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SLUDGE DRYING IN TUNNELS USING PHOTOVOLTAIC PANELS

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Abstract
The objective of this work is to give the fundamental information that should be known about sludge drying methods. The purpose of all types of sludge processing is to reduce the volume, stabilise the sludge, remove water and kill pathogenic organisms. It is processed in stages that contain a sequence of treatments such as thickening, dewatering and drying.
Sludge drying in tunnels using photovoltaic panels is a continuous operation from the sludge treatment which reduces the water content of sludge by heating it for short periods. Dried product not only reaches granular formation with 92 - 95% DS but also gets stabilized. This is a complicated process with contemporary heat and mass transfer attended by physical-chemical transformations. Drying occurs as a result of vaporization of liquid by supplying heat to wet feedstock.

Keywords*: dehydration, drying process, tunnel dryer, sludge*

Introduction
Sewage sludge is formed during mechanical, biological and chemical treatment of wastewater. This causes the generation of large amounts of sewage sludge and its management becomes a growing problem.
Raw sludge obtained from wastewater treatment consists of 95 to 99% water. Remaining part is the solid sludge with different compositions depending on the type and characteristics of influent, treatment technology applied and operational conditions (Houdková et al 2008). Typical raw sludge consists of 60.27% carbon, 6.51% hydrogen, 24.89% oxygen, 8.35% nitrogen, and 0% sulphur (Houdková et al 2008). After digestion, the values change to 62.70% carbon, 8.27% hydrogen, 19.45% oxygen, 7.38% nitrogen, and 2.22% sulphur, respectively (Houdková et al 2008). The contents of dried sludge from municipal wastewater treatment plants (WWTPs) are similar to the composition of brown coal, which has 21 MJ/kg of calorific value (Stasta et al 2006). Sludge also includes phosphorus and potassium compounds. Typical values for stabilized wastewater sludge are 3.3% nitrogen, 2.3% phosphorus, and 0.3% potassium (Tchobanoglous et al 2003, Gljzen 2002). Although these values are lower compared to fertilizers for typical agricultural use (5% nitrogen, 10% phosphorus, and 10% potassium), sludge provides sufficient nutrients for good plant growth (Tchobanoglous et al 2003). In order to benefit from the solid particles of sludge the obstacle of high water content should be reduced.
Dewatering, drying and thickening are three techniques to remove water from sludge. These techniques can remove water by up to 32%, 6% and respectively 63% (Flaga 2007). Drying has a number of advantages compared to dewatering and

thickening. It can remove more water than dewatering and thickening, which results in volume of sludge to be minimal Reducing sludge volume decreases transportation cost. Also, dried sludge with thermal drying does not need any stabilization or pathogen removal Dry sludge can be stored easily and safely (Flaga 2007). Moreover, dry sludge is preferable than the wet one because it can be used as an alternative fuel source in a combustion facility or as a soil conditioner in agriculture (Stasta et al 2005).

Sludge Thickening

Thickening is a process, which reduces the water content in sewage sludge; thereby not only solid content of sludge increases but also overall sludge volume decreases. Thickening process can enrich 0.8% of DS content of sludge to 4%. This process is desirable because it reduces both the capital and operational cost of subsequent sludge-processing steps. Even though sludge thickening process leads to high volume reduction ratio (almost 80%), physical characteristic of sludge is still fluid. Settling thickening, gravity thickening, flotation thickening, centrifugal thickening, gravity-belt thickening, rotary-drum thickening are some thickening processes (Tchobanoglous et al 2003, McFarland 2000).

Sludge Dewatering

Dewatering is the water removal technique to reduce the water content and total volume of sludge. Typically dewatering comes after thickening and after dewatering, sludge is no longer a fluid. Dewatered sludge can be carried with a belt conveyer easily or transported by trucks. Since after dewatering sludge becomes a solid, the transportation and sludge handling costs are reduced, incineration efficiency is increased and leachate production potential during landfilling is reduced. Typical dewatering processes are centrifugation and belt filter press (Tchobanoglous et al 2003, McFarland 2000).

Centrifugation uses the centrifugal force developed by a rotating cylindrical drum or bowl to achieve liquid-solids separation. The centrifuge is essentially a high-energy settling unit. By this technique, it is possible to reach 25-35% dry solid content (DSC) (McFarland 2000, Chen et al 2012).

