Study on Environmentally Friendly Sludge Drying Method

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Abstract. In 2012, the marine outflow of sewage sludge was prohibited due to the revision of the Marine Pollution Act and introduction of the Treaty of London, which is an international environmental regulation of disposal of wastes. As a result of the revision of the enforcement regulations of the Waste Management Act, the simple and direct landfill of sewage sludge was prohibited. Treatment costs such as incineration or solidification of sewage sludge and landfill are increasing. Incheon city’s sludge treatment had depends on the marine outflow. It is inevitably inevitable to make an efficient alternate treatment plan for sewage sludge. Considering the right to live in a healthy and pleasant environment for the residents near the sewage treatment facility, research on the development of sludge drying technology using environmentally friendly energy is essential.

In this research, by using renewable energy to reduce secondary processing cost of sewage sludge, development of sewage sludge treatment technology that can treat sewage sludge economically and environmentally by minimizing energy consumption. In this study, developed a drying facility in a greenhouse form with easy sun penetration by sewage sludge drying technology using the principle of moisture evaporation by solar thermal energy. Then, temperature, humidity, solar radiation amount measured by using the measurement sensor, and the sludge was dried while maintaining optimum conditions such as stirring and aeration of sludge at an appropriate time.

Keywords: sewage sludge, solar energy, drying

1. Introduction

Sewage sludge is valued as a fertilizer and has value as recycled resources, and it is now recognized as a resource in many countries. In this regard, sludge drying technology is an important technology that is applied as a treatment method with resource recycling in mind. It is difficult to directly use sludge with high water content, therefore it is applied in the pretreatment process for reducing the moisture content in most processing and recycling process, or after completely drying, sludge in the drying process is adopted. [1]

Drying is a relatively simple operation, but it is not easy to understand the physical and chemical properties of the dried material (shape and homogeneity, hydrophilicity / appearance of water, existence / nonexistence of crystals, thermal sensitivity, toxicity, Surface hardening, shrinkage, ease of assembly, aging and chemical change), various methods are used. Studies on conventional dryers are mainly limited to large scale industrial dryers and there is limited research on the drying of sludge containing large amounts of water and organic matter. Therefore, it is essential to develop a dryer suitable for sludge containing big amount of water and organic matter, and it is very important to analyze the drying characteristics of the dryer.

Fossil fuel used as the current energy source not only limits resources but also emits global warming and air pollutants such as CO₂ and NOx. Therefore, energy is needed to replace fossil fuels that have been used for a long time. In order to compensate for this, utilization of renewable energy is emerging.
Renewable energy is represented by solar, solar, wind, geothermal, and bioenergy. Among them, the use of solar energy is relatively simple, inexpensive, and advantageous for practical use than using other renewable energy.

Solar energy is divided into solar power energy and solar thermal energy. Solar thermal energy is a technology for absorbing radiant energy from the sun to convert it into thermal energy to produce heating and hot water production, solar power energy is a technology to produce electricity by directly converting sunlight into electricity using solar power generation system.

In this study, developed a drying facility in a greenhouse form with easy sun penetration by sewage sludge drying technology using the principle of moisture evaporation by solar thermal energy. Then, temperature, humidity, solar radiation amount measured by using the measurement sensor, and the sludge was dried while maintaining optimum conditions such as stirring and aeration of sludge at an appropriate time.

2. Theoretical Background

2.1. Solar Thermal Drying

In recent years, drying using solar energy has been recognized as an excellent characteristic that the total amount of solar energy is large, no environmental destruction, and the energy cost is unnecessary. As a result, it is beginning to be considered systemic applications in a large amount of drying treatment of grains, foods, woods, agricultural products and the like at a relatively low temperature.

When it is used as a dry heat source, the direct heating method in which the solar energy is directly given to the material to be dried and the indirect heating method in which the drying is performed by the hot air obtained by heating the air with the solar energy once using the collector. It is necessary to comprehensively consider the type of dry material, the throughput, equipment and operation cost, auxiliary heat quantity of solar heating wire, and energy situation. In designing a solar energy system, average radiation data is needed in the target area. [2]

2.2. Sludge Drying Treatment Method

The drying process of sewage sludge is classed as different drying characteristics depending on the high moisture content of sludge, adhesiveness and kind of sludge, and the drying method is based on heat transfer method, direct heating method and indirect heating system. The direct heating drying method is superior in drying performance. On the other hand it is causing mechanical problems such as in the process of drying sludge with a high moisture content, the solution liquid is solidified and solidified in the mass, particles stick to the surface. For this reason, various improvement studies on the heating device and the drying process are required due to the lowering of the drying speed and the possibility of generation of secondary pollutants such as odor and air pollutants.

