosity and specific surface area, and the adsorption force of water molecules is strong, leading to water loss. Moreover, there are also a large number of charged groups on the surface of the sludge, which are usually negative [31]. Water molecules are polar molecules that are aligned in an electric field. Charged groups on the surface of the sludge constitute the inner layer of the electric field. Cations attracted to the particle surface and water molecules arranged in a directional manner constitute the outer layer of the electric field, forming a double electric layer. The water molecules are firmly bound to the surface of the sludge particles. The greater the charge of sludge, the more difficult to remove water. To sum up, sludge particle size, extracellular polymer and charge action are the main reasons for high moisture content and poor dehydration performance of sludge.

2.3 Determination of the characterization method of sludge dewatering

2.3.1 Capillary water absorption time (CST)

CST refers to the time required for sludge water to permeate 1 cm thick filter paper under the action of capillarity. As an important indicator of sludge dewatering performance, the shorter the CST time, the easier the sludge dewatering. To calculate the change of sludge dewatering performance, the CST value before and after sludge pretreatment should be measured, and the CST reduction rate formula (T, %) should be calculated, as shown in formula (1) [32]:

$$T_{\text{red}} = \frac{T_i - T_{\text{pre}}}{T_{\text{pre}}} \times 100\%$$  \hspace{1cm} (1)

In formula (1), $T_{\text{pre}}$ is the CST value of the pretreatment sludge, s; $T_i$ is the CST value of undisturbed sludge, s.

2.3.2 Sludge filtration specific resistance SRF

SRF is a comprehensive indicator to characterize the filtration characteristics of sludge, referring to the
resistance to intercept 1 Kg of dry sludge at 1 m² filtration area. The calculation formula is as follows [33-34].

\[
\frac{dv}{dt} = \frac{\Delta p \times A^2}{[\mu \times (r \times C \times v + R_m \times A)]}
\]

In the formula (2), \( \frac{dv}{dt} \) is the filtration speed, mL/s; \( \Delta p \) is the filtration pressure, Pa; \( A \) is the filtration area, cm²; \( \mu \) is the dynamic viscosity coefficient, Pa·S; \( v \) is the product of filtered liquid, mL; \( t \) is the filtering time, s; \( r \) as the SRF, cm/g; \( C \) is the weight of filter biscuit per unit volume, g/mL; \( R_m \) is the resistance of the filter medium, cm⁻¹. The bigger the SPF, the harder it is to filter and the worse the dehydration.

3. Conduct sludge dewatering by physical method
Physical methods of dehydration is mainly by electrolytic method, ultrasonic method, freezing and thawing method and biological carbon adsorption method to improve the particle size of sludge granule, lower the viscosity of the sludge and specific surface area to weaken the adsorption of water molecules reaction or damage the EPS extracellular polymer to reduce the coupling between sludge flocculent body material as well as the charge of the change sludge electric group.

3.1 Influence of electrolysis on sludge dewatering performance
The soil particles in the sludge are negatively charged and mixed with many charged groups. Water molecules are polar molecules. Under the action of electric charge, the water molecules are tightly bound around the soil particles, so that the water molecules are not easily lost. The electrification of sludge was improved by electrolysis, and the dehydration performance of sludge was changed by dissolving flocculent. In current studies, Ti/RuO₂ electrode [35], graphite plate electrode [36], copper-graphite electrode-CPAM[37], Ti/RuO₂-S₂O₈²⁻/Fe(II)[38], Ti/PbO₂ electrode[39] and other combined electrolysis technologies are used for sludge pretreatment. When the electrode is placed in the sludge, the charge and flocculent will change due to the oxidation of the electrode. With the increase of voltage, the oxidation capacity of the electrode and the amount of hydroxyl (·OH) changed, and the flocculents and EPS were first cracked into fine particles and then oxidized into proteins and polysaccharides. Organic matters were oxidized, and the internal water flowed out with the death of cells. From these representations, it can be concluded that the CST curve first increases and then decreases. In terms of cost, large area of sludge treatment energy consumption, difficult to implement. Therefore, in the aspect of electrolytic sludge, many scholars have improved the electrode and accelerated the speed of electrolytic reaction.

3.2 Influence of ultrasonic on sludge dewatering
Ultrasonic is a high cost, clean, no secondary pollution sludge dewatering pretreatment technology. Scholars have used single-frequency [40] and dual-frequency ultrasound [41] to treat sludge. Ultrasound is a high frequency sound wave that causes the sludge to vibrate quickly. High-speed vibrations cause the sludge to bubble and burst. When the bubble bursts, it is accompanied by strong hydration shear force and high temperature [42]. These hydration shear forces and high temperatures within the resulting sludge rapidly changed the composition of the sludge: polymer organics and cell wall rupture, flocculent decomposition, and the release of water from EPS. As a result, the dewatering performance of sludge has been improved. The advantage of ultrasonic is that the arrangement is simple and does not pollute the instrument.

