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**Title: The potential of the sludge bed
ecotechnology and anaerobe-
reactor for treating concentrated
sludge fractions at the Fuhais
Research and Demonstration site**

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INTRODUCTION

Sustainable sewage sludge treatment requires dewatering and further processing, which is becoming a growing challenge in many regions around the world. Sludge management has become a key issue in wastewater treatment, representing some 20–60% of the operational costs of conventional wastewater treatment plants (WWTPs). This is particularly critical in the case of WWTPs of small rural communities, which, in practice, may have to transport sewage sludge to larger WWTPs instead of implementing their own sludge treatment technology. The high water content of the sludge results in large daily flow rates to be handled and treated. Thus, the search for decentralised sludge treatment solutions to improve sludge dewatering (volume reduction) and stabilisation continues to be of major interest.

The main sludge treatment operations are aimed at increasing the concentration of total solids in order to reduce the sludge volume (i.e. sludge thickening and dewatering) and stabilising the biodegradable fraction of organic matter (i.e. sludge stabilisation via anaerobic digestion or composting). One of the objectives of the SMART I project was to select and install decentralised sludge treatment technologies in pilot plants in order to demonstrate their suitability under the Jordanian climatic conditions. Within the SMART II project, these technologies are monitored for a long-term basis and their performances are assessed in order to optimise them for implementing in real decentralised conditions.

The objective of this interim report is to analyse the treatment performance of the installed sludge drying reed bed eco-technologies and anaerobic bioreactor that are in operation at the Fuhais research and demonstration site, Jordan.

1 SITE DESCRIPTION

1.1 LAYOUT

Figure 1 shows the location of the two pilot-scale sludge treatment technologies at the Fuhais site. Among other decentralised wastewater treatment and reuse technologies, these two technologies are representing the technologies for sludge treatment at the demonstration and research site.

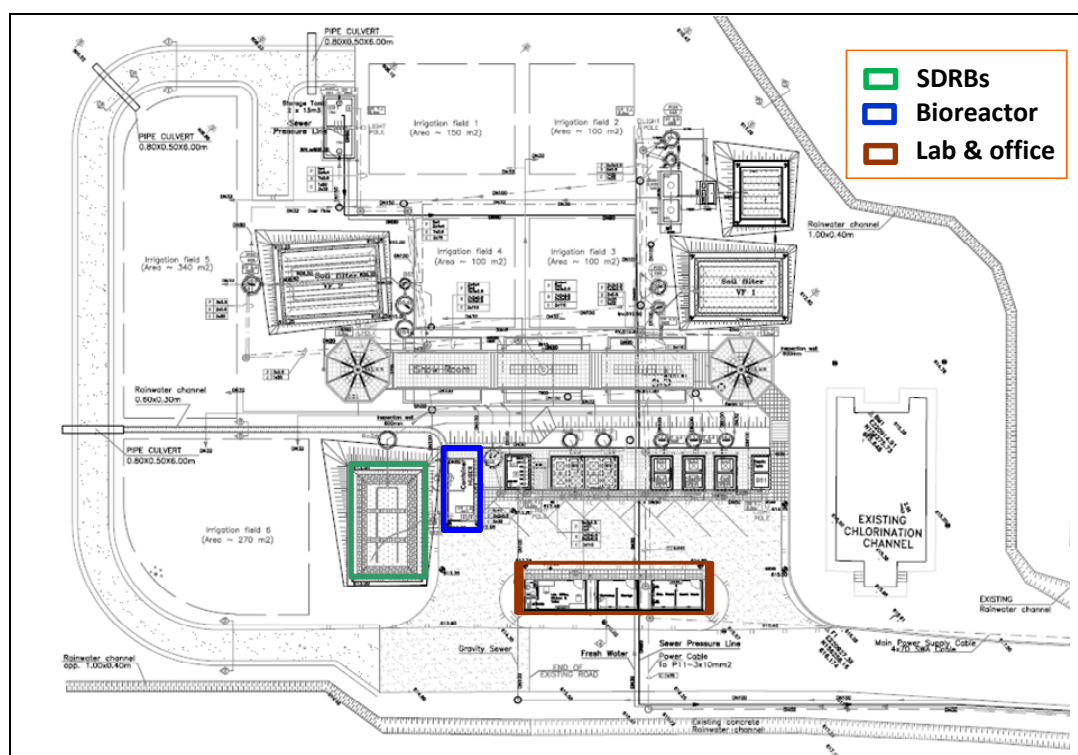


Figure 1: Site location of the two sludge treatment technologies and other facilities.