In the indirect heating drying method, heat is transferred via indirect contact between a heat source and sludge by using steam or oil, and only moisture evaporated from sludge is generated by dry gas, it is easier to operate and manage than direct heating and drying method. It is advantageous for deodorization due to its small throughput. [3]

At the time of thermal decomposition of the organic substance, the process of drying the moisture by physical separation is carried out up to 200 ° C. At this time, a lot of energy (540 kcal / kg-H\(_2\)O) is required and if the temperature is higher than this, the chemical pyrolysis proceeds.

Advantages and disadvantages of sludge drying are as follows. [3]-[5]
- Advantages of sludge drying treatment
  1) When the treatment cycle is short
  2) Good weight loss effect
  3) Relatively easy to manage
  4) Excellent in technical reliability and stability
  5) Easy to manage by simple process
  6) Excellent level of domestic and overseas technology
  7) Construction cost is inexpensive
8) Required area is relatively low
- Disadvantages of sludge drying treatment
  1) Cause of complaints due to odor of dried sludge
  2) In case of cement raw material of dry sludge, it is difficult to reuse due to complaints
  3) When the byproducts can not be reused, additional disposal costs
  4) Maintenance is expensive due to high fuel requirement for drying
  5) Difficulty in long-term storage due to the absorbency of dried sludge

2.3. Drying Theory

![Diagram of moisture content and temperature over time]

Fig. 1: Temperature and moisture content characteristics by sludge drying

<table>
<thead>
<tr>
<th>Odor</th>
<th>Concentration (ppm)</th>
<th>VOCs</th>
<th>Concentration (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>20.647</td>
<td>Chloromethane</td>
<td>10.44</td>
</tr>
<tr>
<td>Hydrogen sulfide</td>
<td>0.159</td>
<td>1,1,1-Trichloroethane</td>
<td>11.94</td>
</tr>
<tr>
<td>Methyl mercaptan</td>
<td>0.008</td>
<td>Benzene</td>
<td>475.14</td>
</tr>
<tr>
<td>Dimethyl sulfide</td>
<td>0.023</td>
<td>Toluene</td>
<td>246.09</td>
</tr>
<tr>
<td>Dimethyl Disulfide</td>
<td>0.006</td>
<td>Ethylbenzene</td>
<td>39.96</td>
</tr>
<tr>
<td>Trimethylene mine</td>
<td>&lt;0.005</td>
<td>m-Xylene+p-Xylene</td>
<td>53.76</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>0.191</td>
<td>Styrene</td>
<td>96.54</td>
</tr>
<tr>
<td>Propion Aldehyde</td>
<td>0.016</td>
<td>1,2,2-Tetrachloroethane + o-Xylene</td>
<td>11.76</td>
</tr>
<tr>
<td>Butyl Aldehyde</td>
<td>0.028</td>
<td>1,2,4-Trimethylbenzene</td>
<td>19.38</td>
</tr>
<tr>
<td>n-Valericaldehyde</td>
<td>&lt;0.001</td>
<td>1,4-Dichlorobenzene</td>
<td>11.49</td>
</tr>
<tr>
<td>i-Valericaldehyde</td>
<td>0.03</td>
<td>1,2,4-Trichlorobenzene</td>
<td>19.83</td>
</tr>
</tbody>
</table>

The drying process in accordance with the water movement in the sludge can be divided into three stages: free water (first limiting moisture content, moving moisture during the rapid drying period), the moisture contained in the individual particles themselves (secondary critical moisture contents, migration during the second rate drying period), and the number of chemical bonds (equilibrium moisture content, no migration of dry water).
Drying characteristics of sewage sludge vary depending on various factors such as sludge type, moisture content, presence or absence of digestion and heat treatment, kind of dehydration aid, target moisture content. Generally, in a range where the moisture content is high, it is rapidly dried, and the rate of reduction of moisture after that tends to remarkably decrease. When drying at constant temperature, humidity, and conveying gas flow rate, the relationship between moisture content and sludge temperature with elapsed time can be classified as follows: [6]