3.3 Effect of freeze-thaw method on sludge dehydration
Freeze-thaw method is used to improve the dewatering performance of sludge by freezing solution [43]. The cells and fungi in the sludge will be damaged at low temperature, and the binding water in the cells will flow out. After freezing and thawing, the colloid property of the sludge was
destroyed and the dewatering property of the sludge was improved. When the freezing time is enough to crystallize the water in the cell, the cell structure in the sludge is destroyed, the sludge particles gather, the particle size increases, the specific surface area is reduced, and the binding force of the sludge to water is weakened. In the process of temperature rise and dissolution, cell fluid flow, free water increase, sludge dewatering performance has been improved. The pretreatment of sludge dewatering by temperature is used on a large scale with high cost and slow efficiency.

3.4 Effect of activated carbon on sludge dewatering

The number of drainage channels in the sludge is another factor affecting the sludge dewatering. Activated carbon is a kind of porous material with good adsorbability and stable chemical properties. Therefore, some scholars have modified activated carbonto make it have a larger specific surface area and pore capacity, and use this to increase the adsorption capacity of activated carbon [44-45]. When the adsorption capacity of activated carbon is greater than that of macromolecules, it can "snatch" water molecules attached to macromolecules to enhance the water release capacity of sludge. The adsorption capacity of modified activated carbon is used as an auxiliary material for other dehydration methods to enhance its dehydration efficiency.

4. Summary

In the field of sludge dewatering, physical methods are not frequently used. The main conclusions are as follows:
(1) When deep cracking of microbial cells is needed, the organic matter in oxidized sludge can be pretreated by electrolysis.
(2) When the microbial cells in the sludge, extracellular polymer EPS is destroyed, it is necessary to achieve a better effect of sludge dehydration by adding activated carbon to the sludge.
(3) Physical methods for treating large amounts of sludge are costly and need to be further developed.

Acknowledgements

This research was financially supported by science and technology research project of Jiangxi provincial department of education (GJJ18038686), doctoral research initiation fund project of East China University of Technology (DHBK2018048) and project supported by graduate innovation fund of East China University of Technology (DHYC-201931).

Reference

[1] Wei Wang, Yuxiang Luo, Wei Qiao. Possible solutions for sludge dewatering in China[J]. Frontiers of Environmental Science and Engineering in China: 102-107.
[2] Cieslik, B.M.; Namiesnik, J.; Konieczka, P.(2015) Review of sewage sludge management: Standards, regulations and analytical methods(Review)[J]. Journal of Cleaner Production, 1-15.
[3] Yang T., Hao X K., Chen B Y., et al.(2018) Effects of Al^3+ on dehydrogenase activity(DHA) and extracellular polymeric substances(EPS) of activated sludge in a sequencing batch biofilm reactor( SBBR)[J]. Acta Scientiae Circumstantiae, 38(4): 1453-1459.
[4] Xu Chunlian, Jiang Jinyuan, Jin Shunlong, Zhang Zhao, Zhang Wei, Sho Chenxi. (2016) Current situation and prospect of sludge mechanical dewatering technology. Environmental Engineering, 34(11):90-93.
[5] Liu Kangan, Li Yunbao, Yang Fan, Gao Junfa, Zhang Jiabao, Han Shuang, Qin Jinyi, Ma Zhiqun. (2019) Experimental Study on Dewaterability by Ferric Salt and Aluminum Salt Combined with Potassium Silicate Conditioning Sludge. Applied Chemical Industry: 1-7.
[6] Zhang Chao, Li Ben-gao, ChenYin- guang. (2011) Advance in the key factors affecting the dewaterability of waste activated sludge[J]. Environmental Science & Technology, 34(6G):152-156.
[7] Jun Zhou; Guanyu Zheng; Xueying Zhang; Lixiang Zhou. (2014) Influenes of Extracellular Polymeric Substances on the Dewaterability of Sewage Sludge during Bioleaching[J]. PLOS ONE, Vol.9(No.7).
[8] Houghton, Jennifer I.; Stephenson, Tom. (2002) Effect of influent organic content on digested sludge
extracellular polymer content and dewaterability[J]. Water Research, Vol. 36(No.14): 3620-3628.

[9] Mikkelsen, Lene Haugaard; Keiding, Kristian. (2002) Physico-chemical characteristics of full scale sewage sludges with implications to dewatering[J]. Water Research, Vol. 36(No.10): 2451-2462.

[10] Wu, BR (Wu, Boran); Chai, XL (Chai, Xiaoli); Zhao, YC (Zhao, Youcai). (2016) Enhanced dewatering of waste-activated sludge by composite hydrolysis enzymes.[J]. BIOPROCESS AND BIOSYSTEMS ENGINEERING, Vol.39(No.4): 627-639.

