

SLUDGE DRYING

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ABSTRACT

The article focuses on the sludge drying issue. Different aspects of the drying process are brought up. Starting with a question if sludge drying is really a necessity, through discussing the results of sludge drying, the process of sludge drying, types of dryers, sludge dryer localization, suitable range of sludge drying, energy consumption and costs of sludge drying, and finally pointing out some problems connected with sludge drying application (e.g. sticky phase, vapours removal, sludge storage).

KEYWORDS

Sludge drying, sludge treatment, sludge dryers, sludge drying facilities, sticky phase.

1. INTRODUCTION

The quantity of treated sewage as well as the level of their treatment results in the increasing amount of sewage sludge. On the other hand the requirements concerning the conditions of sludge neutralization and storage are growing. As a result of that new solutions regarding sludge treatment, management and utilization are in demand.

Years of neglecting of the sludge issue caused that nowadays sewage treatment factories have to cope with a huge amounts of sludge which has gathered over the years of reckless sludge management. Sludge condensation and dewatering processes are no longer enough to cope with the still growing amounts of sludge or to reach the required standards. The form of the product obtained after dewatering process is hardly acceptable by several potential clients, including among others agriculture, forestry as well as power industry [1]. The product requires further transformation, more advanced treatment. This shall be the task of the sludge drying process, understood as the thermal drying process in which thermal energy is delivered to the sludge in order to evaporate water. Sludge drying process reduces mass and volume of the product, making its storage, transport, packaging and retail easier and also enables incineration or co-incineration of sludge.

In view of the above, the analysis of problems connected with sludge drying is fully justified.

There is even more than that. The analysis is of a great importance since there are several serious problems regarding sludge drying. Starting from high energy demand for a drying facility, the problem of the source of that energy, the problem of choice of the best method of drying (type of a drier) for particular type of sludge, through the problems regarding the organization of sludge drying process so that it was efficient and safe for the environment, and ending on the quality of product obtained after sludge drying.

2. IS DRYING A NECESSITY?

This is the question which is worth asking. It should be remembered that the process of sludge thermal drying is not a cheap solution mainly because of its high energy demand. At least as long as there is no source of “waste” energy that can be reused for drying (e.g. biogas, flue gases of a comparatively high enthalpy, low-parameter steam). On the other hand it is impossible to obtain a significant dry mass content in the sludge without an application of the drying process. It is connected with the types of water in sludge.

Water present in sludge may be of the following types:

- water between pores (unbound) that is subordinate to gravity force and can be easily removed from sludge by gravity settling (thickening);
- free capillary water, hold in sludge by adhesion and cohesion forces, that is readily removed from sludge by mechanical dewatering without using chemicals; e.g. in centrifuges where centrifugal force (inversely directed) opposes capillary force and helps to get rid of capillary water;
- physically half-bound water, that is bound inside flakes of sludge;
- bound water
 - biologically - in intracellular form, it is a part of the cells of living organisms present in sludge, bound by molecular forces to the constant phase of sludge;
 - chemically - in intercellular form, it is a part of the crystal lattice of molecules of the constant phase of sludge;
 - physically – in colloids, bound by the surface tension present on the border of phases; [2]

The bound water, in intercellular form and in colloids, is partially removable by mechanical dewatering but requires the addition of polymers. The intercellular water is retained in the sludge by chemical bonding, which may be broken by the addition of polyelectrolytes which cause a change in the surface tension. The same situation is with water physically bound and half-bound. The intracellular bound water is only possible to remove if the sludge particle walls will be broken either by heating, freezing or by electroinduced forces. That means, that without e.g. thermal drying it will be impossible to remove biologically bound water from sludge.

Assuming that:

- ✓ the initial percentage of dry solids (dry solids - DS) concentration is 2%, which means that there is 2% of dry mass in sludge,
- ✓ the final percentage of DS in sludge is 90%,
- ✓ the total possible concentration of DS in the processed sludge (from 2% of DS to 90% of DS) makes 100%,
- ✓ after thickening 7% of DS can be achieved and after dewatering 35% of DS can be achieved,

it can be estimated that approximately only 6% of the total possible DS concentration can be obtained by thickening, further 32% of the total possible DS concentration can be obtained by dewatering and the rest 62% of the total possible DS concentration has to be obtained by thermal drying if 90% of DS in sludge is to be achieved.(Fig.1)