1. Preheating period: Period in which the water content changes variously due to the preheated sludge
2. Period of Constant Rate Drying: The water content is linearly decreased, the sludge temperature is constant
3. Decrease drying period: Decrease rate of water content is moderate and water content is final

2.4. Volatile Organic Compounds from Sewage Sludge

The gas discharged from the sewage sludge drying process varies depending on the characteristics of the sewage sludge and drying conditions. Odor and VOCs in the dry gas are low odor complex odorous substances, and all the acidic, basic and neutral gases coexist. According to some research results of drying gas of sewage sludge, main malodors and VOCs were sulfur compounds and aldehydes. [6]

2.5. Sewage Sludge Production

Annual incidence of sewage sludge in Incheon city was estimated to be 95,565 tons per year. In 2009, 101,212 tons were generated, but in 2013, the total amount was 98,449 tons. Monthly sewage sludge production in Incheon city was higher than that in April and October. Incheon city sewage sludge, the amount generated every month shows that the amount generated is high in April and October. It was up to 9,644 tons (9.8%) in April and 7,177 tons (7.3%) at least in July. [7]

2.6. Relationship between Moisture Content and Organic Matter in Sludge

Table 1: Sludge analysis results by region

<table>
<thead>
<tr>
<th>Area</th>
<th>Classification</th>
<th>Moisture content(%)</th>
<th>Organic(%)</th>
<th>Ash content(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>wet</td>
<td>dry</td>
<td>wet</td>
</tr>
<tr>
<td>Rural</td>
<td>Max.</td>
<td>83.1</td>
<td>12.3</td>
<td>73.1</td>
</tr>
<tr>
<td></td>
<td>Min.</td>
<td>62.3</td>
<td>6.0</td>
<td>35.3</td>
</tr>
<tr>
<td></td>
<td>Avg.</td>
<td>78.4</td>
<td>10.8</td>
<td>52.2</td>
</tr>
<tr>
<td>Urban</td>
<td>Max.</td>
<td>80.1</td>
<td>14.4</td>
<td>61.8</td>
</tr>
<tr>
<td></td>
<td>Min.</td>
<td>66.3</td>
<td>8.4</td>
<td>31.0</td>
</tr>
<tr>
<td></td>
<td>Avg.</td>
<td>73.8</td>
<td>11.7</td>
<td>44.8</td>
</tr>
<tr>
<td>Industrial complex</td>
<td>Max.</td>
<td>81.6</td>
<td>14.1</td>
<td>65.9</td>
</tr>
<tr>
<td></td>
<td>Min.</td>
<td>72.0</td>
<td>9.2</td>
<td>45.0</td>
</tr>
<tr>
<td></td>
<td>Avg.</td>
<td>78.0</td>
<td>12.1</td>
<td>45.8</td>
</tr>
</tbody>
</table>
When sewage sludge is incinerated and composted, moisture content and organic matter content act as important variables. In incineration, the calorific value is affected, and in composting, microorganisms have an influence on available nutrients. The moisture content of the generated sewage sludge is determined by the efficiency of the dewatering machine. In the case of some recent sewage treatment plants, low pressure dehydration is switched to a high pressure dehydrator, and the dehydration efficiency has increased, but the dehydration efficiency is still not high. According to the data investigated by the Korea Environment Corporation, moisture content, organic matter content and ash content of 31 samples of 28 sewage treatment plants were analyzed and classified as rural, urban and industrial complex, it is shown in the table.[7]

As a result of analyzing the relationship between moisture content and organic matter content in dried sludge, showed a tendency to increase the content of organic matter as the moisture content became higher. And it was confirmed that the dehydration efficiency is lowered when the content of organic matter increases. In addition, as a result of examination of the organic matter content of the dried solid, the volatile solids mass increased as the organic matter content in the dry solid increased, while the ash content tended to decrease.

3. Method

Sewage sludge from S sewage treatment plant in Incheon was used for the study. Samples were collected in accordance with Chapter 2, Section 1 of the waste process test method. The moisture content of the dewatered sludge is 78.5% and the initial condition of the experiment is shown in [Table 3].

