"Technology transfer-oriented research and development in the wastewater sector - validation at industrial-scale plants" (EXPOVAL) – Subgroup 6: Solar sewage sludge drying

First results from investigations with a pilot plant

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Abstract

Drying sewage sludge is one main aspect in biosolids management. For subsequent developing and adapting design rules for solar dryers several investigations were performed in a pilot scale solar dryer. The pilot dryer was operated outside simultaneously to a full scale dryer and afterwards inside a hall. Total solids and climate data were analysed and logged regularly. The amount of faecal coliforms and ammonium was measured as well. Operation next to the full scale plant was aiming on comparing evaporation rates of both plants. Operation inside a hall was performed in order to assess the influence of external heat input on drying process. The results showed a constant drying progress and that drying was feasible. Although differences in evaporation rates occurring from operation, aeration and scaling existed, evaporation rates comparable to full scale dryers could be recognized. Under floor heating proved to have 25 % higher evaporations rates. Measurements in TKN showed a degradation of more than 50 %, this ammonium could be detected as NH_3 in the discharged air. Reduction in faecal coliforms could be analysed without reaching secure disinfection.

Keywords

Biosolids, Climate impact, Sewage sludge management, Solar drying

INTRODUCTION

The requirements for wastewater treatment worldwide are becoming more complex. Additionally the produced sewage sludge needs to be treated with adequate techniques regarding the legal requirements on sludge reuse or disposal. Design rules for wastewater and sludge treatment have been established in Germany. To apply these in foreign countries, adaptations are necessary, especially on local climatic conditions. One of the most important treatment steps to reduce sludge masses is the reduction of sludge water during natural or mechanical drying of the sludge. One appropriate technology is the solar drying of stabilized sewage sludge. It is relatively easy to implement and to handle, and operating costs for electricity and heat are low. In addition, the amount of pathogens in sludge solids can be reduced by solar UV radiation and the high reduction of water content. Therefore with this drying technology sludge solids can be produced which are qualified for agricultural reuse. Worldwide, a huge number of solar sludge drying plants are already operating. Experiences on constructing and operating these plants are available, whereas design rules, especially for different climatic regions do not exist. Hence, the general objective of this research project is to determine and to quantify factors that influence the sludge water evaporation so that the evaporation rate can be predicted based on climatic and operating data. Currently, several investigations are in progress regarding different external heat input devices so that sludge drying with supplementary heat can also be possible in temperate climatic zones in winter. The additional energy demand for external heat input has to be compared with the advantages of a higher year´s total drying performance and the minor drying area needed.

General information on the project

The investigations on solar sludge drying are part of the joint research project EXPOVAL financed by the German Federal Ministry of Education and Research. The overall objective of the project is a full-scale validation of municipal wastewater and sludge treatment concepts under varying climatic conditions which appear to be especially promising in regard to treatment results and economic efficiency. Existing German design rules will be adapted and extend and new design rules where none exist so far will be developed. The boundary conditions for all investigations include a wastewater temperature range from 5 to 30°C, and salt contents higher than 2 g/L. Therefore investigations are carried out on all continents in various climatic zones at commonly used technologies. The joint project is subdivide into seven groups working on different wastewater and sludge treatment technologies so that in the end recommendations on design and operation for complete treatment chains can be presented. The results will be published in a technical guide by the German Association for Water, Wastewater and Waste (Emscher Wassertechnik GmbH 2012).

Subgroup 6 of the joint project works on the full scale validation of existing solar dryers in different climatic regions and the development of design rules for this technology. For this purpose a pilot scale solar dryer has been constructed by HUBER SE, an internationally operating German company specialized on technical solutions for water, wastewater and sludge treatment. This pilot scale plant will operate simultaneously to full scale solar dryers in order to quantify different influences on the drying process and to optimize operation. The locations selected for the investigations include Penzing and Braunschweig in Germany, basically for optimizing and upscaling the pilot scale plant. Further on-site investigations will be realized in Cali in Columbia with subtropical climatic conditions and in Klodzko and Zagan, Poland, with temperate climate and cold winters.