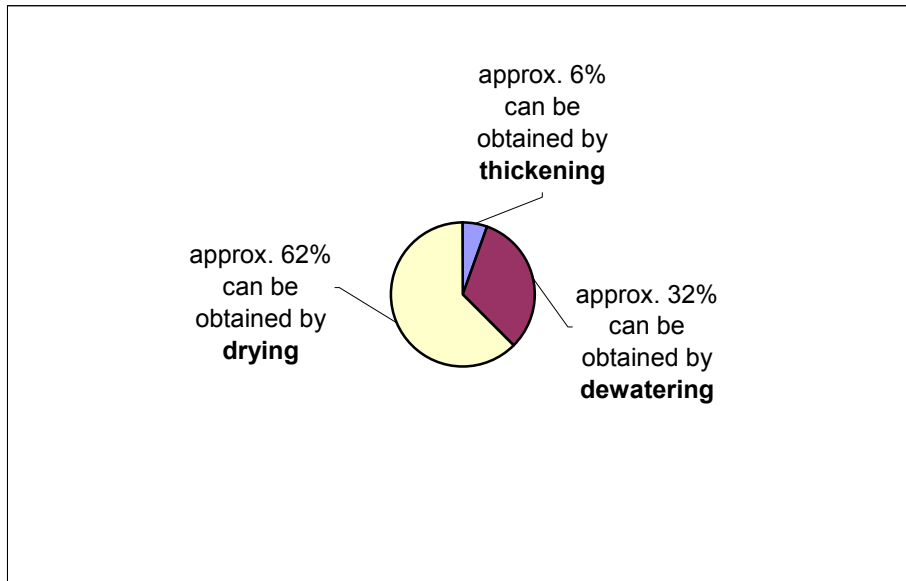


Fig.1 The percentage of the total possible dry solids concentration which can be obtained by thickening, dewatering and drying processes.

The conclusion is that if water content in sludge has to be diminished to minimum (approximately 90% of DS) or if there is a need to get moisture removal higher than it is guaranteed by mechanical dewatering, thermal drying is necessary. Thermal drying of sludge removes water from sludge to significantly higher degree than the best dewatering processes. When taking into consideration a wide range of sludge thermal utilization methods (e.g. incineration), sludge drying should be treated not only as a necessary but also as an integral process; only ways of diminishing amount of conventional fuel used to produce energy for drying should be looked for.

3. THE RESULTS OF SLUDGE DRYING PROCESS

The main goals of thermal drying of sludge are:

- to eliminate water from sludge and diminish volume of sludge (approx. 4-5 times [7]) in order to make the transportation cost lower and the sludge storage easier;
- to increase sludge calorific value, so that sludge could be easily incinerated without any additional fuel;
- to make sludge hygienic (without pathogenic organisms);
- to stabilize sludge (what is achieved by drying sludge to the sludge dry mass above 90% of DS);[4]
- to improve sludge structure before spreading by the agricultural equipment;
- to make sludge a fertilizer or a soil conditioner of high market value. [3]

Sludge dried in modern drying facilities consists in 5-10% of water, is in the form of granules (1-4 mm), and there is no more than 1% of dust in it. [7]

Presuming that 1/3 (33,3 %) of sludge dry mass is mineral (does not undergo incineration process), the high calorific value of dried sludge is approximately 14 MJ/kg of DS. In case of 50% of mineral fraction in sludge dry solids the high calorific value of dried sludge is about 11 MJ/kg of DS. The high calorific value of digested and dried sludge is usually lower then of raw sludge by about 2 MJ/kg of DS. [9]

After Kowalik [10] the high calorific value of digested and completely dried sewage sludge is similar to the slimed peat, about 12-14 MJ/kg of DS.

According to Grabowski and Oleszkiewicz [8] the high calorific value of raw sludge ranges from 16 to 20 MJ/kg of DS and for digested sludge between 10-15 MJ/kg of DS. The raw sludge consists of organics (combustible fraction) in 75-85% of DS; after stabilization (digestion) of sludge this value lowers to 45-60% of DS.

Dried sludge can be also a natural fertilizer which interacts with the environment less (if at all) in comparison to artificial fertilizers. The tests show that organic soil conditioners which came into being during thermal drying processes have following advantages[3]:

- provide a slow release of nitrogen;
- supply plants with basic nutrients;
- increase sandy soils ability to hold water;
- increase aeration and drainage of loamy and clayey soil;
- increase ability of soil to hold nutrients;
- don't cause a threat to ground water, as it happens in case of artificial fertilizers;

However, it should be remembered that sludge may pose a sanitary threat to human health and life or to the environment. Stabilized sludge is inhabited by microfauna and microflora, forming a specific biocenose. In its composition can be distinguished: bacteria, viruses, parasitic worms, fungi, protozoa and many many other microorganisms. Some of them are dangerous (pathogenic) and some are neutral (saprophytic) from a sanitary point of view.

