Application of 3D Cilia Filter Cloth in Mechanical Dehydration

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Abstract: A three-dimensional (abbreviation 3D) cilia filter cloth of high lifetime was introduced because the ordinary filter cloth has short service lifetime and unsatisfactory results when it was applied in mechanical dehydration. The dehydration effect of 3D filter cloth is much better than that of ordinary filter cloth. The 3D filter cloth could withstand six times higher tension above the ultimate tension of ordinary filter cloth. The effect of dehydration under higher pressure for 3D cloth is greater than that under lower pressure. The 3D filter cloth decreased the water content of dehydrated mud cake by an average of about 18% compared with the ordinary filter cloth. The water content of mud cake was lower than 59%, combined with preconditioning technology for the sludge, which achieves reduction and resource utilization of sludge.

1. Introduction
The filter cloth is commonly used in solid-liquid separation technology. The two most important reference standards for its production are both the service lifetime and the effect of the filter cloth. The filter cloth used in mechanical dewatering technology is usually woven with monofilament polyester fiber material, which has the characteristics of high tensile strength, flexure resistance, acid and alkali resistance and temperature change resistance [1-2]. However, it has shortcomings such as short lifetime, easy deviation, high maintenance cost and unsatisfactory dewatering effect [3]. Based on the principle of surface tension, this paper independently develops a three-dimensional ciliary filter cloth with more one-dimensional direction than ordinary filter cloth structure (three-dimensional is abbreviated as 3D) to solve the problems of short service lifetime and unsatisfactory dewatering effect, and applies it to the residual sludge dewatering treatment of domestic sewage treatment plants to reduce sewage pollution in China and decrease the cost of sludge treatment and disposal technology [4].

2. Three-dimensional structure of cilia filter cloth
The main performance indicators of filter cloth are material, weaving method, thickness, filter hole density, service lifetime, etc. [5]. The filter cloth produced by electrostatic wool planting method can easily peel off the cilia. In this paper, 3D cilia filter cloth is made of two kinds of high tensile strength silk threads through warping, knitting, heat setting and other manufacturing processes, and then sewed and bonded with high strength and large aperture coarse woven monofilament cloth by special adhesives [6]. A three-dimensional structure is formed in the space structure, and the base cloth is a large aperture composite mesh cloth. The one end of cilia is knitted with the cloth at the angle direction of 30-50 degree, and the other end is the free end. The schematic diagram is shown in Figure 1. The combination of the base cloth and the cilia structure depends on the method of knot weaving, which makes the implanted cilia very firm and ensures that the cilia remain intact when the base cloth is damaged. The overall tensile strength and bending resistance of the filter cloth by using the composite base cloth technology are better...
than those of the ordinary braided filter cloth.

Figure 1. Schematic diagram of three-dimensional structure of 3D filter cloth

3. Application of 3D ciliary filter cloth in mechanical dehydration
The filter cloth plays a key role in the mechanical dewatering process of sludge concentration and pressure filtration. The quality of filter cloth and its correct selection directly affect the final filtration effect and its lifetime [2]. The mesh holes of the filter cloth need to be increased in order to improve the dewatering efficiency. However, at the same time, the leakage rate becomes large and the interception rate becomes small. The filter mesh structure of ordinary filter cloth has the contradiction between rejection rate and dewatering efficiency [7]. But the three-dimensional cilia filter cloth has the characteristics of high interception rate and high permeability.

3.1 Dehydration characteristics of 3D ciliary filter cloth
Before dehydration, the cilia of 3D filter cloth are standing and the opening ratio of two-dimensional filter cloth is large, and the filtrate can be filtered quickly. As shown in Figure 2 (a), the friction coefficient between the filter cloth and the cilia is the largest, the amount of sludge captured is large, and it is not easy to leak. While dewatering, the pressure exerted on the filter cloth causes the cilia to lie flat in the same direction, as shown in the upper part of Fig. 2 (b). At this time, the micropore formed on the surface of the substrate cloth has small diameter and high pore density, which can effectively prevent sludge leakage. The capillary phenomenon of the cilia [8] enhances the dewatering speed and effect and avoids side leakage. At the end of dehydration, when the pressure applied to the filter cloth is relieved, the cilia will stand up, easily bounces up the pressed mud cake and immediately restores to its original state, as shown in the lower right part of Fig. 2 (b). The point-to-surface technology used in the contact between filter cloth and sludge makes it difficult for sludge to adhere to the filter cloth. It can be seen that there is less sludge residue on the ciliary end, and it is not easy to block the meshes, thus the amount of cleaning water for the filter cloth is effectively reduced.

