Experimental study on municipal sludge rotary deep dewatering device

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Abstract. In view of the problem of drying high-humidity and high-viscosity sludge, it is analyzed in the water characteristics and drying characteristics of municipal sludge, optimizing the design of key components of ordinary rotary cylinder dryer and conducting industrial simulation experiments. The results show that: the self-cleaning and dispersing rotary cylinder dryer has higher heat exchange efficiency, smaller discharge particles and better drying effect than ordinary rotary cylinder dryer, which is a useful exploration for the research, development and popularization of municipal sludge deep dewatering process.

1. Introduction

At present, China's municipal sludge production exceeds 40 million tons. Because of its high water content and complex composition, including a variety of pathogenic microorganisms, heavy metals, organic pollutants, etc., which have caused great difficulties in the treatment and disposal of sludge [1-2]. If the sludge cannot be disposed of properly, it will inevitably lead to more serious secondary pollution, which will greatly reduce the sewage emission reduction results [3-4].

The municipal sludge has a factory moisture content of about 80%. The high water content makes the sludge landfill, composting and incineration difficult, and the sludge moisture content can only be reduced to 20%-30% to avoid mold and odor and reach a stable state, so the sludge must be dehydrated and dried [5-7]. At present, the relatively mature sludge drying processes at home and abroad include rotary cylinder type, multi-layer step type, rotary disc type, fluidized bed, paddle type drying, etc., wherein rotary cylinder type drying has large processing capacity and small power consumption, other advantages, but there are shortcomings of high heat consumption [8-10]. If the structure of the rotary cylinder dryer is optimized and the convective heat transfer is improved, it has broad application prospects in sludge treatment and disposal.

In this paper, it is studied on the water characteristics and drying characteristics of municipal sludge, optimized on the key components of the ordinary rotary cylinder dryer and carried out on industrialized verification experiments. Which provides a theoretical basis for developing sludge rotary cylinder drying equipment, solving the drying problem of high humidity and viscous sludge.
2. Experimental materials and devices

2.1. Test sample

The municipal sludge used in the experiment was taken from the dewatering workshop of Water (Jinan) Co., Ltd., its moisture content was about 78%, and the shape was as shown in Fig. 1.

2.2. Experimental device and method

2.2.1. Analysis of sludge moisture characteristics. The experimental device is the German NETZSCH STA409PC thermo-gravimetric differential heat meter for the analysis of municipal sludge moisture characteristics (as shown in Figure 2). The temperature control program was started at room temperature with a heating rate of 1 °C/min and the carrier gas was 20 ml/min of nitrogen. The injection volume of the sludge sample is about 20 mg. The comparative test sample was about 20 mg of deionized water. The energy required to evaporate a unit mass of water in a sample is:

\[ E_s = \frac{Q - Q_p}{\Delta m} = \frac{p\Delta t - mc\Delta t}{\Delta m} \]  

(1)

In the formula, \( E_s \): The energy required to evaporate per unit mass of water in a sample, J/g; \( \Delta m \): The quality of the sample's evaporated water during this period, g; \( C_s \): Sample heat capacity, J/(g•K); \( \Delta t \): The rise temperature of the sample during this period of time, K; \( m \): Average mass of the sample during this period of time, g.

The combined energy of water in municipal sludge is the difference between the energy consumed by evaporation of water and pure water, so it can be expressed as:

\[ E_B = E_{S1} - E_{S2} \]  

(2)

In the formula, \( E_B \): Unit mass water binding energy, J/g; \( E_{S1} \): Energy required to evaporate per unit mass of water in a sludge sample, J/g; \( E_{S2} \): Energy required to evaporate per unit mass of water in a pure water sample, J/g.

2.2.2. Analysis of sludge drying characteristics. The device used for the sludge drying characteristics test was the DHS16-A rapid moisture analyzer (as shown in Figure 3). The weight loss method was used to determine the change of moisture content of the material with time. Initial sludge quality is \( m_0 \), The mass at \( n \) minutes is \( m_n \) (\( n=1,2,3,... \) the unit is g), The final quality of sludge drying is \( m_t \), the time interval is \( \Delta \) (min), and \( m_d \) is the quality of sludge as a dry matter. The relationship is:

Moisture content of sludge samples during drying:
The real-time weight data of the sludge samples obtained in the test were processed by the above relationship, and the first-order differential and second-order differential were obtained by rigid7.5 mapping to obtain the sludge drying rate and critical moisture content.