As shown on the plan, the site is also fitted with its own laboratory and offices facilities to ensure the site's administration, including operation, maintenance and routine monitoring. The offices facilities also include a control room from where the operational parameters of the different treatment systems can be both controlled and modified.

1.2 SLUDGE COLLECTION AND EFFLUENT DISPOSAL

Collection of influent sludge

Within the framework of SMART II project, it is planned to treat septage collected by tankers from cesspits within the already installed sludge treatment technologies (sludge drying reed bed eco-technology and anaerobic bioreactor) at the Fuhais demonstration site. But due to the difficulty to

identify the frequent source of septage sludge, secondary treated municipal sewage sludge has been used. Septage sludge will be used when the source of supply and collection system can be identified.

We continue our investigations on the potential of these two technologies to treat this municipal sewage sludge for volume reduction and stabilisation under Jordanian climatic conditions. The SDRBs were commissioned in July 2009 and due to some additional construction works to supply the sludge more conveniently, the sludge application started from November 2010 by using the secondary treated sludge (0.5% – 3% TSS content) from the nearby municipal WWTP. The influent sludge is collected from the sludge thickener after the secondary treatment at the WWTP on a weekly basis and stored at the sludge storage tank at the site. The sludge storage tank is equipped with an inflow pump which can be operated both automatically and manually to feed the sludge as required by the daily/weekly loading schedule of the technologies. However, sludge production and characteristics are highly dependent on the daily wastewater composition and the treatment steps used by the WWTP. Hence the solids content of the influent sludge varies from time to time.

Treated effluent (leachate/sludge) disposal

The effluents from the sludge treatment technologies are collected in a pump sump and sending back to the municipal WWTP of Fuhais for conventional treatment. The pump capacity has been sized to be able to accommodate any treated effluent production from the site, in normal operation conditions or under higher hydraulic load.

1.3 TECHNOLOGY DESCRIPTION

The aim of the sludge treatment technologies installed at the Fuhais research and demonstration site is to investigate on ecologically efficient way for treating different sludge fractions, which would provide a high quality resource for reuse in agricultural purposes or soil amendments.

Two different types of decentralised sludge treatment technologies are installed at the Fuhais test site. The ecotechnology based Sludge Drying Reed Beds (SDRBs) are designed by the Environmental and Biotechnology Centre (UBZ) of the Helmholtz Research Centre UFZ and the anaerobic bioreactor is provided by the company Huber SE, Germany, in a container. The evaluation and optimisation of the treatment performance of these technologies and their adaptations under the specific Jordanian climatic conditions are the prime objectives of this research work.

1.3.1 SLUDGE DRYING REED BED FOR ECOTECHNOLOGICAL SLUDGE TREATMENT

Sludge drying reed beds (SDRBs) could represent a simple and cost-effective ecotechnology for sludge management. Our research work aims to investigate the dewatering and sludge stabilization efficiency of SDRBs and to adapt the technology to the climatic conditions of arid/semi-arid regions.

The production of high quality dried biosolids which can be re-used as organic soil amendment, contributes to the competitiveness of the technology.

SDRB technologies for municipal sewage sludge require minimal energy input and are based on both the dewatering and aerobic conditioning. Compared to conventional unplanted sludge drying beds, which need to be excavated on a regular basis before the fresh sludge application, the planted beds can be filled up with intermittently loaded fresh sludge over a long period of time (e.g. 5-10 years). SDRBs are basically impermeable beds with bottom layers of gravel and sand which are planted with *Phragmites australis* or other locally available plants. Figure 2 shows the schematic of the sludge dewatering mechanisms in case of planted beds (by evapo-transpirations) and in conventional unplanted bed (only by evaporation).