In 2013 first investigations started at a full scale solar dryer in Penzing, southern Germany, in order to adjust the pilot plant operation to full scale performance. Additional investigations were realized placing the pilot-scale dryer in a hall in Braunschweig so that the influence of climatic factors could be kept at their minimum and the full effect of operational adjustments on drying performance could be considered.

Basic information on drying and solar drying

Water still present inside the sewage sludge after dewatering can only be removed by vaporization or volatilization. This cannot be achieved with mechanical treatment, but heat energy is needed in order to achieve a higher content of total solids (TS) in the sludge. The dried solid can be reused in agriculture, incinerated or dumped. Drying technologies can be distinguished into convection, conduction and radiation drying systems in regard to thermal heat transfer.

In convection drying systems the wet sludge gets into direct contact with the heat-transfer medium, mostly hot air. The air circulates around the wet sludge and heats the particles, whereas the humidity is transferred from the sludge into the gas. In conduction drying systems the heat is transferred to the wet sludge through a solid barrier. In most cases steam or thermo-oil is used as a transfer medium that does not get into contact with the sludge. The vapour escaping from the sludge is removed separately from the heat transfer medium. A further way of energy transport is radiation drying where the energy is transferred without any heat carrier via electromagnetic or infrared radiation. The heat is created inside the sludge when electromagnetic radiation is converted into thermal radiation (DWA 2005).

Solar drying is a combination of convection and radiation drying. The dewatered sewage sludge is spread on a concrete floor inside a drying hall constructed of transparent material (comparable to conventional greenhouses). Thus, solar drying is an enhancement of open air drying beds without atmospheric weather influences. As the sludge bed is prevented from rain, drying area and drying time are lower than in open air drying beds. External heat input can enhance the drying process by under floor heating integrated into the bottom plate or by air circulation. Walls and roof of the drying hall construction are made of transparent material like glass, Plexiglas, polycarbonate or polyethylene sheets (Bux 2013) and generate the greenhouse effect. Here, visible sunlight and shortwave infrared radiation pass the transparent roof and enter the greenhouse. Radiation meeting the sludge surface is reflected as long-wave thermal radiation that cannot leave the greenhouse again. Thus the energy stays inside the drying hall and warms up the internal air which can absorb higher amounts of humidity. When cold air enters the dryer it is warmed up and can take up additional water from the sludge. Thus the evaporation rate is increased significantly and the drying process is accelerated. Regular agitation breaks up the dried surface of the sludge and leads to evaporation from beneath (Lue-Hing, Zenz et. al. 1992). Therefore and to avoid anaerobic zones, the sludge is mixed and turned frequently. Solar dryers can work as batch as well as a continuous process. Nowadays there are nearly 300 plants in operation in Europe (Jacobs 2013) and several more all over the world. These solar drying plants treat sewage sludge in a range from 1,000 up to 600,000 population equivalents (Bux 2013).

MATERIAL AND METHODS

Throughout the drying process samples were taken regularly as well in the pilot plant as in the full scale plant. The samples were taken as cores with a cylinder. Sampling points were located regular throughout the drying area. These samples were analysed on several parameters, measurement methods are shown in Table 1.

Table 1: Analysis methods of the performed measurements

Parameter	Abbreviation	Analysis method
Total solids / organic total solids	TS/oTS	DIN EN 12880:2001-02
Total Kjeldahl Nitrogen	TKN	DIN EN 25663 (H11), modified
Sieve analysis		DIN 66165
Faecal coliforms	FC	According to compost analysis (BGK-Methodenbuch) (BGK 1998)

