Summary of Application of Solar Thermal Evaporation Technology in Wastewater Treatment

Xiaohui Wang*
Technology Inspection Center of Shengli Oil Field, Dongying 257000, China

*Corresponding author e-mail: xh_wang@slof.sinopec.com

Abstract. In view of the current problems of sludge drying, this article mainly proposes a sewage source heat pump + solar heat collection system sludge drying technology, and expounds the feasibility of using sewage source heat pump and solar heat collection system as the heat source for sludge drying. The main principles, the structural characteristics of the main equipment and the operation precautions. It is clarified that this sludge drying method has good expansibility and practicability, and has the value of engineering application and further development.

Keywords. Solar energy, photothermal evaporation technology, sewage treatment, sewage drying, sludge drying.

1. Introduction
The sludge is the solid precipitation material remaining in the sewage treatment process. Sewage treatment plants across the country can produce a large amount of wet sludge every year, and the treatment of sludge is an important part of the sewage treatment process. Traditional sludge treatment is mainly sanitary landfill, composting and direct incineration. The sludge incineration treatment method is now more and more widely used, and it is considered to be the more effective and most thorough sludge treatment method. Previous studies have shown that when the moisture content in the sludge drops to 38%, it can be burned without auxiliary fuel; when the moisture content drops to 23%, the activity of microorganisms can be completely inhibited, thereby maintaining the stability of the sludge sex. Therefore, the development of low-cost sludge drying methods is the key to sludge incineration and utilization [1]. The sludge drying technology mainly includes thermal drying, solar drying, microwave drying, etc. The most widely used and most mature technology is thermal drying. After the sludge is thermally dried, it not only greatly reduces the volume, but also eliminates odor and kills pathogens. Therefore, thermal drying technology has been widely used in developed countries in Europe and America. Based on the winter sludge solar drying experiment, this paper adopts the method of numerical calculation, taking the parameters of the sludge and climatic conditions during the experiment as variable parameters to establish a mathematical model of solar drying of sludge to guide the solar drying room the design of.

2. Mathematical model
In the process of sludge drying, there is a phase change at the liquid level. This paper uses the VOF model to track the liquid level. The VOF method determines the phase interface by calculating the
volume of the fluid and the grid in the grid. The gas and liquid phases share a set of mass and momentum. And the energy conservation equation [2]. During the drying process, it is assumed that the porosity of the skeleton of the dry sludge remains unchanged, and both liquid and gas are regarded as incompressible Newtonian fluids, and the gas in the mainstream state is a mixture of water vapor and air. Fluid continuity equation:

\[
\frac{\partial \rho_f}{\partial t} + \frac{\partial \rho_f u_i}{\partial x_i} = 0
\]  

(1)

In the formula, \(\rho_f\) represents the density of the fluid.

\[
\rho_f = \rho_i \alpha_i + \rho_g \alpha_g
\]  

(2)

In the formula, \(\alpha_i\) and \(\alpha_g\) represent the volume fraction of water and gas in each control unit, and \(\alpha_i + \alpha_g = 1\); \(\rho_i, \rho_g\) represents the density of water and gas, respectively. The density of gas is calculated according to the weighted average of water vapor and air mass.

\[
\rho_g = Y_a \rho_a + Y_v \rho_v
\]  

(3)

In the formula, \(\rho_a, \rho_v, Y_a, Y_v\) represents the density and mass fraction of air and water vapor, respectively. The gas-liquid interface solves the gas-phase volume content transfer equation:

\[
\frac{\partial \alpha_g \rho_g}{\partial t} + \frac{\partial \alpha_g \rho_g u_i}{\partial x_i} = \dot{m}
\]  

(4)

In the formula, \(\dot{m}\) represents phase change mass transfer. Fluid momentum equation:

\[
\frac{\partial \rho_f u_i}{\partial t} + \frac{\partial \left(\rho_f u_i u_j\right)}{\partial x_j} = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j} \left[ \mu_f \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right] + \rho g_i + S_{\beta} + f_{ST}
\]  

(5)

In the formula, \(\mu_f\) represents the viscosity of the fluid; \(S_{\beta}\) represents the surface tension; \(f_{ST}\) represents the force between the fluid and the sludge. In the non-porous area above the sludge, this term is zero. In porous media, since the fluid velocity is very small and the inertial force is negligible, the force between the sludge and the fluid is determined by Darcy’s law.

3. Experimental process

3.1. Experimental materials and equipment

3.1.1. Experimental device. Figure 1 is a system diagram of an experimental device for solar drying of sludge. The drying chamber is equipped with partitions, and the drying chamber is divided into two upper and lower channels. The sludge is placed on the conveyor belt in the upper channel and is connected to the air collector [3]. The hot air conducts convective heat exchange; the lower channel is connected to a gas heater to supplement heat when the solar radiation is insufficient to ensure the normal progress of the drying process (not used in this experiment). In the experiment, parameters such as the inlet and outlet temperature of the solar air collector, the air temperature and humidity and wind speed in the drying room, the amount of solar radiation and the weight of sludge were measured.
3.1.2. **Experimental materials.** The experimental sludge is wet sludge taken from a sewage treatment plant, which is a jelly and has a high moisture content. The main characteristic data analysis results of the sludge are shown in Table 1.