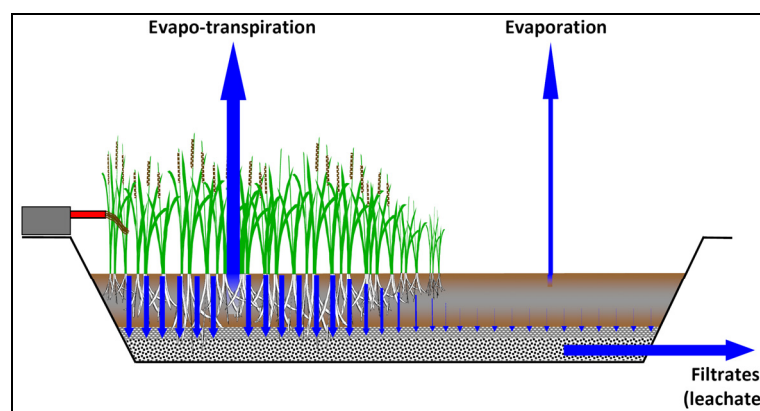


Figure 2: Schematic of sludge dewatering (volume reduction) in case of planted and unplanted SDRB

The SDRB systems consist of several beds that are alternately fed with a homogeneous distribution of sludge over the surface. These allow sufficient rest period for dewatering and progressive mineralization of the sludge deposit. Drainage pipes are incorporated in the bottom of the beds to enhance the dewatering of the sludge. The collected leachate can be then additionally treated further for reuse or directly pumped back to the WWTP.

The interconnected mechanisms and reactions that are taking place in the SDRB are: i) dewatering by percolation and evapo-transpiration, ii) oxygen transfer by diffusion via the pore system of the medium and the aerenchyma of the plants, and iii) stabilization by microbial processes. The plants play a key role in the SDRB system due to : i) the evapo-transpiration, which decreases even water with high osmotic potentials also from the lower sludge layers, ii) the complex plant-root system, which aggregate the medium and thereby build up porosity and drainage pathways, iii) the transfer of oxygen that assist the biochemical activation of the microbial population in the root zone, aerobic biological mineralization and stabilization and (iv) production of plant biomass that can be used for energy recovery. Figure 3 shows the schematic of the oxygen input within the planted beds (by diffusion via the pore spaces of the bed medium, via the complex plant-roots and also ventilation through the drainage pipe at the bottom of the beds) and conventional unplanted beds (only at the top of the water-saturated surface and a very few from the bottom drainage pipe due to lack of pore spaces).

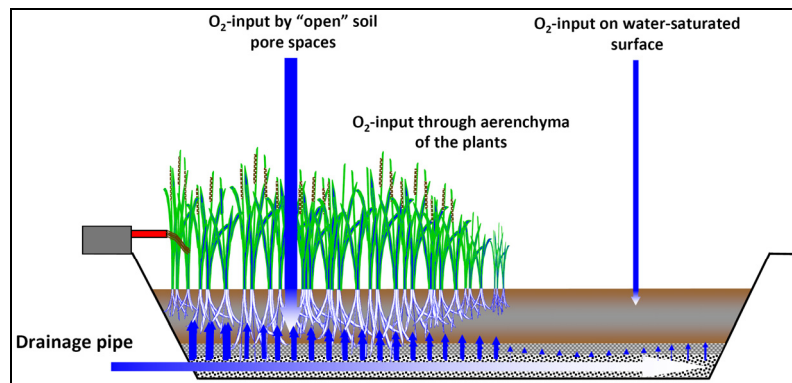


Figure 3: Schematic of oxygen input in case of planted and unplanted SDRB

Effects of sludge loading rate and plant-root growth on sludge dewatering efficiency as well as the hygienic quality of the leachate and accumulated biosolids are highlights of our research work in pilot scale systems. The reuse of the conditioned biosolids as a potential nutrient-rich soil amendment for agriculture is also one of the main focus of our studies. Figure 4 shows the cross-sectional view of the SDRBs at the Fuhais Research and Demonstration site, Jordan.

