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Bioleaching process enhances sludge dewaterability

Bioleaching, an innovative biological sludge conditioning method, has proven more effective in sludge dewatering than chemical conditioning based on results from pilot and full-scale testing at the Ningbo Southern Wastewater Treatment Facility in Zhejiang, China. **Weizhong Xiao** and **Sami Sarrouh** of T&M Associates, Inc. and Yu Yuan and Juan Tao at the Ningbo facility explain why.

In municipal wastewater treatment facilities, the sludge dewatering process is considered one of the most important steps toward achieving minimum sludge volume for the lowest possible handling cost. Therefore, the intrinsic dewaterability of sludge – and biological process sludge, in particular – is one of the key parameters used in determining how effective and efficient the mechanical dewatering performance could be.

To improve sludge dewaterability, various technologies have been developed, with most of the focus on chemical conditioning such as adjusting the types and dosages of various chemicals to alter the sludge physicochemical characteristics that help release trapped water. Until now, not much effort has been put into developing biological approaches that, in most cases, could be more cost-effective.

New water resource recovery facilities (WRRFs) have been designed and implemented at a strikingly fast pace in China over the last decade because the more stringent government regulations for water quality have increased demand for them. By 2015, 4,000 WRRFs with the total amount of treated wastewater have been built and operated with the total treatment capacity of 225 million m³/day. Sludge production is estimated to be approximately 7.5 million dry tons per year. However, the treatment of sludge generated through the WRRFs has not been developed at the same level. The typical biosolids stabilization process, such as anaerobic digestion, has therefore not commonly been used. One of the reasons for this is that the sludge in China has much lower volatile solids content in comparison to that of North American and European countries. Instead, sludge volume or mass reduction, i.e., sludge dewatering and drying, has been considered an appropriate treatment strategy in China.

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The dewatered sludge obtained by adding cationic-synthetic polymers, such as cationic polyacrylamide (PAM), followed by conventional mechanical dewatering often contains moisture as high as 80 percent, which results in large amounts of sludge to be transported and disposed. Therefore, the production of dewatered sludge with a high percentage of dry solids (DS) content, with 40 percent or above, through sludge conditioning processes or sludge conditioning and then mechanically dewatering, is of paramount importance for both reducing the amount of sludge produced and the cost of subsequent disposal. For the last few decades, many efforts have been devoted to improve sludge

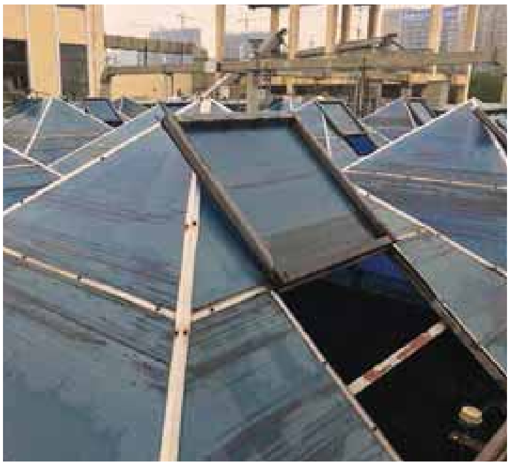

Figure 1a (top), 1b (far left): Full-scale application for bioleaching process

Figure 2: Dewatered cake through plate and frame filter press after the bioleaching process. Photos by T&M Associates

dewaterability through sludge conditioning prior to mechanical dewatering, predominantly with focus on physical or chemical approaches such as hydrothermal, microwave, ultrasonic, and chemical conditioning. Efficient sludge conditioning can alter sludge structure and physical states of water in sludge, change bound water in sludge into free water, and eventually improve sludge dewatering characteristics to achieve a high solid content. The dewatering improvement from the conditioning has been proved in numerous studies and engineering application as described below.

It has been well reported that thermal conditioning improves the sludge dewaterability, releasing bound water content at 170 for 90 minutes. It has also been noted that microwave radiation readily leads to the disruption of sludge microorganism cells and then to the release of bound water. Consequently, the specific resistance of filtration (SRF) of conditioned sewage sludge is decreased by more than 20 percent through a 3-minute microwave treatment. Ultrasonic treatment has been reported to have both positive and negative effects on sludge dewatering. In the most frequently employed chemical conditioning, ferric chloride and calcium oxide are typically added to sludge followed by synthetic polymer to improve sludge dewaterability. After the conditioning, sludge can be concentrated quickly and further dewatered by a chamber filter press into a sludge cake with moisture content below 60 percent.

These conventional physical conditioning methods – thermal, microwave, and ultrasonic treatment – require energy input into the sludge system to destroy the cells or change the sludge water distribution. When sludge is conditioned with ferric chloride and calcium oxide, large amounts of inorganic substances are used and incorporated into sludge. Therefore, the organic matter or thermal value of dry sludge cake is drastically decreased, which is unfavorable in subsequent disposal or reutilization of sludge cake if sludge is incinerated or used for land applications. Therefore, there is an urgent need to search for a suitable and cost-effective technology to improve sludge dewaterability without altering the organic matter or thermal value.