Figure 2. Schematic diagram of dehydration principle of 3D cilia filter cloth

3.2. Advantages of cilia filter cloth
Under the pressure of 1200 pascal, the cilia of 3D filter cloth can be overwhelmed. Through the measurement, the average filtration accuracy of 3D filter cloth is about 0.01 mm, its porosity is about 40%, and its permeability rate is between 2000 and 3500 litre per second per square metre. The pulling force provided by capillary phenomenon [8] enhances the dehydration rate of 3D ciliated filter cloth. The longitudinal tensile strength of 3D ciliated filter cloth is high. It can work steadily for a long time without deformation even under the tension force of 20000 newton per meter. But the tension force is required to be below the value of 3000 newton per meter for the ordinary braided filter cloth which works steadily for the same long time. When the tension exceeds this value, the deformation of the ordinary braided filter cloth will occur. According to the basic theory of filtration compaction [9] and Darcy's law [10], the basic filtration equation of filter cake [11] can be obtained by combining capillary model with permeation model, i.e.:

\[
\frac{dV}{Adt} = \frac{N_0 \pi d_a^2 \Delta P}{128 \alpha \mu L} = \frac{1}{r_e} \frac{\Delta P}{\mu L}
\]
In the above formula of (1), $\frac{dV}{dt}$ denotes the filtration rate, $t$ is the filtration time, $V$ is the total amount of filtrate at the filter time $t$, and $A$ is the surface area of the filter bed. $\alpha$ is the correction coefficient of the bending degree of the capillary channel ($\alpha = \frac{L_0}{L} > 1$, $L_0$ is the thickness of the filtrate, $L$ is the thickness of the filter cake). $r_e$ is the specific resistance of the filter cake ($r_e = \frac{L_0}{N_0\pi d_0^2}$). $\Delta P$ is the pressure difference at the both ends of the filter cake. $\mu$ is the viscosity of the filtrate. $N_0$ is the number of capillary holes in the cake on the filter bed. $d_0$ is the diameter of the capillary holes.

According to the formula (1), it can be deduced that the filtration rate is proportional to the pressure difference under the case of the same porosity and cake specific resistance and thickness. Therefore, the filtration rate of 3D ciliated filter cloth is at least six times that of ordinary filter cloth. So that, the filtration rate of cilia filter cloth to filter cake is higher than that of common filter cloth.

3.3 Application comparison of 3D cilia filter cloth and ordinary filter cloth in belt mechanical dewatering

The sludge of Guangzhou Huadu Shiling Sewage Treatment Plant was selected as the experimental sample. The dewatering performance of two kinds of filter cloth was analyzed and compared. The sampling is a mixture of excess activated sludge and primary sludge from the plant.

A type of sludge dewaterer with the bandwidth of 2 metre was used. The amount of Cationic flocculant for 2.4 cubic metre was added every hour, and the flow rate of sludge pump was 32.5 cubic metre per hour. There are two pieces of filter cloth of the upper and the lower. The upper and lower tension values are set to be 2747.5 newton per meter and 3141.5 newton per meter, respectively. The relationship between the water content $w$ of mud cake and the working time $t$ is shown in Table 1 when the filter cloth is cleaned and not cleaned during the test, using 3D cilia filter cloth and ordinary filter cloth respectively. Under the cleaning conditions, the dehydration effect of the former is better, and the water content of mud cake is reduced by about 8.6% on average compared with that of the latter. Under the condition of unclean washing, the dehydration effect becomes worse and the values of water content $w$ increase. However, the variation of dehydration effect from 3D filter cloth is not obvious, and the changing trend is slow. When it works for 60 minutes, the value of water content $w$ only rises by 5.3% and the 3D filter cloth can still dehydrate the sludge when the machine continues to work, while the ordinary filter cloth cannot. The variation of dewatering effect of ordinary filter cloth is obvious to be worse, and the increasing change trend is steep. When it works for 30 minutes, the water content $w$ increases by 10.0% and makes the value of water content $w$ become 90.1%, which is close to 93.5% of the original value of water content $w$. Furthermore, the ordinary filter cloth adheres to the sludge seriously and can not be dewatered any more, so there is no data in the later period as shown in table 1. It shows that the 3D filter cloth can keep good dewatering effect for a longer time without washing. The peeling property of the mud for the 3D filter cloth is stronger than that for the ordinary filter cloth, and it is not easy for the 3D filter cloth to adhere to the sludge.