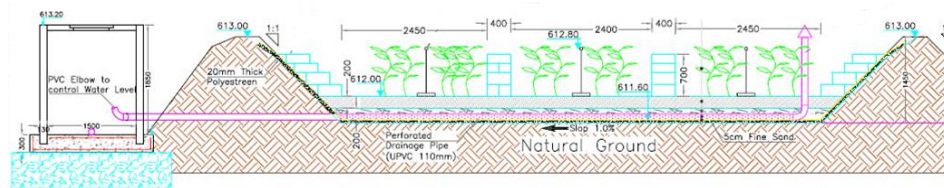


Figure 4 : Cross-sectional view of the sludge drying reed beds (SDRBs) at Fuhais site

The site includes, amongst other decentralised technologies, three ecotechnology based pilot-scale sludge drying beds (SDBs) which were planted with locally available *Phragmites australis*, *Arundo donax*, and *Typha latifolia*. The beds consist of 5 cm fine sand at the bottom layer, then covered by a PE membrane, followed by a perforated drainage pipe (110 mm) which was also buried under the washed gravel of 4-8 mm (zeotuff) material. Washed WADI sand of 0-5 mm ($d_{10} > 0.25$ mm) was spread over the bed surfaces as the top layer of the SDRBs. The collected rhizomes of the selected plants were planted within this top layer of the beds. The drainage pipe is connected to ventilation risers to enhance oxygen transfer at the bottom of the beds (see Figure 4).

After the plants were well-established within the beds, a homogeneous distribution of 500L, 1000L and 500L of secondary treated sludge was applied with a long hose on a weekly basis over the beds 1, 2 and 3, respectively. Only half of the specific design load ($50\text{-}60 \text{ kg DM/m}^2\cdot\text{y}$) was applied at the beginning. Three different plant species were planted on the three beds in order to investigate the response of these locally available plants (growth rate, no. of shoots etc.) to different sludge loading rates and how they contribute to the rapid sludge dewatering (EVT rate) and mineralisation process. Figure 5 shows the photo of the three SDRB ecotechnologies along with the sludge distribution tank and a long hose at the Fuhais site.



Figure 5: Photo of the three SDRBs which are operating under sludge loading rate at the Fuhais site

After this initial investigation phase, the sludge loading on bed 2 was increased to 1500L, while keeping the same loading on bed 1 and 3 (500L). The idea behind this investigation is to find out the plant activity under longer sludge retention time, higher retention of solids on the bed surface and also to compare the quality of dried biosolids (sludge stabilisation) among the beds at the end of this study.

1.3.2 ANAEROBIC BIOREACTOR

Anaerobic treatment processes are able to transform C-containing substrate into biogas. The organic fraction of wastewater, for example, is a valuable source of energy. In this study, the anaerobic treatment aims to the stabilisation of municipal sewage sludge and to produce high quality fermentation residues. The production of biogas contributes to the competitiveness of the technology. In addition to that, the anaerobic treatment leads to a significant reduction of pathogenic organisms. Sewage sludge used in this research work is the same secondary treated sludge (product of the nearby WWTP at Fuhais) that is used for the SDRBs operation. The primary goal of the investigation was to determine the biogas yield from secondary treated sludge under the stable operating condition of the digester.

The company HUBER SE, Germany supplied a containerized pilot-plant which is used as a test unit for sludge treatment. The plant consists of a hydrolysis stage and an anaerobic reactor operated under mesophilic conditions. The digestion is carried out in this two-stage anaerobic bioreactor. Figure 6 shows the process flow diagram of the anaerobic bioreactor technology at the Fuhais site. The bioreactor is fed four times a day to ensure regular supply of substrate for the biocoenosis process.

Several test series were conducted with different retention times in order to achieve a stable operating condition within the bioreactor. After a very long start-up phase, the anaerobic reactor is set to operate with a hydraulic retention time of 25 days.