<table>
<thead>
<tr>
<th>Moisture Content(%)</th>
<th>Irradiation</th>
<th>Humidity(%)</th>
<th>Temperature(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>78.5</td>
<td>554</td>
<td>48.2</td>
<td>38.8</td>
</tr>
</tbody>
</table>

The experiment was performed in which dehydrated sludge 0.15 m$^3$ was packed in the total volume of 1.26 m$^3$ of Pilot Scale sludge drying equipment used in the experiment. The drying equipment used for the experiment consisted of two sets, one operating the blower fan turned on for 24 hours and the other with the blower fan turned off.

The sludge stirring cycle was set to 5 times / day, and the measurement items were water content, complex odor, TVOC, H$_2$S, NH$_3$, internal / external temperature, humidity, and solar radiation.

4. Result

4.1. Sludge Moisture Content Reduction Analysis

![Figure 3: Reduction of sludge moisture content according to operation of fan](image)

[Figure 3] shows the sludge moisture content reduction according to fan operation. A is result of operating the blower fan turned on, and B is result of operating the blower fan turned off. Until the first three days, the content
was the same regardless of fan operation. But after results of moisture content were 12.5% (A) and 44.5% (B) from the initial moisture content of 78.5% during 0 to 15 operation days. In addition, the operation time for the initial sludge moisture content of 78.5% and the moisture content of 40% was found to take about 10 days in pan on operation (A), and about 15 days in pan off operation (B). The efficiency was analyzed as 84% and 43%, respectively.

The reason for the influence of the fan operation on the sludge drying is that the air speed increases due to the air blowing. As a result, the pressure decreased, and, it is considered that the fluid contained in the sludge, that is, the point at which the moisture breaks down, easily evaporates the moisture.

4.2. Sludge Drying Device Internal Temperature Change

Fig. 5-4] shows the temperature change inside the sludge drying device depending on whether or not the fan is in operation. And the internal temperature of unoperating fan(B) was constantly about 5 °C higher than operating fan(A) on average during fan operation. The reason why the temperature of the unoperating fan is higher is that the internal heat due to blowing is continuously discharged to the outside and the internal temperature is supposed to be lowered.

![Fig 4: Sludge Drying Device Internal Temperature Change](image)

4.3. Sludge Drying Device Internal Humidity Change

[Figure 5-5] shows the internal humidity of the sludge drying device depending on whether or not of fan operation. The internal humidity appeared generally higher case of operating fan until the 10th operating period, and after that appeared higher case of unoperating fan. It is considered that this is closely related to the sludge moisture content, and the sludge moisture content of operating fan during operation is reduced to 40% or less, and the influence of evaporation of moisture contained in the sludge that it is decreased.

The internal humidity minimum 40.1%, maximum 87%, average 61% at the case of operating fan(A), and at case of unoperating fan (B), minimum 46.4%, maximum 82.2%, average 58%.

![Fig 5: Sludge drying device internal humidity change](image)
4.4. Sludge Volume change

[Fig. 5-6] shows the change in the sludge volume reduction in the sludge drying device depending on whether or not of fan operation. Based on the 15th day of Operation, the rate of reduction of sludge volume sludge volume reduction rates were 85.2% (0.15 m³ ⟷ 0.02 m³) at operating fan and 60% (0.15 m³ ⟷ 0.06 m³) at unoperating fan.

The sludge reduction rates showed a tendency to decrease significantly until operation 10-15 days, as the sludge body mass decreased to a low level by the unified operation until the operation 10 days.

![Fig 6: Sludge volume change](image)

5. Conclusion

It is essential to stir the sludge at appropriate times for drying sewage sludge. Stirring for drying sludge can not be performed artificially made by humans in time. And due to it is sensitive response to internal temperature and internal humidity, stirring should be carried out efficient drying can be done. Therefore, the stirring device necessary for optimum drying is required to made compact so that the power consumption is low and the dead zone is minimized. And the stirring device necessary for optimum drying is excellent in mobility and easy to maintain. Lastly, it is necessary that the stirring strength is automatically adjusted according to the sludge dry state. As influencing factors for drying sewage sludge by using solar thermal energy, it can be cited the adjustment of internal circulation fan rotation number, sludge stirring frequency, number of times of discharging fan operation and discharge amount, sludge laying thickness, sludge drying time it can.

6. Acknowledgment

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7. References