Table 1. Relationship between water content $w$ of dehydrated mud cake and working time $t$ with different cloth

| Time/min | Result of 3D filter cloth $w$/% | Result of ordinary filter cloth $w$/% |
|----------|---------------------------------|-------------------------------------|
|          | Cleaning                        | Not cleaning                        | Cleaning                       | Not cleaning |
| 0        | 71.6                            | 70.5                                | 79.5                           | 80.2         |
| 10       | 73.5                            | 71.2                                | 81.2                           | 85.1         |
| 20       | 72.8                            | 72.5                                | 80.5                           | 87.5         |
| 30       | 72.6                            | 73.2                                | 80.1                           | 90.5         |
| 40       | 72.1                            | 74.1                                | 81.6                           |              |
| 50       | 72.7                            | 75.4                                | 80.8                           |              |
| 60       | 71.9                            | 75.8                                | 81.5                           |              |

Table 2 shows the relationship between water content $w$ and working time $t$ of mud cake dewatered by 3D filter cloth under high tension of 6397.4 newton per meter and 7310.7 newton per meter, respectively. The dewatering effect is obviously improved. The water content $w$ is less than 65%, which
is at least five percentage points lower than that under low tension. The third column in Table 2 is the result of pre-conditioned sludge dewatered by 3D filter cloth. The water content $w$ is less than 59%, which meets the requirements before sludge disposal (GB/T 23485-2009). The tension of 3D filter cloth is several times greater than that of ordinary filter cloth. Compared with ordinary filter cloth, the dewatering effect of 3D filter cloth can reduce the water content of mud cake by about 18% on average.

Table 2. Relationship between water content $w$ of dehydrated mud cake and working time $t$ with different case about preconditioning under the same high tension.

| Time/min | Result of 3D filter cloth w/% |
|----------|--------------------------------|
|          | Not precondition | Precondition |
| 0        | 64.4             | 58.2         |
| 10       | 64.2             | 55.5         |
| 20       | 63.5             | 56.4         |
| 30       | 64.2             | 58.1         |
| 40       | 63.6             | 57.8         |
| 50       | 64.2             | 58.4         |
| 60       | 63.8             | 56.8         |

4. Conclusion
The dewatering speed, filtering accuracy and pressure filtering strength of 3D ciliated filter cloth are better than those of ordinary filter cloth. It has advantages like few fibre knots, not easily polluted, not easy to wrinkle and deviate, not easy to stick sludge, acid and alkali resistance and oil resistance, stable operation even under high strength, good recovery and so on. Long lifetime and good dewatering effect of 3D cilia filter cloth bring low cost and high efficiency solutions to various sludge dewatering. The 3D cilia filter cloth produces dehydration mud cake with lower water content, achieves the environmental protection goal of sludge reduction and recycling, and brings good economic benefits to society.

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Reference
[1] Zhang S.X.. (2018) Preparation and performance evaluation of polypropylene woven filter fabric. Donghua University, Shang Hai.
[2] Liu C. (2014) Analysis of membrane filter cloth selection for sludge deep dewatering. Water Purification Technology, 33(s1): 101-104.
[3] Zhao.F.X. (2007) Experience in using filter cloth of belt pressure filter dewaterer. Water Supply and Drainage, 33(10): 109-109.
[4] Li X.W., Li J., Li C., etc. (2016) Current application situation and development trend of sludge treatment and disposal technologies in China. China Water and Wasterwater, 32(6): 26-30, 35.
[5] Wang X.K., Zhu Y., Zou Y.N., etc. (2012) Discussion on factors affecting advanced mechanical sludge dewatering. China Water and Wasterwater, 28(10): 23-25.
[6] Yang J.L. (Yang J.L.) The influence of colloidal particles and filter cloth materials on viscose filtration.) The influence of colloidal particles and filter cloth materials on viscose filtration. Man-made Fiber, 5: 34-35.

[7] Zhang X.W. (2018) Study on particle size distribution characteristics of filter press cake and pressurized filter cake. Taiyuan University of Technology, Taiyuan.

[8] Tianjin University Physics Chemistry Teaching and Research Section. (2017) Physical Chemistry (Volume 2). Sixth edition. Higher Education Press, Beijing.

[9] Wang Z.L. (1985) Study on pressure and dehydration of pressure filter. Environmental Science, 6(3): 28-33.

[10] Wen D.S., Huang Z.H., Gao H.Y., etc. (2010) Engineering Fluid Dynamics (Volume 2). Third edition. Higher Education Press, Beijing.

[11] Zhao Y. (2006) Study on the microstructure of the filter cake and the expression filtration theory. Zhejiang University, Hangzhou.