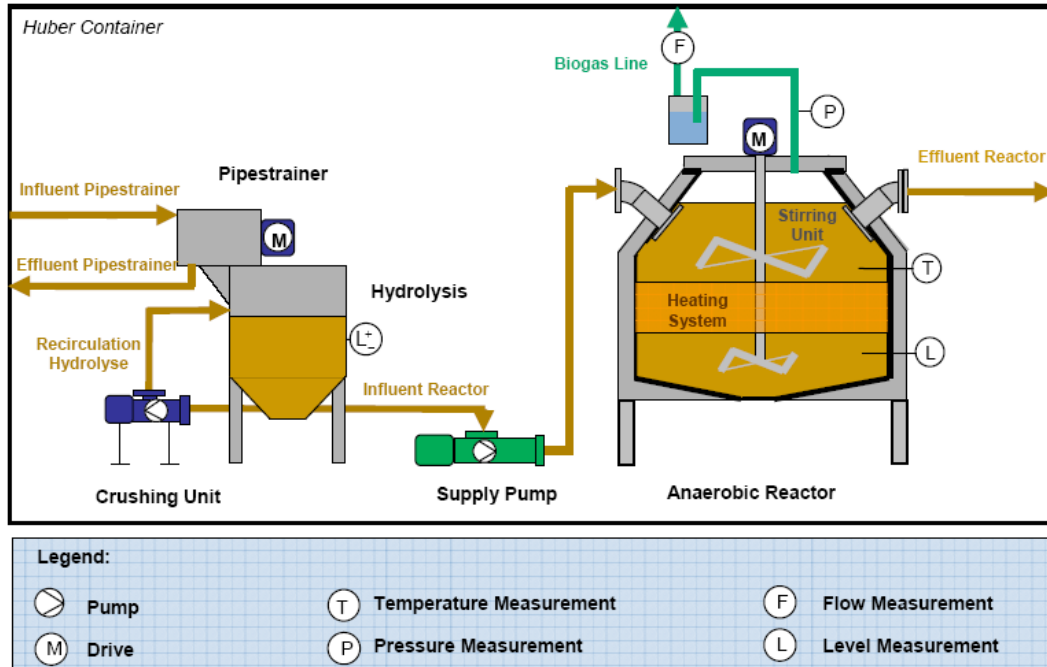


Figure 6: Process flow diagram of the anaerobic bioreactor technology at the Fuhais site

Figure 7 shows the inside view of the already operating anaerobic bioreactor plant at the Fuhais demonstration site in Jordan.



Figure 7: Anaerobic bioreactor plant at Fuhais (inside view)

Anaerobically digested sludge was planned to be dried in the SDRBs for sludge dewatering and stabilisation. But due to a very small amount of effluent sludge production (60 L/d), it was decided to send it via the overflow tank to the nearby WWTP.

2 MONITORING PROGRAM FOR THE SYSTEMS

Both the sludge treatment technologies at Fuhais are monitored in terms of taking readings, sampling and analysis of the influents and effluents according to an already established monitoring program. Frequent operation and maintenance are also included within this program. It is necessary to follow such a program in order to monitor the treatment performance of the systems more frequently and taking necessary steps from time to time if any maintenance task is required on an urgent basis.

2.1 SAMPLING AND SCHEDULE

The monitoring program has been organised to monitor each technology by taking some on-site readings on a daily basis and sampling on a weekly basis. In most cases, taking of readings and sampling from the technologies are performed on-site but due to lack of adequate facilities for sludge analysis at the Fuheis on-site laboratory, the sludge samples are carried to the local Al-Balqa University (BAU) laboratory for the analysis. The leachate sample from the drainage outlet tank is collected and analysed by the existing on-site analytical laboratory facilities at the Fuhais site. Table 1 gives the sampling labels according to their location and the details of the sampling schedule.