Table 1. Main characteristic data analysis of sludge samples

| Industrial analysis/% | Elemental analysis/% |
|-----------------------|----------------------|
| Mt 82.42              | Ad 54.95             |
| Vd 40.09              | FCd 4.96             |
| Cd 23.25              | Hd 4.36              |
| Nd 3.77               | St, d 0.69           |
| Od 12.98              |                      |

3.1.3. **Experimental equipment and instruments.** The dry experiment light source is provided by the TRM-PD artificial solar simulation transmitter, and the XG3000 3kW tube xenon lamp is installed; we use the QTS-4 solar radiation autograph to record; use the electronic balance to measure the sludge quality, and the weighing accuracy can reach 0.0001g; Use a copper-constantan thermocouple to measure the temperature, and then record it in a personal computer through a data acquisition instrument; use a digital thermohydrometer produced in Taiwan to measure the relative humidity of the environment and hot air; use a TESTO650 hot wire anemometer to measure the air velocity. The moisture content of the sludge sample is measured using an electric heating blast drying oven.

3.2. **Experimental results**

As shown in Figure 2, the moisture content of the sludge changes with time. It can be seen from the figure that the drying of sludge is divided into two stages: constant-rate drying and reduced-rate drying. In the constant-rate drying stage, the moisture content of the sludge basically decreases along a straight line. When it reaches 200%, the heat transfer resistance increases due to the evaporation of water in the lower part of the sludge, and the resistance to the diffusion of water vapor also increases [4]. The decline rate of moisture content slows down and enters the slow-down drying period. When it reaches 35%, the drying stops. From this, the critical moisture content of the sludge is about 200%, and the equilibrium moisture content in winter is about 35%.
3.2.1. Radiated power. Figure 3 shows the dehydration rate of the sludge when the radiation time is 2min and w (additive) is 10120%. From Figure 3, as the radiation power decreases, the dehydration rate of the sludge also decreases. At 900W the dewatering effect of sludge is the best. The dewatering rate of sludge is not much different at 720 and 540W, but the dewatering rate of sludge drops sharply at 315W, and the dewatering effect is obviously poor. It can be seen that the dehydration rate of sludge is higher at 900, 720 and 540W, all reaching more than 90%, and the amplitude is small; while at low fire (315W), the dehydration rate of sludge decreases suddenly [5]. It can be seen that under the same conditions, High fire (900W), medium high fire (720W) and medium fire (540W) three radiation levels can achieve basically the same dehydration effect.

The radiation power can achieve better drying effect at 540–900W. For example, the dehydration effect is basically the same at 540 and 720W, and under the appropriate radiation time, 540–900W can achieve good dehydration effect. This shows that, as long as the radiation time is appropriate, the dehydration effect of the radiation power above 540W is generally the same, and the continued reduction of the radiation power will directly affect the dehydration rate. Therefore, it can be considered that the appropriate microwave radiation power causes the accelerated movement of the charged sludge particles through the action of the high-frequency electromagnetic field [6]. The collision promotes the destabilization of the sludge structure; at the same time, microwave radiation causes the temperature gradient generated in the sludge, which destroys the binding force between the
bound water and the extracellular polymer of the sludge, thereby improving the dewatering performance of the sludge. The sludge uses the high concentration of water contained in the sludge, and the water is the medium that absorbs microwaves. Therefore, the difference in the moisture content of the material leads to different effects under different radiation powers. The experiment found that when the moisture content of the material is high, the use of 540W radiation power can reduce processing costs.

3.2.2. Radiation time. Figure 4 shows the dehydration rate of sludge when the radiation power is 720W and w (additive) is 10%. It can be seen from Figure 4 that as the radiation time increases, the dehydration rate of sludge also increases, at 2 The increase in the dewatering rate of the sludge is very small at 5 min and the dewatering rate is about 50%, which has a good dewatering effect. With the extension of the radiation time, the dewatering rate of the sludge increases significantly, but the extension of the operating time will inevitably affect the energy consumption Therefore, radiation time is also one of the factors that must be considered in engineering optimization.

![Figure 4. Dewatering rate of sludge under different irradiation time](image)

3.2.3. The influence of air temperature is one of the key factors affecting the drying rate of sludge. Generally, the solar radiation intensity is also high when the temperature is high. To simplify the calculation, it is assumed that the solar radiation intensity remains unchanged. Figure 5 shows the simulation results of the average water content in the sludge at different temperatures. It can be seen that the higher the temperature, the greater the drying rate [7]. The average drying rate in 3000s under the three air temperatures are 0.047, 0.182, and 0.434 kg/(m²·h) respectively, that is, as the temperature rises, the average drying rate increases; for every 1°C increase, the drying rate increases by 138 5%-287.2%. If the influence of temperature and solar radiation intensity are considered at the same time, the influence of temperature on the drying rate is greater.
Figure 5. The effect of temperature on the average water content of sludge

4. Conclusion
Experiments and simulation predictions were carried out on the pure solar sludge drying process in winter. The experimental study found that the drying of sludge was divided into two stages: constant-rate drying and reduced-rate drying. The critical humidity was about 200%, and the equilibrium humidity was about 200% after drying. The VOF model is used to track the phase interface of water and gas in the sludge. Based on the assumption of local heat balance, a solar sludge drying model is established. The sludge drying rate obtained by simulation has the same order of magnitude as the experimental measurement results. This model can be used to predict the solar drying capacity of sludge.

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