During thermal drying process sludge undergoes pasteurization (approx. 30 minutes in the temperature min. 85°C). After drying in contact dryers, where sludge is warmed up to 100 -140°C, sludge is even partially sterilized. [5] Accordingly, thermally dried sludge is considered as sanitary safe.

4. THE PROCESS OF DRYING

4.1 The exchange of mass and heat.

The exchange of mass and heat between dried sludge and air (material and factor) is of essential significance for the drying process. [1] The heat exchange is achieved through radiation, convection and conduction. Moisture mass goes from the area of higher concentration to the area of smaller concentration as a result of diffusion.

While being in contact with the heated factor moisture from the surface of sludge evaporates to the air. The rate of moisture evaporation differs for materials depending on their properties. It is highest in the first phase of drying when water content in sludge is greatest. Then it diminishes. The rate of moisture evaporation depends also on the contact surface of a drying medium and a dried material. [1] The more extended the contact surface is the higher rate of moisture evaporation can be obtained.

In case of sludge the extension of the contact surface can be achieved through granulation. Granulation extends the contact surface of the drying medium and the dried material which keeps the drying rate at a high level what is the basic condition for making the drying process economically rational. [1]

4.2. Three phases of drying

The first phase of sludge drying process is preliminary drying. During this very short phase the temperature of sludge is increasing up to a certain, constant value. After preliminary drying the next phase called essential drying begins. It is the longest phase of drying during which moisture evaporates from the surface of the sludge particles with a constant speed, not dependent on the type of sludge. The whole surface of sludge particle is covered with water which constantly evaporates and is replaced by the water from inside of the particle. The temperature of sludge during basic drying phase is constant and is the same as the temperature of surrounding water (50-85°C) [7]. The time of basic drying depends on the difference between the moistness on the surface of the sludge particle and the amount of not bonded water inside the sludge particle. The last phase of sludge drying is final drying. It begins when the moistness of sludge reaches the critical value, for which the temperature of sludge is beginning to increase. Water from the surface of sludge evaporates quicker than it is replaced from the inside of the particle. The speed of drying in the last phase is decreasing until balanced hydration (dependent on the drying temperature and air humidity) is achieved. [5]

The speed of drying is dependent on:

- the temperature of drying and air humidity;
- the speed and the direction of a heat carrier flow;
- the size of uncovered surface of sludge (contact surface);
- mixing of sludge;
- the time of sludge retention in a drying facility;
- the way of organizing the contact of sludge with the heating factor. [5]

4.3. Types of driers

There is quite a big variety of technical solutions of dryers. The classification of dryers is based on the method of supplying heat to the sludge particle. According to that dryers can be divided into:

- convective dryers (represented by drum dryers) in which sludge has a direct contact with the drying factor (e.g. hot air);
- contact (tray and layer) dryers in which sludge has contact only with a hot surface, that is heated from the other side by the heating factor;
- mixed convective-contact dryers;
- infrared dryers with the use of infrared radiation or high frequency currents.

According to Urbaniak and Hillebrand [1] drum and fluidized dryers are particularly useful for the drying and stabilization in the form of granulate.

Direct drying facilities (with a direct contact of sludge with heating factor) which are applicable to sludge drying are [3]:

- ❖ pneumatic dryers (flash dryers);
- ❖ rotary or drum dryers;
- ❖ fluidized bed dryers.

That type of dryers is usually working with the heating factor of a high temperature therefore often has problems with sludge dust and dust explosions. While using convective dryers expensive (up to 30-35% of all the cost of the drying facility) equipment for air protection and deodorization is necessary. Among the main disadvantages of direct dryers should be put also: a significantly high pollution (by dust and volatile compounds) of the gases coming out of the dryer and a necessity of dried sludge recirculation (dependent on a degree of sludge dewatering).

Indirect dryers which are applicable to sludge drying are [3]:

- ❖ paddle dryers;
- ❖ hollow flight dryers;
- ❖ disc dryers;
- ❖ multi-shelf dryers

Among the advantages of indirect dryers should be put: reduced odour and dust risk; reduced air pollution; also the fact that dried sludge recirculation is no longer a necessity. The main disadvantage of that type of dryers is the fact that they are less economically efficient than the direct dryers.[3] Indirect dryers have also limited efficiency of drying and usually long time of sludge retention. [4]

! The choice of sludge drying facility should be dependent on the sludge type and the method of sludge utilization. It should be emphasized that not all drying facilities are able to dry sludge only partially (less than 85-90% of DS) and, after all, not always there is a necessity to dry sludge up to 90% of DS or more.

