Study on the effect of Fermentation and Resource Utilization of Municipal Sludge

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Abstract. In this study, a large number of field experiments were carried out to study the aerobic fermentation of dewatered activated sludge by using the dewatered sludge of Harbin Municipal Sewage Treatment Plant as raw material and using a horizontal rotary aerobic sludge fermentation device. The paper also studied the effect of fermented activated sludge as organic fertilizer in the field. The results showed that the sludge fermentation temperature continued to rise from 50 to 55 °C, and the highest temperature was 58 °C. The water content of sludge decreases gradually with the extension of fermentation time. After 17 days of fermentation, the water content of sludge decreases from 60% to 40%. The change of ammonia nitrogen shows that it first increases and then decreases. Although the content of nitrate nitrogen increases and decreases, the value of start and end of fermentation has not changed much. Total nitrogen content showed a downward trend. Cellulose can be degraded rapidly in the early stage of sludge fermentation, but slowly in the later stage. Aerobic fermentation is an effective way for sludge resource utilization.

1. Introduction
With the acceleration of urbanization in China, the amount of municipal domestic sewage discharge is increasing, and sewage treatment facilities are increasing. The accompanying sewage treatment process produces municipal sludge, which has become a new environmental problem. Therefore, the reuse of municipal sludge has become a new environmental research hotspot.

The physical properties of municipal sludge are fine particles and low density, and chemical flocculants are often added in the process of water treatment, which are flocculent structure, poor dehydration and difficult to disperse. So it is not conducive to the smooth progress of aerobic fermentation. It is necessary to add conditioners with carbon source as the main component and porosity as well as sludge fermentation week. The aerobic fermentation cycle of municipal sludge is closely related to the activity of microorganisms. Therefore, this experiment studies the changes of physical and chemical properties of sludge in the early, middle and mature stages of fermentation, so as to realize the purpose of sludge resource utilization.[1]

In many methods of sludge recycling, aerobic sludge fermentation has attracted the attention of many countries and become the main research direction of sludge recycling because of its low capital investment and operation cost, high degree of sludge stabilization, harmlessness, easy operation and agricultural application of fermented products.

The content of heavy metals in the tested materials is within the control standard of agricultural pollutants in sludge. Moreover, the sludge contains high organic matter, nitrogen, phosphorus and
potassium, which is feasible for agricultural use. Therefore, the purpose of agricultural effect test is to analyze the effect of sludge fertilization on soybean quality and yield and on improving soil fertility.

2. Materials and methods

2.1. Materials

2.1.1. Test materials. The sludge come from municipal sewage treatment plant of Herbin.

2.1.2. Instruments and equipment.
Electric furnace, electronic balance, micropipette, crusher, oven, constant temperature and humidity incubator, flow analyzer. AR852 Infrared Thermometer, pH Meter, Magnetic Stirrer, Infrared Cooker, Refrigerator, Conductivity Meter, Flame Photometer.

2.2. Conceptual design

2.2.1. Aerobic fermentation of sludge
(1) Test device of sludge fermentation and Judgment
Use the horizontal rotary reactor which is designed to perform aerobic fermentation of sludge, that the volume is 2.65m³. There are spirals on the inner wall of the reactor, on which there are small holes for oxygen supply. The reactor is turned upside down and backward alternately, and forced aeration by 750 W fan.

| Table 1 | The basic characters of the experimental materials. |
|---------|---------------------------------------------------|
| Fermented material | TOC | TP | Cellulose | Water |
| Sludge | 35.5 | 3.2 | - | 80% |
| Rice husk | 33 | 0.45 | 40.8 |

(2) Maturity judgement
After adding conditioner, the ventilation of material has been improved very well. As the fermentation proceeds, the temperature of sludge rises, the water in sludge evaporates, and the sludge becomes loose. After aerobic fermentation, the taste of sludge disappears, and the color changes from black to dark brown, and there is no obvious moisture. The temperature of material in the later stage of fermentation is changed. The degree of fermentation naturally decreased and gradually approached the ambient temperature. The pH of fermentation products was close to neutral, and the organic matter content was lower than 65%, which reached the general standard of sludge agriculture.

2.2.2. Agricultural effect of activated sludge
(1) Test materials
Activated sludge, Rice husk (conditioner), Chemical fertilizer.