In the last two decades, bioleaching technology has been developed as a potential microbial method to remove heavy metals from sewage sludge facilitated by *Acidithiobacillus thiooxidans (A. thiooxidans)* and *Acidithiobacillus ferrooxidans (A. ferrooxidans)*. Surprisingly, sludge dewaterability appears to be improved after bioleaching, exhibiting that the SRF of bioleached sludge is drastically reduced in comparison to fresh sludge. However, through the last decade, the study on sludge bioleaching focuses on the removal of sludge-borne heavy metals instead of on sludge dewaterability.

Comparing the effects of physical, chemical methods with bioleaching technology on sludge conditioning will aid in evaluating the advantages and problems of various conditioning methods and will improve our understanding in developing bioleaching as a potential technology. However, little information in this topic area is available. Until now, the variation of nutrients in filtrate and dewatered sludge from different conditioning methods has not been compared systematically in previous studies.

Therefore, the present study aims to investigate the effect of bioleaching on sludge dewaterability in addition to the chemical properties of the resulting filtrate and sludge cake in comparison to other physical or chemical conditioning approaches.

The bioleaching process, an innovative and promising biological sludge conditioning method, has proved to be more effective than chemical conditioning. Bioleaching was originally used in the mining industry to extract and recover the heavy metals from insoluble ores. The involved biological transformations are governed by bio-oxidation, primarily mediated by two groups of chemolithoautotrophic and extremely acidophilic bacteria: *A. ferrooxidans* and *A. thiooxidans*. Although the process has been used for decades, only recently was it noted that bioleaching can improve sludge dewaterability by at least 4-10 percent with the same type of dewatering technology compared to the control test by solubilizing the extracellular polymeric substances (EPS) of the sludge that impedes the dewaterability the most.

China's Ningbo Southern Wastewater Treatment Facility treats municipal wastewater with a conventional anaerobic–anoxic–aerobic (A2O) bioprocess. The produced sludge was dewatered by centrifuge after chemical

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conditioning, resulting in total solids (TS) after dewatering of approximately 20 percent, though optimal protocols were applied. One approach that was implemented to improve the dewaterability included replacing the centrifuge with a plate and frame filter press. After replacing, the dewaterability only improved from 20 percent TS to 30-35 percent. To further increase the dewatering performance, employing an innovative technology became necessary.

When used for dewatering, one of the advantages of the bioleaching process is that the dewatered cake TS content can be as high as 40-45 percent under filter press without using chemical conditions, while the chemically conditioned cake TS percentage is rarely higher than 30 percent. This resultant high cake TS percentage is desperately needed for many circumstances.

By nature, the microorganisms responsible for bioleaching are chemolithotrophic because they utilize ferrous and reduced sulfur as their energy resources for growth. During the bio-oxidation, reduced sulfur is converted to sulfate, releasing protons and causing the resultant pH to decrease to 3-4 or even lower. This bio-acidification is also hypothesized to be one of the reasons for improving the sludge dewaterability in addition to other mechanisms. However, typical municipal sludge doesn't contain a significant amount of reduced inorganics after the aeration processes. The anaerobic digested sludge does carry a certain amount of sulfide-related compounds, and ferrous under some circumstances, but not an adequate amount to sustain and grow a sufficient organism population to achieve dewatering improvement. In laboratories, researchers developed Medium 9K reagent to cultivate the involved organisms, but it is unpractical for industries, especially for the wastewater treatment industry, to use 9K medium reagent directly due to its prohibitive cost. Therefore, developing a relatively low-cost process to achieve a reasonable dewaterability improvement reagent for bioleaching becomes critical in order to use the bioleaching process in municipal sludge treatment.

Tests

Pilot and full-scale tests were conducted at Ningbo Southern Wastewater Treatment Facility (the Facility) in Zhejiang, China, a typical A^2O biological process treatment facility targeting both carbon and nutrient removal. All of the raw sludge tested was gravity-thickened secondary sludge with a TS percentage varying from 0.5-2.5 percent during the test period.

The pilot tests were carried out in six parallel-operated flat bottom circular plastic reactors for a total of 19 different reagents. Medium 9K reagent was also used for control purposes. Each reactor has a volume of 5 liters (L). Aeration was provided by a coarse bubble hose anchored at the reactor bottom. There was no precise control on the aeration intensity due to the limited site conditions. The reaction was designed as batch operation with a total residence time of 48 hours. The tested sludge consisted of one-third seeding sludge obtained from a nearby incubation center, where two involved groups of microorganism were inoculated with the 9K medium reagent, and two-thirds of the Facility's secondary sludge from full-scale gravity thickener. Two sludge streams were filled into the reactor simultaneously, and aeration was started immediately following. After 5 minutes, aeration of the tested reagent was spiked into the reactor, and aeration continued for 48 hours. A 100-milliliter (ml) sludge sample was taken every 6 hours for a vacuum filtration test. It had been demonstrated in another study that the vacuum filtration time has strong positive correlation with the final filter press cake TS percentage; therefore, the filtration time was used to evaluate the dewaterability.