There are some directions, given by the French specialists [4] concerning the profitable range of sludge drying. (Table 1) According to the directions the best range of sludge drying can be found regarding the way of sludge utilization. If sludge is to be used for agriculture suggested profitable degree of drying is 60% of DS and more. The same is with sludge co-incineration with waste. When sludge incinerating in specially adjusted furnaces is taken into consideration suggested profitable degree of sludge drying is 35-45% of DS (partial drying) or above 90% of DS (if dried sludge is to be mixed with sludge of 35-45% of DS before it is directed to the incinerating facility in order to get “fuel” of specific properties).

Table 1 French specialists’ directions concerning the profitable range of sludge drying. (Range of sludge drying as a function of its utilization) [4]

Method of utilization	Range of drying			Goals of drying
	30-40%	60-90%	above 90%	
Agricultural	unprofitable (in respect of technical and economical issues)	profitable	profitable	1. Transport and storage convenience 2. Stabilization and sanitation (above 90% of DS)
Incineration	profitable 35-45% of DS)	unprofitable (in respect of technical and economical issues)	Profitable (if part of the sludge is totally dried and mixed with sludge of 35-45% of DS before it is directed to the incinerating facility)	1. Autothermic incineration
Co-incineration with waste	unprofitable (in respect of technical and economical issues)	profitable	profitable	1. Easier transportation, storage and operating of incinerating facility,

5. ENERGY CONSUMPTION AND COSTS OF DRYING

The comparison of the total costs of different sludge utilization options often indicates sludge drying as the best option. [3] The final decision should take into consideration not only economical factors but also others like: reliability of the solution, easy service, ease of storage and transportation or whether the considered solution is environmentally friendly.

Energy consumption of the sludge drying process to a great extent depends on water content in sludge directed to a drying facility. Using highly-effective belt press or chamber press for sludge drying is advised. Depending on the method of sludge stabilization 20-35% of DS in dewatered sludge can be achieved. Korczak-Niedzielska and Gromiec [7] suggest sludge dewatering to minimum 18-20% of DS before it is directed to the drying facility.

Energy consumption of the sludge drying process also strongly depends on technical solutions of drying facilities like:

- ❖ type of a dryer;
- ❖ method of heat recovery;
- ❖ detailed technical solution of gases, steam or other heating factors delivery;
- ❖ characteristic of sludge. [7]

As thermal drying of sludge inquires significant amount of energy it is advised to use biogas, energy from sludge or waste incineration or other “waste” energy for diminishing the amounts of fossil fuels needed for producing energy for sludge drying.

The estimated consumption of energetic factors for sludge drying according to French specialists is as shown in Table 2.

Table 2 The consumption of energetic factors used for drying of sludge of 25% of DS, assuming that for 1 ton of evaporated water 100 l of fuel oil is consumed.[4]

Energetic factor consumption	Unit	Drying to 35% of DS	Drying to 95% of DS
Fuel oil	l/t of DS	120	300
Electric energy	kWh/t of DS	30	50

When using available in the sewage treatment plant biogas the cost of drying of 1m³ of sludge with dry solids up to 25% is approximately 50-60 PLN (13-15 EUR). In case of using fuel oil the cost increases up to 80-100 PLN (21-26 EUR).

6. SLUDGE DRYER LOCALIZATION

Localization of a sludge drying facility is a very important issue, especially from the economical point of view, therefore should be well considered. There are three options which can be taken into consideration:

- a sludge drying installation localized on the territory of every sewage treatment plant where sludge pre-treatment is taking place and drying would be an extension of the sludge treatment line;

- a central sludge drying facility, common for several sewage treatment plants, where the quantity of sludge undergoing the process of drying could be significant in comparison to the quantity which can be obtained within one sewage treatment plant;
- a transportable station for sludge drying.

While localizing sludge dryer on the territory of every sewage treatment plant there is no need for equipment for the transportation of wet sludge from the treatment plant to drying facility and for packaging or storage of the large quantities of sludge. What is also important in that solution the vapours from the sludge drying facility can be sent directly to the sewage treatment line what enables recovery and reuse of the energy from the condensate. A serious disadvantage of this option of the sludge drier localizing are comparatively high to a central drying station investment and operating costs.