(2) Test design
The soil fertility of Xiangfang farm is uniform and the terrain is flat. The fertilizers were divided into four groups, and randomly arranged in blocks and repeated five times. First, the blank. Second, 15 tons of municipal sludge compost per ha. Third, N40P100 that 4 and 100 are subscribed in fertilizer purity. Forth, 15 tons of municipal sludge compost per ha and N40P100. The Urea was used as nitrogen fertilizer and super phosphate as phosphorus fertilizer. Adding rice husk to sludge can adjust the physical and chemical properties of sludge and degrade cellulose rapidly. The plot area is 18 m², and set protection line intermittently. The 0–20cm of plough layer soil samples were collected at different periods of crop growth, and the measured values were analyzed by variance.

(3) Analysis index
The chemical indexes of soil include soil organic matter, soil total nitrogen, soil total phosphorus, soil alkali hydrolysis nitrogen, soil available phosphorus, soil available potassium, and soil total salt content.

(3) Analysis method

2.3. Test data processing
The test use the SPSS V13.0, Blast program, MEGA4 software and Microsoft Excel 2013 to analyze and process experimental data.
3. Data and analysis

3.1. Sludge fermentation test

The physical properties of the sludge after fermentation about 17 days are compared with the shape of the original sludge as shown in the table below.

| content                        | sludge                          | fermentation production (17 days later) |
|--------------------------------|---------------------------------|----------------------------------------|
| Moisture content               | 80%                             | 40%                                    |
| Apparent properties            | Viscous and not easy to disperse| Soft and loose                         |
| Properties after drying        | Hard to break                   | Loose and easy to break                |
| Smell                          | effluvial                       | tasteless                              |

3.2. Changes of Physicochemical Indexes during Sludge Fermentation

3.2.1. Temperature

During the test, the temperature was measured and recorded every morning and evening. Three different positions were selected for each measurement. The average temperature was recorded, and then the average temperature of the day was calculated. During the fermentation process, temperature rises, high temperature and low temperature in turn. The temperature of the whole fermentation material reaches the high temperature stage, but the duration is short. It takes 4 days for the temperature to reach 50 °C, and 3 days for the temperature above 55 °C. The maximum temperature of the reactor body is 58 °C.

3.2.2. Rate of water content

At the initial stage of fermentation, the moisture content is controlled at 60%. Excessive moisture content will cause anaerobic environment, which is not conducive to the activities of microorganisms. Water content is measured every two days, multi-point sampling, mixing, and average values are measured three times. The water content gradually decreased with the prolongation of fermentation time. After 17 days of fermentation, the water content decreased from 60% to 40%.

3.2.3. pH

The change of pH value is a good index for bio-oxidation and microbial activity of reactor compost. The appropriate pH value can make microorganisms play an effective role. Retaining the effective nitrogen component in the compost will affect the composting efficiency if the pH value is too high or too low. But the change of pH value is affected by composting materials and conditions.[2]

From the above figure, the change of pH in fermentation process fluctuated, with a minimum of 5.90 and a maximum of 6.75, with a small range. The reason was that in the initial stage of composting, there were more energy substances available and microorganisms multiplied rapidly. The organic acid produced by the activity of composting decreased the pH value of compost, and the accumulation of organic acid resulted in the minimum value in the middle stage of fermentation. However, small molecular organic acids volatilize with the increase of composting temperature. At the
same time, ammonia produced by microbial decomposition of nitrogen-containing organic matter makes the pH value of compost start to rise again. The main metabolites of different microbial flora are different in acidity and alkalinity, which makes the pH fluctuate.

Figure 3. The pH change during fermentation.

Figure 4. The NH$_4^+$-N change during fermentation.

3.2.4. NH$_4^+$-N

The content of ammonia nitrogen increased by 13% in the first 9 days of fermentation, because the microorganisms in the reactor decomposed nitrogen-containing organic matter to produce a large amount of NH$_4^+$-N. With the fermentation proceeding, the content of NH$_4^+$-N decreased from 22.36 mg/kg to 21.83 mg/kg, because NH$_4^+$-N was converted into ammonia volatilization and nitrification, which resulted in NH$_4^+$-N content lower.

3.2.5. NO$_3^-$-N

Although the content of nitrate nitrogen increased and decreased, the value of the beginning and end of fermentation did not change much. The reason is that the nitrogen-containing organic compounds are decomposed to produce ammonia, and the released ammonia is assimilated and absorbed by microorganisms, or oxidized by nitrogen-fixing microorganisms to nitrite or nitrate, which makes the content of ammonia increase, but at the same time some of it will escape. The two processes are carried out simultaneously.[3]

3.2.6. Cellulose

As can be seen from the figure 6, cellulose content decreased from 28% to 23% from the beginning to the end of fermentation. On the 7th to 10th day of sludge fermentation, cellulose decomposed rapidly, and the stack temperature decreased from 48 C to 40 C, which indicated that this temperature range was suitable for cellulose degradation and slowed down in the later stage of fermentation.