Tested reagent composition and the sludge characteristics are listed in Table 1.

Sample analysis included the sulfate, total iron, ferric, chloride, and pH, all measured with a HACH DR3900 spectrophotometer and HACH HQ11d Portable pH/ORP Meter, respectively. The filtration test was performed using a 47-millimeter (mm) fiberglass filter with a nominal pore size of 1 micron.

Full-scale application was carried out in the facility's existing 586,700-liter concrete tank as shown in Figure 1 (page 32). The tank was partitioned into 12 identical size chambers creating a plug flow pattern. Fifty percent of the tank effluent was sent to the filter press without further chemical conditioning, and the other 50 percent of tank effluent was returned to the tank inlet, mixing with raw sludge for biomass retaining. The dewatered cake through plate and frame filter press is shown in Figure 2.

Results and discussion

The performance evaluation was done in two consecutive steps. The first step was to normalize the filtration time to that of the Medium 9K reagent control filtration time. Those normalized filtration times less than 100 percent, or not significantly higher than 100 percent, were screened out for next-step evaluation. The second step was to normalize the reagent chemical cost to the Medium 9K cost based on the amount of reagent used and its individual component unit prices. Figure 3 represents the pilot testing results. The results indicated that the Reagent #13, and Reagents #15-#18 were the ones that should be given attention from both evaluation criteria.

Reagent #15 was selected as the final reagent to use in the full-scale test. Figure 4 represents the full-scale performance for the 1-month testing period. The results indicated that Reagent #15 had equivalent dewatering performance, as Medium 9K reagent did, but with only 30 percent of the cost of Medium 9K. The average cake TS percentage was approximately 40 percent. Further studies will be conducted to investigate how much more dewaterability the bioleaching process can achieve.

Authors' Note

Supervising Engineer Weizhong Xiao and Senior Technical Engineer Sami Sarrouh work at the engineering consultancy T&M Associates, Inc., based in Cleveland, Ohio, United States. Plant Superintendent Yu Yuan and Research Scientist Juan Tao work at the Ningbo Southern Wastewater Treatment Facility in Ningbo, China. For more information on pilot study results and reference, contact Weizhong Xiao at wxiao@tandmassociates.com.

Table 1. Tested Reagent Major Composition (by weight) and Sludge Condition in Percentage

Reagent #	Ferrous sulfate heptahydrate, ($FeSO_4 \cdot 7H_2O$)	chloride hexahydrate ($Fe(Cl)_3 \cdot 6H_2O$)	S
1	20	78	2
2	20	78	2
3	20	78	2
4	20	78	2
5	20	78	2
6	77	17	6
7	77	17	6
8	77	17	6
9	75	19	6
10	75	19	6
11	90	0	10
12	90	0	10
13	90	0	10
14	79	0	21
15	79	0	21
16	79	0	21
17	79	0	21
18	79	0	21
19	79	0	21

Sludge TS% 1.5~2%

Figure 3. Normalized Reagent Performance and Cost

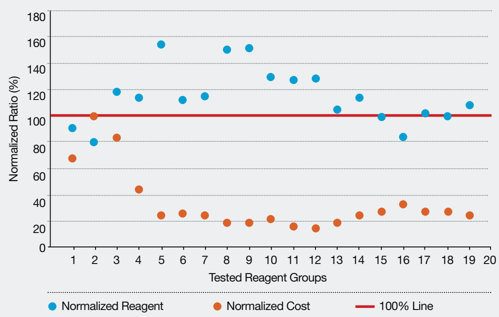

Figure 3: Normalized reagent performance (filtration time and the cost), relative to the Medium 9K reagent. Highlighted reagents were considered appropriate for full-scale test.

Figure 4. Full-Scale Dewatering Application

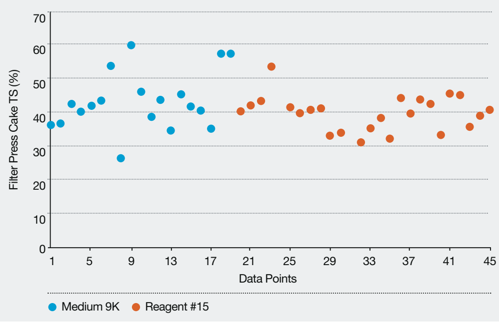

Figure 4: Full-scale filter press dewatering test results