Operation principle of the pilot scale solar dryer

For developing design rules and validating the existing solar dryers a pilot plant was built by company HUBER SE (Germany). The pilot scale plant is a mobile solar dryer in a reduced scale, shown in Figure 1. It consists of a sludge drying area of about 7 m² and a transparent cover made of UV-resistant polycarbonate. The size meets a scale of 1:100 regarding full scale plants and was dimensioned to fit into a 20'-intermodal-container so it can easily be transported to different locations. The drying area consists of a sludge pan separated from the rest of the plant and can hold up to 1000 kg of dewatered sewage sludge. Changes in sludge masses are automatically balanced and logged. For mixing and turning the sludge a rotation device is situated in a slide rail above the sludge bed. The mixing frequency can be adjusted manually in a wide range. Two fans make sure the internal air stays turbulent and saturated air is removed from the plant and replaced by fresh air. For investigations on different devices for external heat input the ventilation fan can be replaced by a fan heater and a floor heating under the sludge bed can be used. In contrast to full scale plants the pilot plant was constructed for batch-tests, but a semi-continuous process is possible as well.

The plant includes a lot of measurement devices for sludge weight, surface temperature, ammonia emissions, sludge layer level, solar radiation intensity, temperature and humidity inside as well as outside the dryer. Additionally the energy consumption of all electronic and mechanical devices can be registered.

Figure 1: The setup of the pilot plant

Simultaneous operation of the pilot and full scale solar dryer in Penzing, Germany

First investigations focusing on the upscaling of the pilot scale sludge drying were realized in Penzing, southern Germany. This site was chosen because of the short distance to the constructing company of the pilot scale plant and the existence of a large scale solar dryer. The pilot plant was situated nearby the large scale dryer facing south, so that the majority of the sludge area could be reached by the sunlight.

Pilot scale plant operation inside a hall in Braunschweig, Germany

After the on-site investigations in Penzing, the pilot scale dryer was operated inside a hall in Braunschweig, northern Germany, in order to assess the influence of external heat input on drying velocity, energy demand and odour production with minimum weather influences. Both under floor heating and fan heater were used as external heat sources successively. To characterize the drying process TS in the solids, energy consumption, climatic data and ammonia concentration inside the plant were measured regularly. Six batches were performed with different operation conditions. An overview of the energy input conditions of the different batch investigations is given in Table 2.

Table 2: Overview of batch investigations in Braunschweig

	Energy input
Batch 1	Under floor heating, 55°C
Batch 2	Fan heater, level 3
Batch 3	Fan heater, level 2
Batch 4	Under floor heating, 55°C
Batch 5	Under floor heating, 80°C
Batch 6	Under floor heating, 55°C

In all experiments the same digested and dewatered sewage sludge from a municipal wastewater treatment plant was used. After the first three trials, sludge was added during the drying process in batch 4 and 5 to get an impression of the consequences of a semi-continuous operation.

Boundary conditions of the drying process. Because of the placement of the pilot plant inside a hall, weather influence could be kept at their minimum. Neither precipitation nor global radiation affected the drying process, whereas small variability in temperature and humidity during day and night-time were detectable. Compared to the investigations in Penzing where relative humidity could vary between 20 and 100 % throughout one day, the variation inside the hall was only about 10 % within 24 hours. Nevertheless in dependency of to the drying progress humidity differed between 30 and 90 %. Temperatures inside the pilot plant varied within five Kelvin during the day compared to temperature differences up to 30 K during on-site treatment in Penzing. Temperature and relative humidity of batch 4 are exemplarily shown in Figure 2. In the following explanations the term “inside” means “inside of the pilot plant”. The term “outside” means “outside of the plant but inside the hall”.