2.2.3. Sludge drying industrial simulation test. The process flow chart of the sludge drying industrial simulation test bed system is shown in Figure 4. During the test, the rotary cylinder with the self-cleaning and the ordinary rotary cylinder are sampled once, and the sampling position is the same. The position is shown in Figure 5. Showing and analyzing the distribution change of the moisture content of the sample.

![Figure 4](image-url)  
**Figure 4.** Process flow chart of sludge drying industrial simulation test.

1. Fuel Storage Tank, 2. Burner, 3. Combustion Furnace, 4. Double Helix Feeder, 5. Rotary Cylinder Dryer, 6. Discharge Valve, 7. Tail Gas Detection System, 8. Induced Draft Fan, 9. Washing Tower.

![Figure 5](image-url)  
**Figure 5.** Schematic diagram of sampling point inside rotary cylinder.
3. Experimental results and discussion

3.1 Analysis of water characteristics of municipal sewage sludge

Figure 6. Change of water binding energy during sludge dehydration.

Figure 7. Critical moisture content of different particle sizes at 120 °C.

Figure 6 shows the change of water binding energy in the process of water loss of sludge samples. It can be seen from Figure 6, most of the water in the sludge belongs to physical-mechanical combined water, which accounts for more than 80% of the total water and as the moisture content of the sludge is reduced, the water becomes more and more difficult to evaporate and the binding energy is getting larger and larger. When the moisture content of the sludge is less than 15%, the water mainly exists in the form of physic-chemical combined water and the binding energy also increases sharply. Therefore, it is uneconomical to reduce the sludge moisture to below 15% during the actual drying process.

3.1.1 Effect of particle size on critical moisture content. The critical water content is the boundary point between the constant-speed drying stage and the deceleration drying stage. The smaller for the critical water content, the later for the transition to the deceleration stage, and the shorter time required to complete the same drying task. In the experiment, water is the main influencing factor of sludge stickiness, with the removal of water, the structure of the sludge will become loose, shrinkage, cracking, etc., as the moisture is below a certain range, the sticky viscosity also disappears. It is shown for the critical moisture content of different particle sizes at 120 ºC in Figure 7. It can be seen from Fig. 7 that the smaller the particle size, the lower the critical moisture content, when the critical moisture content of the particles are larger than 10 mm, it does not change much, but when it is smaller than 10 mm, the critical moisture content decreases rapidly, if the particles of 2 mm is only 25%, it does not cause sticking. Therefore, for sludge drying, the particle size is small and uniform and the critical moisture content is small, the time required to cross the sludge viscous zone will be short, which is advantageous for the drying process.

3.2 Volume change of sludge granule drying process

| Particle size | Φ2mm | Φ4mm | Φ6mm | Φ10mm | Φ14mm | Φ20mm |
|---------------|------|------|------|-------|-------|-------|
| Volume ratio before and after drying (%) | 58.9 | 40.2 | 39.1 | 39.3 | 36.8 | 38.7 |
After the wet sludge particles are dried in the moisture tester for a certain period of time, the volume changes, and the dimensional comparison before and after the drying are shown in Table 1. It can be seen from Table 1 that after the wet sludge particles are dried, the volume of the particles is reduced to 35% to 59% of the original volume due to the water dispersion in the wet sludge particles and it is relatively small for the volume change of the particles having a diameter of 2 mm before and after drying. The samples were cut when the sludge of different particle sizes was dried for 20 minutes, then observing the internal conditions, and found out that the material with the largest particle size had a lot of internal wet materials. The water vapour phenomenon appeared immediately after the cutting, indicating that the gap water moved outward at a very fast speed. For materials with small particle size, the proportion of internal wet materials is getting smaller and smaller and the sample with the smallest particle size has all hardened and no wet parts.