[11] D. Mowla; H.N. Tran; D. Grant Allen. (2013) A review of the properties of biosludge and its relevance to enhanced dewatering processes[J]. Biomass and Bioenergy, 365-378.

[12] Gulbin Erden; Ozlem Demir; (2010) Ayse Filibeli. Disintegration of biological sludge: Effect of ozone oxidation and ultrasonic treatment on aerobic digestibility[J]. Bioresource Technology, Vol. 101(No.21): 8093-8098.

[13] Zhang, Peng; Guo, Jin-Song; Shen, Yu; Yan, Peng; Chen, You-Peng; Wang, Han; Yang, Ji-Xiang; Fang, Fang; Li, Chun. (2015) Microbial communities, extracellular proteomics and polysaccharides: A comparative investigation on biofilm and suspended sludge.[J]. Bioresource Technology, 21-28.

[14] Neyens, Elisabeth; Baeyens, Jan; Dewil, Raf; De heyder, Bart. (2004) Advanced sludge treatment affects extracellular polymeric substances to improve activated sludge dewatering[J]. Journal of Hazardous Materials, Vol.106(No.2-3): 83-92.

[15] Wójcik, M.; Stachowicz, F. (2019) Influence of physical, chemical and dual sewage sludge conditioning methods on the dewatering efficiency(Article)[J]. Powder Technology, 96-102.

[16] Sesay, Mohamed Lamin; Oezcengiz, Guelay; Sanin, F. Dilek. (2006) Enzymatic extraction of activated sludge extracellular polymers and implications on bioflocculation.[J]. Water Research, Vol.40(No.7): 1359-1366.

[17] Niu M Q, Zhang W J, Wang D S, et al. (2012) Study on effect of chemical conditioning using different coagulants on sludge dewatering performance[J]. Acta Scientiae Circumstantiae, 32(9): 2126-2133.

[18] Du, YJ (Du, Youjing); Cao, BD (Cao, Bingding); Zhang, WJ (Zhang, Weijun); Yang, P (Yang, Peng); Xu, QY (Xu, Qiongying); Wang, DS (Wang, Dongsheng); Shen, X (Shen, Xiang). (2017) Improvement of wastewater sludge dewatering properties using polymeric aluminum-silicon complex flocculants conditioning: Importance of aluminum/silicon ratio[J]. COLLOIDS AND SURFACES A-PHYSICOCHEMICAL AND ENGINEERING ASPECTS, 134-145.

[19] Wang HF; Hu H; Wang HJ; Zeng RJ. (2018) Impact of dosing order of the coagulant and flocculant on sludge dewatering performance during the conditioning process.[J]. The Science Of The Total Environment, 1065-1073.

[20] Neyens, Elisabeth; Baeyens, Jan; Dewil, Raf; De heyder, Bart. (2004) Advanced sludge treatment affects extracellular polymeric substances to improve activated sludge dewatering[J]. Journal of Hazardous Materials, Vol.106(No.2-3): 83-92.

[21] Yi Rao. (2019). Research on treatment of sludge dewatering by electroosmosis-pressure filtration. Zhejiang University of Technology, 14-16.

[22] Chen Bin, Gao Huasheng, Ji Wenjie, Zhu Jianjiong, Yue Yuan, Yao Min. (2018) Effect of sawdust and its conditioning mechanism on filtration dewatering of textile wastewater sludge. JOURNAL OF NINGBO UNIVERSITY (NSEE), 31(05): 109-114.

[23] Xu Wendi, Chang Sha, Yu Pengfei, Wang Yongyong, Zhang Rongxin, Fu Jinxian. (2018) Impact of the different sludge pretreatment on the sludge filtration dehydrorated performance. Journal of Safety and Environment, 18(02): 773-778.

[24] Mao Huazhen. (2016) Study on the moisture distribution of sewage sludge and the mechanism of physical and chemical pre-treatment. Zhejiang University

[25] Xing Yi, Wang Zhiquiang, Hong Chen, Liu Min, Si Yanxiao. (2015) Technological optimization of sludge conditioned by Fenton’s reagent combined with surfactant. China Environmental Science, 35(04): 1164-1172.

[26] Guo-Ping Sheng; Han-Qing Yu; Xiao-Yan Li. (2010) Extracellular polymeric substances (EPS) of
microbial aggregates in biological wastewater treatment systems: A review[J]. Biotechnology Advances, Vol. 28 (No. 6): 882-894.

[27] Block, J. C.; Manem, J.; Urbain, V. (1993) Bioflocculation in activated sludge: an analytic approach [J]. Water Research, Vol. 27 (No. 5): 829-838.

[28] Yin, Xuan; Han, Pingfang; Lu, Xiaoping; Wang, Yanru. (2004) A review on the dewaterability of biosludge and ultrasound pretreatment [J]. Ultrasonics Sonochemistry, Vol. 11 (No. 6): 337-348.

[29] Ge Liyun. (2007) Study on Polymeric Substances Internal and External Cellular a...