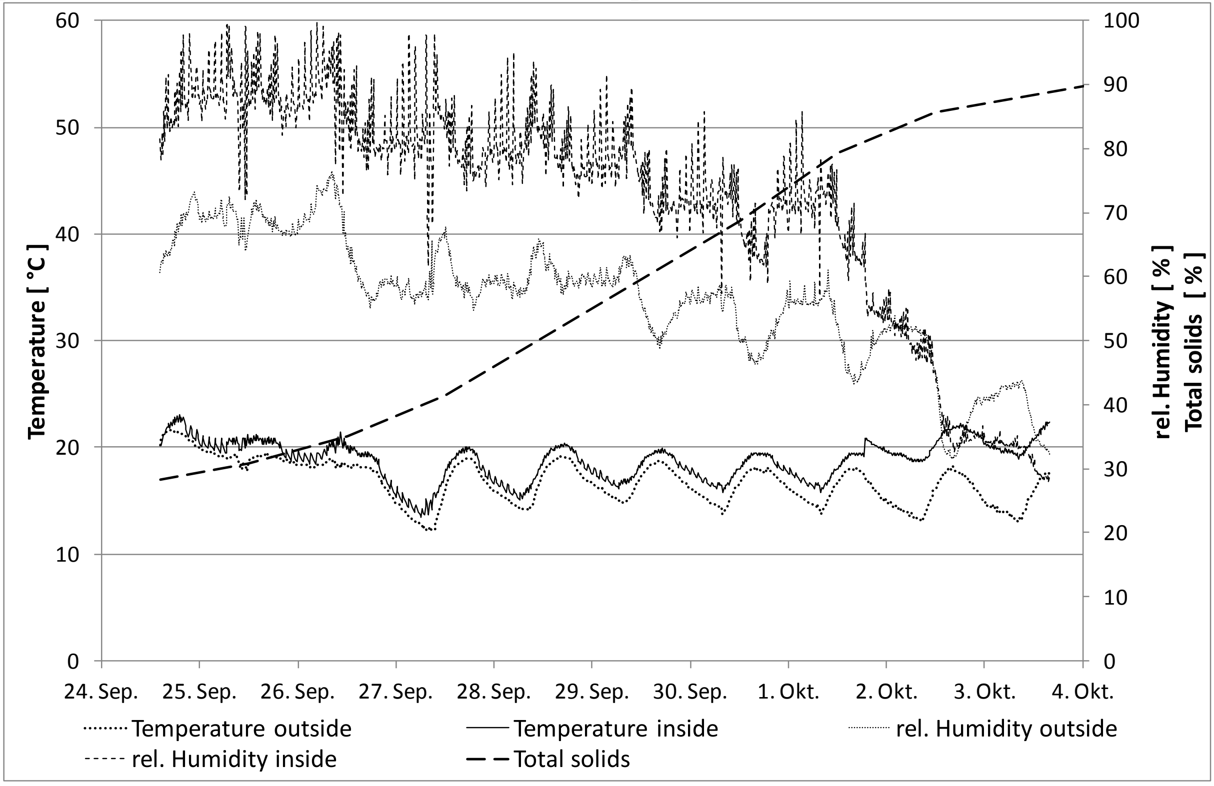


Figure 2: Climatic and sludge solid data during 18 days drying duration (batch 4)

Figure 2 shows that the inside temperature was slightly higher than the outside temperature and both varied during the day. During the whole drying process, the inside temperature did not vary much, only towards the end of the batch trial when the TS reached 80 %. On the contrary, relative humidity inside the plant showed a more comprehensive development. It also reflects the outside conditions, but has much more local maxima and minima, resulting from fan aeration. With a raise in temperature humidity was decreasing rapidly and approaching outside conditions. This indicates that most of the water had evaporated from the sludge and no additional water was taken up by the air. As external heat input sources under floor heating and fan heating were considered solely, for both devices temperature could be adjusted: one-Kelvin steps for under floor heating and three different levels for fan heating.