Belt Filter Press dewaters sludge by forcing the water out from sludge under squeezing shear forces. Product sludge achieves 15-25% DS content while raw sludge solid concentration is 2-5% DS (Tchobanoglous et al 2003, Chen et al 2012).

Sludge Drying

Drying is the process, which can remove high amount of water from sludge. While thickening and dewatering can remove 7% and 35% of the total amount of water, respectively, drying can remove up to 62% additional water content after applying these two systems (Flaga 2007). Sludge drying is an energy intensive process. This system not only reduces volume but also stabilizes sewage sludge. Transportation, storage, packaging and retailing are easy and cost efficient for dried sludge. Drying increases calorific value of sludge. Thereby, sludge can be incinerated without auxiliary fuel. Moreover, its potential as an alternative fuel in cement factories improves. Dried sludge is also beneficial for agricultural purposes. Drying makes sludge hygienic (without pathogenic organism), improves sludge structure and increases its market value (Flaga 2007, Chen et al 2012).

Materials and Methods

The purpose of this study is to investigate the use of dry tunnels using photovoltaic panels to dry sludge to 90% DS.

In order to design the drying tunnel, it is necessary for laboratory experiments to the working temperature and the sludge keeping time inside the drying tunnel.

Laboratory experiments performed will reveal how much the drying space influences the tunnel construction with controlled air movement and without air movement.

Samples are dried to constant mass in an oven at different temperatures. The difference in mass before and after the drying process is used to determine the dry substance and the water content.

The procedure consists in:

- Place an evaporating dish or crucible in the drying oven set at different temperatures for a minimum of 30 minutes and then cool to ambient temperature in a desiccator, with the lid closed. After cooling, weighs the dish or crucible to the nearest 1 mg, (m_a).
- Depending on the expected water content, weigh into the evaporating dish or crucible a suitable amount of sludge, (m_b), so that the dry matter obtained has a mass of not less than 0.5 g.
- Place the evaporating dish or crucible containing the sample in the drying oven set at different temperatures until the residue appears dry, typically overnight.
- After cooling in the desiccator, weigh the evaporating dish or crucible and contents for the first time, (m_c).
- The mass ($m_c - m_a$) shall be regarded as constant if the mass obtained after another hour of drying does not differ by more than 0.5% of the previous value or 2 mg, whichever is the greater. Otherwise, repeat drying until constant mass is reached.
- Calculate the dry substance (w_{ds}) or the water content (w_w) expressed as a percentage of mass or grams per kilogram using the following equations:

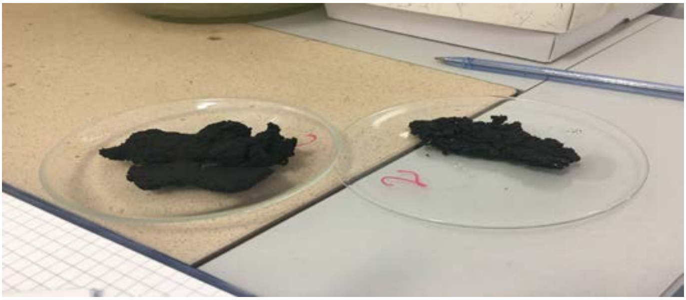
$$w_{ds} = \frac{m_c - m_a}{m_b - m_a} \cdot f \qquad (1)$$

$$w_{wc} = \frac{m_b - m_c}{m_b - m_a} \cdot f \qquad (2)$$

where:

w_{ds} is the dry substance of the sample, in percentages or grams per kilogram;
w_{wc} is the water content of the sample, in percentages or grams per kilogram;
m_a is the mass of the empty dish or crucible in grams;
m_b is the mass of the dish or crucible containing the sample in grams;
m_c is the mass of the dish or crucible containing the dry matter in grams;
f is a conversion factor, f = 100 for expression of results as a percentage and factor f = 1 000 for expression in grams per kilogram.

Values should be rounded to the nearest 0.1% (w/w) or alternatively to the nearest 1 g/kg.



a) b)

Figure 1. Dry substance without air movement (a) and with controlled air movement (b).

Figure 2. Mass of the dish containing the sample in grams.

There is a risk of a cake surface forming. The formation of such cake surface impedes even drying. To avoid this, a glass rod can be weighed along with the crucible. If cake formation occurs during drying, the glass rod is used to stir the sludge to break up the cake and bring the liquid surface into contact with hot air.

Results and Discussion

For dry substance without air movement were obtained 3 samples that are introduced into the drying space at the same time at a temperature of 50 °C and extracted after 30, 60, respectively 100 minutes.