3.2.1 Experimental research and improvement of municipal sludge rotary drying device. In view of the characteristics of sludge moisture and drying, this study carried out the following transformation on the ordinary rotary cylinder drying equipment to increase the sludge drying rate and reduce energy consumption: a) The dispersing device is arranged in the front part of the ordinary rotary dryer (As shown in Figure 8); b) The chain device is set in the first half of the ordinary rotary dryer (as shown in Figure 9); c) the center guide plate lifting flights is internally set (as shown in Figure 10).

Figure 8. Double broken shaft.  Figure 9. Chain.  Figure 10. Lifting flights.

During the experiment, the experimental data under steady state were obtained by continuously adjusting the system parameters such as feeding amount, inlet air temperature, exhaust air temperature and rotating drum speed (see Table 2). During the experiment, the double-spiral feeder was used for feeding, the feeding was smooth and there was no phenomenon of bridging and holding the shaft. After the experiment completely, there was no sticking or accumulating phenomenon in the dryer through the observation of the population door.

Table 2. Parameters taken by the industrial simulation test bench test.

| project                        | Feed amount | Feed moisture | Rotary cylinder speed | Breaking speed | Inlet air temperature | Outlet air temperature |
|--------------------------------|-------------|---------------|------------------------|----------------|-----------------------|------------------------|
| Ordinary rotary cylinder       | 280kg/h     | 82%           | 2r/min                 | 3r/min         | 650±30°C              | 120~130°C              |
| Breaking rotary cylinder with self-cleaning | 280kg/h     | 82%           | 2r/min                 | 150r/min       | 650±30°C              | 120~130°C              |

The dry sludge of the two rotary cylinder drying equipment is shown in Figures 11 and 12. It can be seen from the figures that the residence of the ordinary rotary cylinder sludge is slightly longer, the diameter of the discharge particles is slightly larger, and the small diameter particles (φ2mm-φ10mm)
account for about 70%. The discharge particles of the breaking rotary cylinder dryer with self-cleaning are slightly smaller than the ordinary rotary cylinder dryer, and the small-diameter particles (φ2mm-φ10mm) account for about 90%.

Figure 11. Dry sludge of ordinary rotary cylinder dryer. Figure 12. Dry sludge of breaking rotary cylinder dryer with self-cleaning

Figure 13: Water distribution curve inside the two rotary cylinder dryers.

The water distribution curve of the two rotary cylinder dryers is shown in Fig. 13. It can be seen from the above figure that the moisture content of the sludge dried is 57.2% by the ordinary rotary cylinder dryer, which is about 18% higher than that of the breaking rotary cylinder dryer with self-cleaning. The moisture content of the sludge at the sampling point 6 has reached about 56%. At the sampling point 5, the moisture content of the sludge is about 50%, which has been dehydrated to the point where no bonding occurs, that is, the broken rotary cylinder is dried. The front section of the machine is the fastest dewatering rate.

This is mainly because, compared with the ordinary rotary cylinder dryer, the breaking rotary cylinder dryer with self-cleaning fully breaks and cuts the material by the breaking shaft, which greatly strengthens the contact area between wet materials and hot air. Therefore, the drying intensity and the heat exchange are increased. The surface of the wet material is rapidly dehydrated and quickly passes through a viscous wall stage. The chain prevents wet materials from caking and sticking to the wall in the dryer. With the rotation of the dryer, the lifting flights continuously lifts and sprinkles the material, which overcomes the sticky wall of the material, greatly increases the contact area between the drying medium and the material, and improves the drying efficiency of the system. The lifting flights can not only make the material run well inside the cylinder, but also facilitate the drying of the material, and can reduce the space of each drying stroke, and reduce the cost.
4 Conclusions

(1) When the moisture content of the wet basis of sludge is less than 15%, the binding energy increases sharply, and it is uneconomical to reduce the sludge moisture to below 15%;
(2) The smaller the particle size, the lower the critical moisture content, and the shorter the time required to cross the sludge viscous zone, which is more conducive to sludge drying;
(3) The smaller the sludge particles, the smaller the proportion of internal wet materials, so the smaller the wet sludge material, the easier it is to dry;
(4) After the ordinary rotary cylinder drying equipment is equipped with the dispersing device and the lifting flights, the self-cleaning and dispersing rotary cylinder dryer has higher heat exchange efficiency, smaller discharge particles and dryness than the ordinary rotary cylinder dryer. The effect is ideal.

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