RESULTS AND DISCUSSION

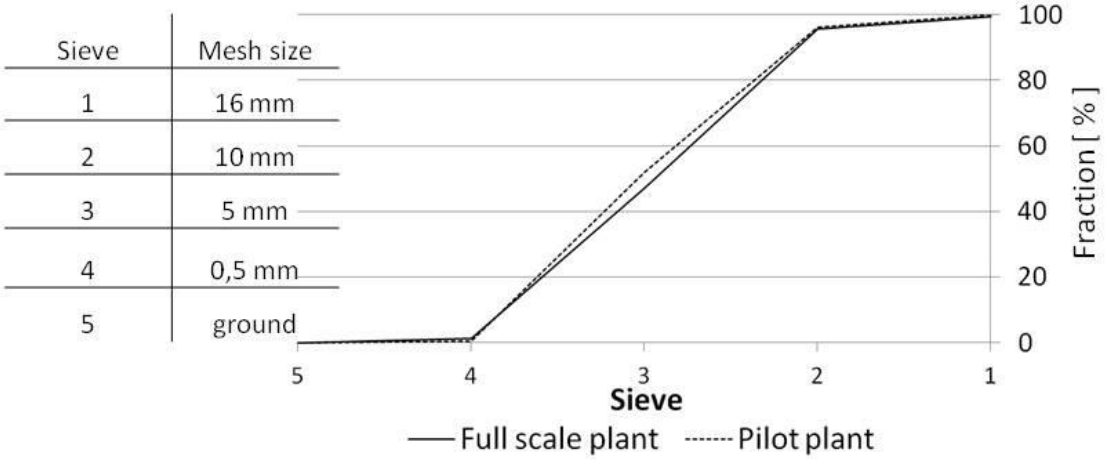
Simultaneous operation of the pilot and full scale solar dryer in Penzing, Germany

During the four-month operation in Penzing evaporation rates between 105 and 344 $g/(m^2 \cdot h)$ in the pilot-scale plant were calculated. These evaporation rates fit quite well to literature data that state values from 79.9 to 137 $g/(m^2 \cdot h)$ (Kassner 2000, converted). Although it has to be considered that investigations in Penzing were run from April to July, whereas bibliographical references evolve from annual monitoring.

Analyses of the evaporation rate in the full scale dryer showed bigger difficulties than in the pilot plant as fewer process data are recorded and operation varies. Additionally the total sludge mass could not be measured throughout the drying process, therefore mass balances had to be calculated solely based on input and output masses. The backmixing of dry sludge into the wet sludge led to further inaccuracies. Differences in evaporation rates of pilot and full scale plant could be observed especially in two sequent batch trials in June and July 2013. The full scale plant showed a evaporation rates of 555 and 154 $g/(m^2 \cdot h)$, whereas simultaneous operation of the pilot plant resulted in 344 and 177 $g/(m^2 \cdot h)$.

It is possible that the differences in evaporation rates of pilot scale and full scale dryer are likely to occur from different aeration, operational aspects and the feeding of the sludge. The aeration differed in time and volume because of different aeration mechanisms: in the pilot plant the discharge of water loaded air was controlled by a fan, fresh air was supplied automatically. In the full scale plant inlet and outlet of air was controlled by opening and closing windows, fans made sure to transport the air through the drying hall. Operational aspects to be taken into consideration in the full scale plant included daily variations in operation. The personnel of the waste water treatment plant adjusted frequency and velocity of sludge mixing and feeding to the dryer according to weather conditions, amount of sludge and personnel capacity.

As the size of the dried sludge granules is another aspect of interest in regard to dust emissions screen analyses of dried sludge solids from the pilot scale and the full scale plant were performed. For both dried sludge granules four sieves (as listed in Figure 3) were used. It can be seen that both grain size distribution curves from full scale and pilot scale dryer show a similar fractioning of sludge solids.



Sieve	Mesh size
1	16 mm
2	10 mm
3	5 mm
4	0,5 mm
5	ground

Figure 3: Results of screen analysis

No granules were bigger than 16 mm, nearly 50 mass-% of the material could be found in 5 and 0.5 mm sieves. Hence more than 90 % of the granule had a size between 0.5 and 10 mm. The fraction of particles smaller than 0.5 mm reaches only around 1 %. This shows that dust emissions are not a primary problem. Although dust settled visibly on technical devices inside the plants it is not enough to lead to dust explosions. Altogether these results show that both pilot scale and full scale drying are comparable regarding dried solids output.

Pilot scale plant operation inside a hall in Braunschweig, Germany

The different investigations showed that sludge drying in the pilot plant inside the hall with external heat input was feasible. Evaporation rated in the same order of magnitude as during on-site operation in Penzing. The results of the sludge drying shown as follows are focussing on batch trial 3 and 4. The boundary conditions of both batches were nearly the same. The same sludge was used and the outdoor temperature was at 19.5 and 16.8°C, respectively. Figure 4 and Figure 5 show weight-, total solids- and ammonia concentration-progress during the drying process of the two batch trials.

