Research on excess sludge homogenization parameters optimization by orthogonal test method

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Abstract. In this study, the orthogonal test method was applied to optimize the operational parameters in the excess sludge homogenization process. The sludge concentration, homogenization speed and homogenization time were used as independent variables, and the Disintegration Degree of Chemical Oxygen Demand (DD COD) was used as the dependent variable. The results showed that, when DD COD was considered as the primary index, three factors including homogenization time, homogenization speed and sludge concentration in sequence had important influence. When the DD COD maximum value was 40%, the optimal conditions were: sludge concentration of 8000 mg/L, homogenization speed of 19000 rpm, and the homogenization time of 35 min.

1. Introductions

The activated sludge process is currently the most widely used sewage treatment method all over the world, which has many advantages, but it also produces a large amount of excess sludge [1]. As the urban sewage treatment rate in China gradually increases and the number of new sewage treatment plants increases, the production of municipal sludge gradually increases [2]. Therefore, the treatment and disposal of sludge has become an urgent problem in China. The excess sludge disintegration is an effective means to achieve sludge reduction and resource utilization [3]. At present, the commonly used methods for treating excess sludge are: chemical method, mechanical physics method, biological method and combined treatment method, etc. [4-8].

Homogenization is an effective method for mechanically cracking excess sludge. The homogenization method cooperates with a precision stator working chamber through a high-speed rotating rotor, and relies on high line speed to generate strong hydraulic shear, centrifugal extrusion, high-speed cutting and collision to realize sludge disintegration. Zhang et al. [1] found that the homogenate treating required the same COD removal rate, and the energy consumption required was much lower than that of ultrasound and heat treatment. Therefore, the use of homogenization to treat the excess sludge has received widespread attention. And to improve the effect and efficiency of sludge, we need to ensure the excess sludge homogenization optimal parameters.

Orthogonal test design is the main method of partial factor design. It uses the orthogonal table to scientifically arrange and analyze the method of multi-factor test. The basic idea is to select some representative points from the comprehensive experiment to test. These points are characterized by “balanced” and “tidy and comparable” [9]. The orthogonal test design has two outstanding advantages...
compared with the common test method: 1) the number of tests is reduced as much as possible in the test arrangement; 2) on the basis of a small number of tests, the obtained test data can be used to analyze the correct conclusions guiding the practice and obtain better results. Therefore, the orthogonal test is perfectly suited for research on excess sludge homogenization optimal parameters. So based on the orthogonal test principle, the sludge concentration, homogenization speed and homogenization time are used as independent variables, and $DD_{COD}$ is used as the criterion to determine the optimal operating conditions for homogenization to treat excess sludge.

2. Experimental part

2.1. Sludge homogenization experiment design

2.1.1. Experimental device. The experimental equipment for homogenizing cracked sludge uses the laboratory high shear dispersing emulsifier homogenizer of Shanghai OuHor Machinery Equipment Co., Ltd., model A25-Digital, which is equipped with two cracked rotors, models 25S6 and 25G. This study used 25G cracked rotor to carry out experiments. The power supply voltage is 220 V, the speed range is 10000 to 28000 rpm, the input power is 500 W, and the output power is 320 W.

2.1.2. Experimental sludge. The inoculum sludge was taken from the Shenyang Shenshuiwan Sewage Treatment Plant Second Settling Tank. Then activated sludge was artificially cultured in the laboratory. The characteristics were as follows: the sludge concentration was 8135 mg/L, the volatile suspended solid concentration was 6000 mg/L, the SCOD concentration was 26.72 mg/L, and the median diameter was 61.282 μm.

2.1.3. Analytical method. 50 mL of sludge was taken and centrifuged at 4000 r/min for 5 min. The supernatant was extracted for measurement of relevant indicators. The COD adopts the standard method for water and wastewater detection in the United States [10]. The amount of COD that can be dissolved by a certain amount of sludge is limited. In this study, the Disintegration Degree (DD) was used to evaluate the excess sludge disintegration effect.

The disintegration degree $DD_{COD}$ characterized by COD is:

$$DD_{COD}(\%) = \frac{SCOD_0 - SCOD_t}{SCOD_{NaOH} - SCOD_0} \times 100\%$$

In the formula,

$SCOD_0$ —— the concentration of dissolved COD in untreated sludge;

$SCOD_t$ —— the concentration of dissolved COD in the treated sludge;

$SCOD_{NaOH}$ —— the maximum soluble COD concentration, that is, the soluble COD concentration after alkaline hydrolysis treatment.

The concentration of $SCOD_0$ and SCOD, in the sludge was taken from the supernatant after centrifugation. For alkaline hydrolysis, sludge was mixed with NaOH (1 mol/l), for 20 min, at 90°C, in the ratio 1:2[1,11-16].

2.2. Orthogonal test design

Orthogonal test design is a design method that uses orthogonal tables to arrange and analyze multifactor experiments. It is to select some representative combinations of levels in the whole level combination of test factors, through the analysis of the results of this part of the test to understand the situation of the comprehensive test, find the optimal level combination. In the analysis of experimental factors affecting the sludge disintegration, in this study, the effects of sludge concentration, homogenization speed and homogenization time on $DD_{COD}$ were considered. The homogenate used to treat the excess sludge conditions varies: (1) Experimental factor A—-sludge concentration (8000 mg/L, 16000 mg/L, 24000 mg/L); (2) Experimental factor B—-homogenization speed (10000 rpm, 14500 rpm, 19000 rpm); (3) Experimental factor C—-homogenization time (5 min, 20 min, 35 min).
Three-factor and three-level orthogonal test design was carried out. The factor level table is shown in Table 1. The experiment was performed using $L_9(3^3)$ orthogonal table, as shown in Table 2. The homogenate treating experiment was carried out according to the conditions shown in Table 2.