Table 1. Experimental values for dry matter without air movement at 50°C

Samples	The mass of the empty dish or crucible	The mass of the dish or crucible containing the sample	The mass of the dish or crucible containing the dry substance after 30,60,100 min.	The dry substance of the sample
	g	G	g	%
1	16.15	54.48	53.25	7.62
2	17.42	62.95	61.16	10.27
3	14.83	48.04	44.76	22.11

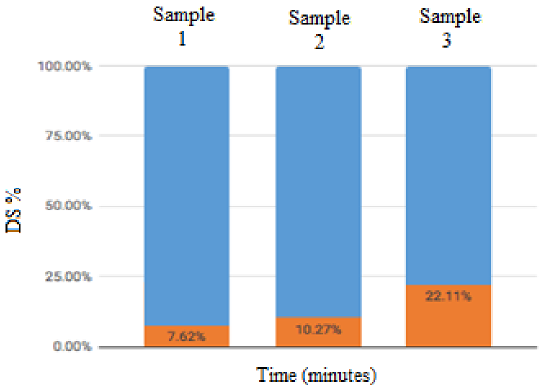


Figure 3. Results for dry substance without air movement at 50°C

Also another 3 samples are introduced into the drying space at the same time at a temperature of 100°C and extracted after 30, 60, respectively 100 minutes.

Table 2. Experimental values for dry substance without air movement at 100°C

Samples	The mass of the empty dish or crucible	The mass of the dish or crucible containing the sample	The mass of the dish or crucible containing the dry substance after 30,60,100 min.	The dry substance of the sample
	g	G	g	%
1	11.73	50.08	46.82	27.79
2	15.90	61.47	55.16	39.69
3	10.31	43.53	35.66	76.33

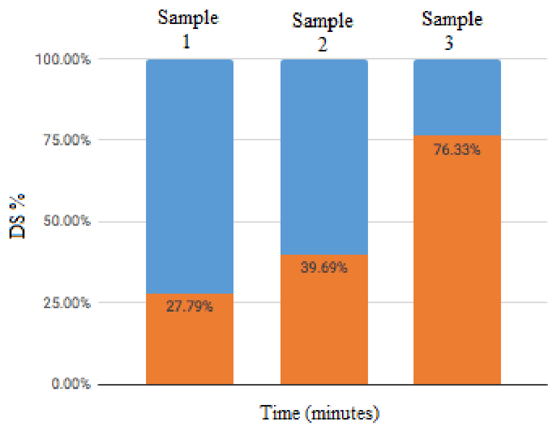


Figure 4. Results for dry substance without air movement at 100°C

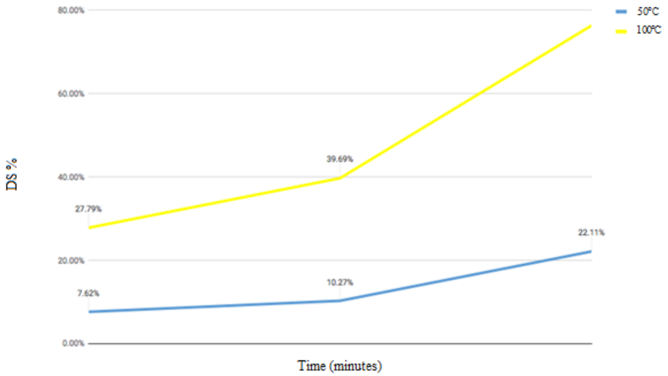


Figure 5. Graphical representation of the results without air movement

Drying area without air movement ensures that the sludge is dried without introducing heat into the entire sludge mass to be dried.
The lack of space ventilation makes the water vapour released by drying to precipitate back into the dry sludge. The drying solution without air movement is a low-productivity solution.
For dry substance with controlled air movement were obtained 3 samples that are introduced into the drying space at the same time at a temperature of 50 °C and extracted after 30, 60, respectively 100 minutes.