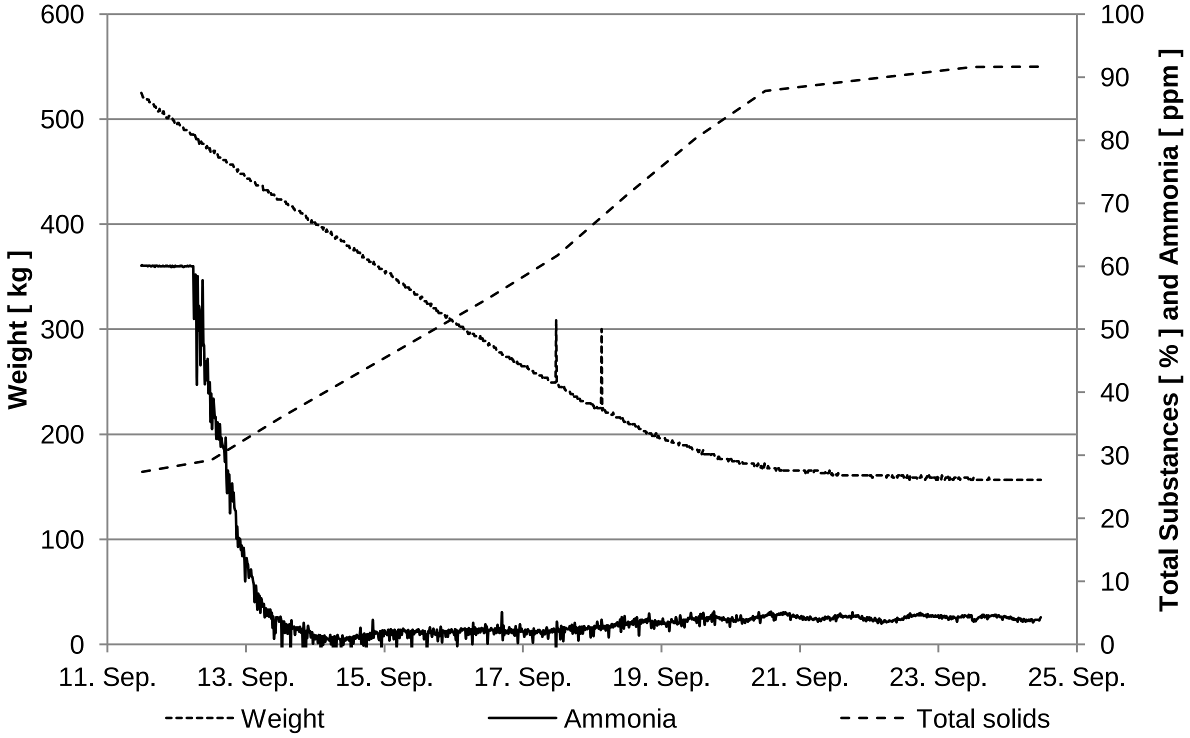


Figure 4: Process data batch 3

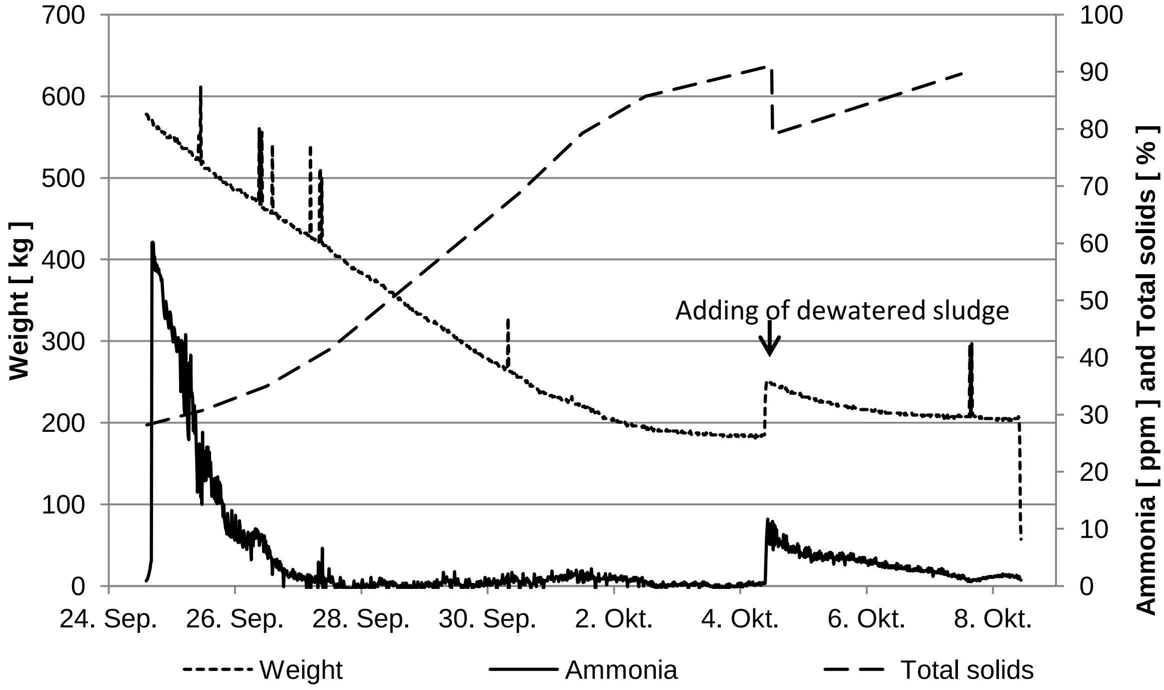


Figure 5: Process data batch 4

As it can be seen in Figure 4 and Figure 5, constant drying could be realized with external heat input and there was no significant difference between both energy sources concerning reduction in weight. Classical drying curves (as published in (Loll and Melsa 1995)) could be replicated with a fast decline in weight in the beginning and a slower in the end. At the same time the TS is gradually rising from 27 % and 28 % of the dewatered digested sludge to over 90 %. The total solids were measured once a day and the curve progression suits quite well to the development of the weight, which was measured automatically four times per hour. The correlation of weight reduction and TS increase due to evaporation can be stated with the given curves. In the fourth batch trial (Figure 5) fresh dewatered sludge was added to the material after nine days of the process to evaluate the effects of a semi-continuous operation.

For comparing the two different ways of energy input, batch trial 3 and 4 were considered between 30 and 89 % of dried solids. In batch 3 the air was heated up by the fan heater using level two which was regulated by the inside air temperature. Energy input in batch 4 on the other hand was realized with under floor heating being controlled at 55°C. The following Table 3 shows the differences in drying behaviour.

Table 3: Comparison of effects o different energy input

	Drying period	Evaporated water	Ratio [kg/h]
Batch 3	214 h	302 kg	1,411
Batch 4	204 h	361 kg	1,770

Although the total drying time in batch 3 is higher than in batch 4, the load in batch 4 was higher. Therefore the drying velocity altogether is higher in the fourth batch as well: the average evaporation reached 1.77 kg of water per hour, whereas in batch trail 3 it was only 1.41 kg per hour. This shows the advantage of under floor heating compared to a fan heater. Taking into consideration the area of the plant of nearly 7 m², evaporation rate in batch 3 can be calculated to 202 g/(m²·h) and 254 g/(m²·h) in the fourth batch. Compared to the measurements in Penzing these rates correspond to evaporation rates for on-site operation with solar radiation in warm spring or cool summer.

The advanced evaporation using under floor heating can be explained by heat transfer mechanisms. Thermal energy is supplied directly to the sludge and afterwards to the air. By that process the energy is used directly for taking up water into the air. On the contrary, thermal energy generated by the fan heater follows the air-sludge transmission before water can be taken up and be discharged with the air.