Table 1. Factors and levels of orthogonal test by homogenate.

| Levels | Sludge concentration(mg/L) | Homogenization speed (rpm) | Homogenization time (min) |
|--------|---------------------------|----------------------------|---------------------------|
| 1      | 8000                      | 10000                      | 5                         |
| 2      | 16000                     | 14500                      | 20                        |
| 3      | 24000                     | 19000                      | 35                        |

Table 2. Orthogonal test table of sludge disintegrated by homogenate.

| Number | Sludge concentration(mg/L) | Homogenization speed (rpm) | Homogenization time (min) |
|--------|---------------------------|----------------------------|---------------------------|
| 1      | 8000                      | 10000                      | 5                         |
| 2      | 8000                      | 14500                      | 20                        |
| 3      | 8000                      | 19000                      | 35                        |
| 4      | 16000                     | 10000                      | 20                        |
| 5      | 16000                     | 14500                      | 35                        |
| 6      | 16000                     | 19000                      | 5                         |
| 7      | 24000                     | 10000                      | 35                        |
| 8      | 24000                     | 14500                      | 5                         |
| 9      | 24000                     | 19000                      | 20                        |

3. Results and discussion

The range analysis method is used to analyze the orthogonal test results [9]. The method is simple and the calculation is not large. It is a very practical analysis method, which can get useful information such as the primary and secondary order of the factors and the excellent solution. The orthogonal test results of homogenate treating excess sludge are shown in Table 3.

Table 3. Orthogonal test results table of sludge disintegrated by homogenate.

| Number | Sludge concentration(mg/L) | Homogenization speed (rpm) | Homogenization time (min) | $D_{COD}$(%) |
|--------|---------------------------|----------------------------|---------------------------|--------------|
| 1      | 8000                      | 10000                      | 5                         | 1.5          |
| 2      | 8000                      | 14500                      | 20                        | 3.0          |
| 3      | 8000                      | 19000                      | 35                        | 19.4         |
| 4      | 16000                     | 10000                      | 20                        | 0.9          |
| 5      | 16000                     | 14500                      | 35                        | 17.1         |
| 6      | 16000                     | 19000                      | 5                         | 0.6          |
| 7      | 24000                     | 10000                      | 35                        | 3.6          |
| 8      | 24000                     | 14500                      | 5                         | 1.7          |
| 9      | 24000                     | 19000                      | 20                        | 9.5          |
| $K_1$  | 23.9                      | 6.0                        | 3.8                       |
| $K_2$  | 18.6                      | 21.8                       | 13.4                      |
| $K_3$  | 14.8                      | 29.5                       | 40.1                      |
| $R$    | 9.1                       | 23.5                       | 36.3                      |
| Excellent solution | $A_1$ | $B_3$ | $C_3$ |
In Table 3, $K_i$ indicate that the horizontal number of any column is $i$ ($i = 1, 2$ or $3$ in this study), and corresponds to the sum of the test results. (For example, the $K_1$ value is the sum of the experimental results corresponding to a level of 1 under each factor.) Range: on any column $R = \max\{K_1, K_2, K_3\} - \min\{K_1, K_2, K_3\}$. The range indicates the influence of the change of the level of each factor on the test result. The greater the difference, the change of the value of the listed factor within the test range will cause the test index to have a larger change in the value, so the one with the largest difference, that is, the factor that affects the test results the most, which is the most important factor. In this study, since $R_C > R_B > R_A$, the primary and secondary order of each factor is: C (homogenization speed), B (homogenization time), A (sludge concentration).

The excellent solution refers to the combination of the best factors in the scope of the test. The determination of the superior level of each factor is related to the test index. If the index is as large as possible, the level that makes the index larger, that is, the level corresponding to the largest value of each column $K_i$, should be selected. Otherwise, the level with the small index should be selected. In this study, the test index is $DD_{COD}$. The larger the index, the better. For factor A, level 1 is the best. For factor B, level 3 is the best. For level C, level 3 is the best. So the best solution is $A_1B_3C_3$, that is, sludge concentration of 8000 mg/L, homogenization speed of 19000 rpm, homogenization time of 30 min. In the third group of experiments in the orthogonal test table, the $DD_{COD}$ was 40%, and the effect was the best in the 9 groups of experiments, which was in line with the actual situation.

4. Conclusions

Based on the basic theoretical method of orthogonal experiment, the optimization of experimental parameters in the excess sludge homogenization process was studied. Three independent factors including sludge concentration, homogenization speed and homogenization time were selected to investigate their influence upon disintegration effect. The order of the three factors affecting the disintegration results is: homogenization speed, homogenization time, sludge concentration. The optimal experimental parameters for excess sludge homogenization is: sludge concentration of 8000 mg/L, homogenization speed of 19000 rpm, homogenization time of 35 min.

Acknowledgement

This research was supported by the Fundamental Research Funds for the Central Universities (No. N160304003) and Shenyang Science and Technology Project in 2018 (No. 18-202-0-11).

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