Table 3. Experimental values for dry matter with controlled air movement at 50°C

Samples	The mass of the empty dish or crucible	The mass of the dish or crucible containing the sample	The mass of the dish or crucible containing the dry substance after 30,60,100 min.	The dry substance of the sample
	g	G	g	%
1	12.38	48.25	45.61	21.32
2	13.43	47.21	41.75	40.66
3	13.19	46.99	38.56	63.91

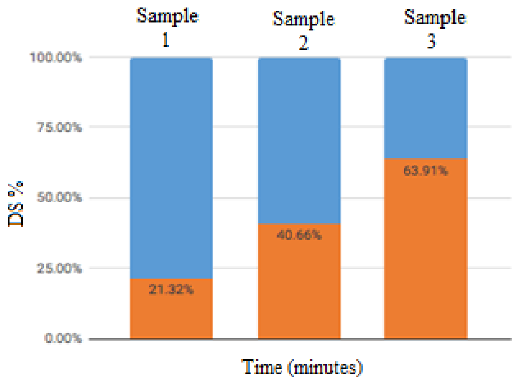


Figure 6. Results for dry matter with controlled air movement at 50°C

Also another 3 samples are introduced into the drying space at the same time at a temperature of 100°C and extracted after 30, 60, respectively 100 minutes.

Table 4. Experimental values for dry substance with controlled air movement at 100°C

Samples	The mass of the empty dish or crucible	The mass of the dish or crucible containing the sample	The mass of the dish or crucible containing the dry substance after 30,60,100 min.	The dry substance of the sample
	g	G	g	%
1	15.23	51.1	43.36	50.82
2	15.69	49.47	38.84	67.75
3	24.60	58.4	37.83	83.62

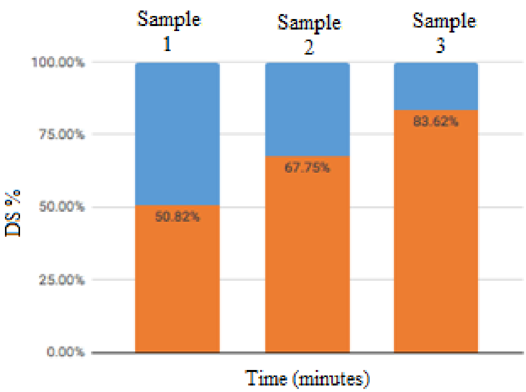


Figure 7. Results for dry substance with controlled air movement at 100°C

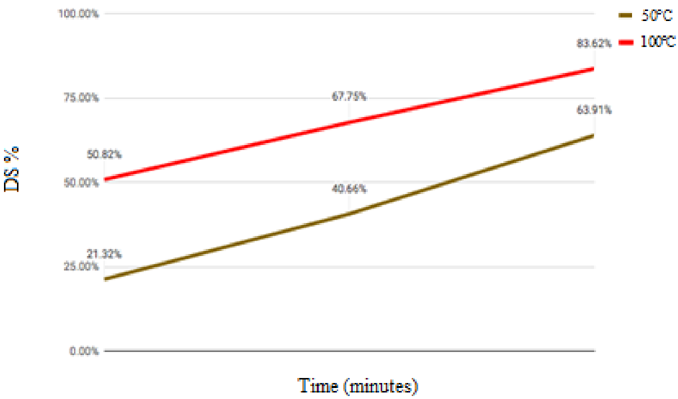


Figure 8. Graphical representation of the results with controlled air movement

Laboratory experiments results from data obtained in the samples for dry substance with controlled air movement at 50°C and 100°C can vary widely from day to day even for the same constant mass, this being also very difficult to determinate. But the results for dry substance with controlled air movement at 100°C allow the user to make a good prediction of how much the drying space influences the drying process, knowing the dry substance and the water content.

Dry tunnels using photovoltaic panels

The drying performance of a dry tunnel, cannot go beyond 70% DS on average. Therefore, dry tunnels should be supported with auxiliary heat to reach 90% DS. This can be achieved through photovoltaic panels.

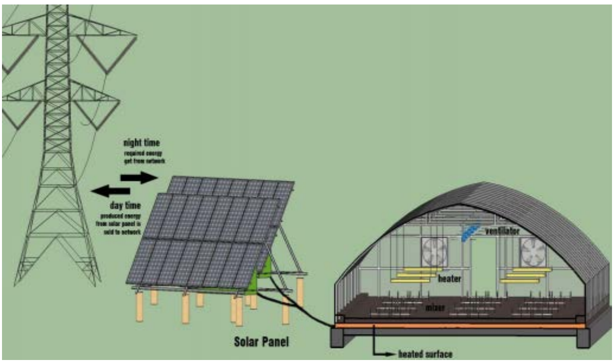


Figure 9. An illustration of the suggested tunnel dryer supported with photovoltaic panels (Kurt 2014).