3.2.7. TN

During the fermentation process, the total nitrogen content showed a downward trend. The content decreased from 1.5% to 1.2%. Although the composting process is a biochemical degradation process of organic matter, it is accompanied by an obvious nitrification process. The nitrogen-containing components are degraded to produce ammonia, which is released or assimilated by microorganisms, or oxidized by nitrogen-fixing microorganisms to nitrite or nitrate, or escaped into the atmosphere.
3.2.8. Organic matter

Organic matter is an important substance for microorganisms to survive and reproduce. The decrease of organic matter content in the final product is due to the consumption of organic matter by microbial activities. With the progress of fermentation, its content gradually decreases, and the highest degradation rate occurs in the first six days, because the materials which are easy to decompose and utilize in the early stage decompose rapidly, releasing heat. In the later stage, cellulose and other macromolecule substances were dominant, and the degradation rate was slow. After fermentation, the total organic carbon content decreased from 39.72% to 30.25%, and the decrease was relatively low. The possible reason is that the biodegradable organic matter in the raw materials used in the experiment is relatively less, followed by the low activity of microorganisms and the less degradation of organic matter.

3.3. Change of microorganism number in sludge fermentation

Fermentation materials generally contain a large number of indigenous microorganisms. When the conditions are suitable, microorganisms grow and multiply rapidly, microbial activities in the middle temperature period are strengthened, and composting temperature increases accordingly. When the temperature is further increased, although the number of microorganisms in the middle temperature will increase slightly, their growth and reproduction speed will slow down or end, and thermophilic microorganisms will gradually replace the medium temperature microorganisms; Similarly, when the temperature is too high, thermophilic microorganisms will gradually replace the medium temperature microorganisms.[4] High temperature also inhibits the further growth of high temperature microorganisms. In the fermentation process, microorganism succession is rapid, and the temperature can reach the required high temperature within a few days.

Bacteria are the smallest organisms with large specific surface area, which can quickly absorb soluble substrates into cells. Therefore, bacteria are often much more than fungi. The number of four stages is $5 \times 10^{17}/g$, $23 \times 10^{12}/g$, $215 \times 10^{9}/g$ and $82 \times 10^{8}/g$, respectively. The number of fungi in the four stages of sludge fermentation was $75 \times 10^{15}/g$, $79 \times 10^{9}/g$, $90 \times 10^{9}/g$ and $15 \times 10^{7}/g$, respectively. The number of actinomycetes varied from $15 \times 10^{14}/g$ in warming period to $66 \times 10^{10}/g$ in high temperature period, $25 \times 10^{7}/g$ in cooling period and $68 \times 10^{6}/g$ in maturing period. Actinomycetes were usually entangled by many cell hyphae and were multicellular hyphae.

![Figure 7. The content of total N during fermentation.](image1)

![Figure 8. The content of organic matter.](image2)

![Figure 9. The change of microorganism quantity during fermentation.](image3)
4. Conclusion
Before and after fermentation, the number of microorganisms showed a downward trend. Microbial activities consumed C and N, and their contents decreased by 23.9% and 19.7%, respectively. Cellulose decomposed fastest between 48 and 40 °C. Fermentation temperature experienced four stages: heating, high temperature, cooling and ripening. Water content decreased with time and ventilation, and ammonia nitrogen content decreased from 22.36 mg/kg to 21.83 mg/kg. Although nitrate nitrogen fluctuated, it was not obvious. Under the condition of 26:1 C/N, the fermentation process lasted 17 days.

The treatment of municipal sludge compost combined with chemical fertilizer resulted in a higher level of available phosphorus content in soil, which was better than that of chemical fertilizer treatment and control. The absorption of available phosphorus in soil varied in different periods of soybean growth, and its value changed. Each treatment had little effect on the total nitrogen content of soil in that year, and the application of sludge was beneficial to the improvement of soil. Total phosphorus and alkali-hydrolyzed nitrogen content. The treatment of municipal sludge compost combined with chemical fertilizer can increase the content of available potassium and total salt in soil, which is higher than that of chemical fertilizer treatment. Agricultural application of municipal sludge compost can improve soybean yield.

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