7. STICKY PHASE

While sludge drying one ought to pay attention to the fact that sludge is changing its consistence from a liquid phase to a paste form. It is then comparable to sticky rubber. The phase is called the sticky phase of sludge. While being in this phase sludge tends to cling to the inside of a dryer decreasing the efficiency of the dryer. The sticky phase phenomenon can also be a cause of the dryer's break down. For average municipal sludge the sticky phase occurs between 45-65% of DS in sludge. To avoid it, mixing previously dried sludge (90-95% of DS) with dewatered sludge (20-35% of DS) is suggested. As a result of this at the entrance to the dryer sludge of 65-75% of DS is obtained.

An application of sludge mixing improves also the structure (granulation) of sludge what is particularly important with reference to sludge further usage, utilization.

Sludge drying to dry solids content ranging from 48-80% is not applied regarding the unfavorable physical properties of municipal sludge. [6] Partial drying (up to 30-48% of DS) and total drying (80-97% of DS) is suggested as the most convenient for the drying process and the drying facility exploitation.

8. VAPOURS REMOVAL

Moist air, called vapours, collected from the dryer should undergo certain processes before it is released to the atmosphere. In the first step it should be separated from particles of the dried material. It is done in the dedusting cyclone-type devices or in bag filters. In the next step vapours should be cooled and the obtained condensate should be taken away to the sewage treatment plant. The vapour condensation system can be direct (in spray devices) and indirect (with the help of membrane heat exchangers). Cooling can be carried out by means of air, treated sewage or water in a closed circle. [1] Heat recovered from hot vapour can be reused. The air without vapour should be deodorized in biological filters or in flame (by the fire method) before it is released to the atmosphere.

9. SLUDGE STORAGE

There is a need of sludge storage - dewatered sludge for drying as well as the dried one. In case of the drying facility failure there should be a possibility to store the dewatered sludge. The storage of dewatered sludge is also convenient for equalization of the quality of sludge.

There should be also an opportunity to store already dried sludge for some time in case of the product (dried sludge) user market falling (shaking) e. g. a breakdown of incineration facility if it is the way of the dried sludge utilization.

The dried sludge should be stored under conditions that prevent it from renewed absorbing the moist from the environment (getting dump). Usually it is stored in silos under the cover of gaseous nitrogen that prevents it from self-ignition. [1]

CONCLUSIONS

- Not always is the sludge drying process necessary, but in many cases it is the only solution.
- Sludge drying process diminishes volume of sludge making the transportation cost lower and the sludge storage easier; increases sludge calorific value; makes it hygienic (without pathogenic organisms); stabilizes it and improves its structure.
- There is quite a big variety of technical solutions of dryers among which contact and convective dryers are most popular.
- The choice of sludge drying facility should be dependent on the type of sludge and the method of sludge utilization. It should be emphasized that not all drying facilities are able to dry sludge only partially (less than 85-90% of DS) and, after all, not always there is a necessity to dry sludge up to 90% of DS or more.
- According to the French specialists if sludge is to be used for agriculture suggested profitable degree of drying is 60% of DS and more. The same is with sludge co-incineration with waste. When sludge incinerating in specially adjusted furnaces is taken into consideration suggested profitable degree of sludge drying is 35-45% of DS (partial drying) or above 90% of DS (if dried sludge is to be mixed with sludge of 35-45% of DS before it is directed to the incinerating facility).
- The process of sludge thermal drying is not a cheap solution mainly because of its high energy demand.
- The comparison of the total costs of different sludge utilization options often indicates sludge drying as the best option. The final decision should take into consideration not only economical factors but also others like: reliability of the solution, easy service, ease of storage and transportation or whether the considered solution is environmentally friendly.
- Energy consumption of the sludge drying process to a great extent depends on water content in sludge directed to a drying facility and on technical solutions of drying facilities. Here can be found a significant costs reduction of the drying process.
- As thermal drying of sludge inquires significant amount of energy it is advised to use biogas, energy from sludge or waste incineration or other "waste" energy for diminishing the amounts of fossil fuels.
- Granulation extends the contact surface and makes the drying process more efficient.
- Sludge drying to dry solids content ranging from 48-80% is not applied regarding the unfavorable physical properties of municipal sludge (the sticky phase). Partial drying (up to 30-48% of DS) and total drying (80-97% of DS) is suggested as the most convenient for the drying process and the drying facility exploitation.
- Moist air collected from a dryer should undergo certain processes before it is released to the atmosphere.
- There is a need of sludge storage - dewatered sludge for drying as well as the dried one.

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