The system was evaluated based on the area required for photovoltaic panels and tunnel dryer. Water removal rate in tunnel dryer is an indicative parameter for the total cost and area requirement.

Kurt (2014) obtained in the case studies, that the amount of water that should be evaporated to reach at most 70% DS impacts the area of the tunnel dryer itself while the amount of water that should further be evaporated to reach 90% DS impacts the additional energy requirement and therefore the area of photovoltaic panels.

An optimization model used in order to determine the costs of sludge drying with a tunnel dryer supported with photovoltaic panels in which the relative energies supplied (and therefore the costs) by the tunnel dryer and photovoltaic panels are a function of an intermediate dry solids. Optimization helps to find the best solution among all the feasible solutions (Kurt 2014).

Seginer and Bux (2005) have used several models for evaporation rates from tunnel dryers. In general, they describe the evaporation rate as a function of weather, "state of the sludge" (dry solids content, sludge temperature) and control within the ventilation rate, mixing rat. Seginer and Bux used the vapor balance method in their initial modeling efforts, which consists of measuring the humidity ratio, "w", of the ventilating air at the inlet and outlet of the unit; multiplying the difference, wo-win, by the density of air and the discharge of the ventilation fans. Based on experimental data, they also proposed a linear equation, for evaporation rate as follows:

$$E = 0.000461R_o + 0.001010Q_v + 0.00744T_o - 0.220\sigma + 0.000114Q_m \qquad (3)$$

where:

E is the evaporation rate (mm/h);

R_o is the outdoor solar radiation (W/m^2);

Qv is the ventilation rate (m^3/m^2-h);

T_o is the air temperature (°C);

σ is the dry solids content of the sludge (kg solids/kg sludge);

Q_m is the air mixing (m^3/m^2-h).

Conclusions

This study concludes after laboratory experiments for dry substance with controlled air movement at 100°C can obtained 83.62% DS, also in a tunnel dryer, and combined with photovoltaic panels, drying of the sludge is more efficient in removal of moisture and enhances volume reduction up to 90% DS. Tunnel dryer is also efficient in removal of bound water content that is not removed using mechanical dewatering systems.

The photovoltaic panels are highly dependent on weather parameters like solar radiations, wind velocity and relative humidity. The combination of tunnel dryer with photovoltaic panels shows from studies that can save more in energy costs.

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References

Chen, G, Yue, PL & Mujumdar, SA 2002, 'Sludge dewatering and drying', *Drying Technology*, vol. 20, no. 4-5, pp. 883-916.

Flaga, A 2007, 'Sludge drying', Polish-Swedish Seminar on Integration and optimization of sanitation systems in urban areas, Polish-Swedish seminars, *Integration and optimisation of urban sanitation systems*, Plaza, E & Levlin, E, (Eds), Cracow, Poland, March 17-18, 2005, TRITA-LWR.REPORT 3018, Report 13 pp. 72-83.

Gljzen, HJ 2002, 'Anaerobic digestion for sustainable development: a natural approach', *Water Science and Technology*, vol. 45, no. 10, pp. 321-328.

Houdková, L, Borán, J, Ucekaj, V, Elsäßer, T & Stehlík, P 2008, 'Thermal processing of sewage sludge – II', *Applied Thermal Engineering*, vol. 28, no. 16, pp. 2083-2088.

Kurt, M 2014, *'Evaluation of solar sludge drying alternatives by costs and area requirements'*, PhD thesis submitted to the graduate school of Natural and Applied Sciences of Middle East Technichal University of Ankara, pp. 45-50.

McFarland, MJ 2000, 'Biosolids Engineering', 1^{st} Edition (McGraw-Hill Series in Water Resources and Environmental Engineering) McGraw-Hill Companies Inc.

Tchobanoglous, G, Burton, FL & Stensel, HD 2003,*'Wastewater Engineering: Treatment And Reuse*', Metcalf and Eddy, Inc. 4^{th} edition, McGraw-Hill, Boston.

Seginer, I & Bux, M 2005, 'Prediction pf Evaporation rate in a solar Dryer for Sewage Sludge', *Agricultural Engeenering Journal: The CGRE Journal*, vol. 7, pp. 1-8.

Stasta, P, Boran, J, Bebar, L, Stehlik, P & Oral, J 2006, 'Thermal processing of sewage sludge', *Applied Thermal Engineering*, vol. 26, no. 13, pp. 1420-142.