The higher drying ratio when using under floor heating also appeared to have a lower energy demand. This is primarily caused by the fact that it is much more independent from aeration compared to the fan heater and temperature is controlled directly at the under floor heating. The fan heater on the other hand is regulated by the inside air temperature and switched on/off frequently. In addition, the sporadic operation of the fan for air discharge caused the continuous outlet of warm air not fully loaded with water. Adjusting the ventilation to lower frequencies could improve the drying progress.

As indicator for odour emissions, ammonia concentration in the discharged air of the plant was measured. The concentrations during the drying process correlated with the drying progress of the sludge. In the beginning a big amount (exceeding the measurement limit of 60 ppm) of ammonia was released, independent of the heat energy source or its temperature level. NH_3-concentrations decreased sharply at 35% TS. After that the ammonia discharge stayed on a more or less constant level at around 20 ppm and approached zero. Only when there was no more change in weight and TS, ammonia emissions stayed on a constant low level. Whenever new dewatered sludge was added to the plant (as illustrated in Figure 5) a peak in ammonia concentration could be recognized, but much lower than in the beginning of the batch trial. Therefore, if the drying plant is run in a semi-continuous operation, the peak emissions are much smaller, whereas the total discharged ammonia stays the same. Instead of one highly concentrated ammonia release, lower dosages are discharged regularly. With semi-continuous operation only emission standards in regulations like the German Technical Instructions on Air Quality Control (BMU 2002) can be met.

Measurements of Kjeldahl-Nitrogen in the sludge solids showed a reduction of 53 % during the drying process. For the measurement of nitrogen compounds sludge samples were taken in the beginning and in the end of the drying process and were analysed for ammonium and organic nitrogen. From 8.83 kg TKN in dewatered sludge 4.15 kg stayed inside the dried material. This shows that more than 50 % of the ammonium must be transferred into the gaseous phase.

Pathogen analyses resulted in a reduction of indicator bacteria both at 55°C and 80°C floor heating temperatures. Salmonella could not be found in any of the dried samples. Faecal coliforms in the sludge were reduced from 1.39×10^4 to 4.35×10^3 MPN/g TS when drying at 55°C. At 80°C a reduction from 2.77×10^6 to 1.39×10^4 MPN/g TS could be realised. These data indicate that a partial disinfection could be achieved. For a secure disinfection (density of faecal coliforms less than 1000 MPN/g TS) as it is required according to standards (EPA 2007) higher floor heating temperatures and adjustments in operation might be necessary. It has yet to be investigated whether the effect of UV radiation during on-site treatment outdoors can further reduce pathogens.

CONCLUSIONS AND OUTLOOK

The first investigations with the pilot scale and the full scale plant show, that drying performance of the pilot plant can be adjusted to full scale operation. This is the key to further develop and enhance design and operation recommendations especially for different climates. Here, especially the fractioning of the dried sludge showed comparable qualities. The measured differences in evaporation rates occurring from the scaling and different aeration will be focussed on in the following studies. When using different ways of energy input the under floor heating appeared to lead to 25 % higher evaporation rates and a lower energy demand at the same time. Both alternatives reached evaporation rates comparable to full scale solar drying under German spring/summer conditions. Ammonia emissions correlated with the drying progress, the high emission peaks during initial feeding of dewatered sludge can be reduced by a semi-continuous operation.

After completion of the batch tests in Germany, further investigations are currently prepared for a simultaneous set-up of the pilot plant next to a full scale solar dryer at the waste water treatment plant in Cali, Columbia. Again, first the upscaling of the pilot plant drying performance will be considered. Based on that reference, several operational influences will be changed, including sludge layer thickness, rotation interval of the mixing device and aeration. Additionally some further operational aspects will be taken into consideration, e.g. the influence of a semi-continuous sludge input on the drying progress and the odour development. After the investigations in Columbia, the pilot plant will be transferred to Poland, where investigations will focus on external energy input for sludge drying in winter.

ACKNOWLEDGEMENT

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