Table 1: Sampling labels, locations and schedule:

Sample label	Technology	Location	Sampling schedule
INFLUENT	Influent sludge for both technologies	Sludge storage tank	Every week (Tuesday)
EFFLUENT	Anaerobic bioreactor	Effluent from anaerobic bioreactor	Every week (Tuesday)
LEACHATE	SDRBs	Drainage outlet tank	Every month (Tuesday)

2.2 PARAMETERS ANALYSED

Due to lack of technical equipments needed to analyse sludge fractions in Jordan, it is not possible to analyse all the parameters that we have planned earlier in our monitoring program. However, the most interesting chemical parameters like COD, TSS, $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, TN, $\text{PO}_4\text{-P}$, and TP are monitored for the leachate which is being collected from the outlet of the SDRBs. Some other parameters are also monitored like inflow sludge TSS and water content, volume (height) of water at the leachate outlet tank, number of green and healthy plant shoots, height of plant shoots, height of dried biosolids on the SDRBs etc. on a regular basis. Table 2 shows the list of different parameters and their analytical method used in this study.

For the anaerobic bioreactor, both influent and effluent samples are taken for analysing the parameters like TSS and VSS content. Biogas productions due to anaerobic sludge mineralization are

monitored from the attached gas-counter connected in series with the biogas effluent outlet of the reactor. For better analysis of the biogas, a gas analyser was also installed for a short time to investigate the concentrations of methane (CH₄), Carbon dioxide (CO₂) and O₂ in the effluent gas from the bioreactor.

Some other important parameters like volatile organic acids (VOA), COD, TOC, TN, faecal indicators, pathogens etc. are not possible to analyse within the sludge samples by the existing laboratory facilities at the Al-Balqa University or any other laboratories in Jordan. Monitoring of all these important parameters on a regular basis is very much essential for investigating the potential of such technology within the framework of a long-term research work.

However, the sludge samples were collected a few times from the inlet and outlet of the bioreactor and carried them to the laboratory of the UBZ at the UFZ, Leipzig, Germany for further analysis.

Table 2: List of the parameters monitored and their analytical method used for sludge treatment at Fuheis

Class of parameter	Parameter	Measuring unit	Method	Brand (device)	Place of analysis
Field (on-site) parameters	Volume (height) of water in outlet tank	cm		Measuring device	Fuhais
	No. of green and healthy plant shoots	-	-	-	Fuhais
	Height of plants	cm	-	Measuring device	Fuhais
	Height of dried biosolids on the bed	cm	-	Measuring device	Fuhais
	Temperature	°C			Fuhais
	Rainfall	mm			Fuhais
	Volume of biogas	L		Gas-counter	Fuhais
	Gas analysis	%		Gas analyser	Fuhais
Lab parameters (Leachate)	COD	mg/L	Test kit	Hach-Lange	Fuhais
	TN	mg/L	Test kit	Hach-Lange	Fuhais
	NH ₄ -N	mg/L	Test kit	Hach-Lange	Fuhais
	NO ₃ -N	mg/L	Test kit	Hach-Lange	Fuhais
	PO ₄ -P	mg/L	Test kit	Hach-Lange	Fuhais
	TP	mg/L	Test kit	Hach-Lange	Fuhais
	<i>E. coli.</i>	MPN/100mL			BAU
Lab parameters (Sludge)	TSS	mg/L			BAU
	VSS	mg/L			BAU
	Water content	%			BAU

2.3 DATA ANALYSIS

Analytical results are collected together on a fortnightly basis on excel spreadsheets, both from Fuhais and BAU laboratories and analysed them for understanding the treatment performance of the respective technologies on a regular basis. This is also important for the optimization of the systems performance and to solve any problem concerning operation & maintenance.

3 ANALYSIS OF THE TECHNOLOGIES PERFORMANCE

Here follows the treatment performance and current activities of the sludge treatment technologies at the Fuhais site. The results are only showing the treatment trend of the technologies at this stage of the project, therefore the data analysis in this interim report will not be considered as the final remarks on the performance of the technologies. Before making any concluding remarks, a full-set of data will be analysed after the termination of the project phase II.

3.1 SLUDGE DRYING REED BEDS

3.1.1 SLUDGE DEWATERING AND STABILISATION

The main goal of sludge treatment ecotechnologies is dewatering (volume reduction), which transforms the sludge from a liquid to a solid waste (or by-product), resulting in the so-called sludge cake. Sludge dewatering is evaluated by the increase in TSS content on the beds. Figure 8 shows the mean solids loading rate (SLR) on each bed at the Fuhais site. Bed 2 is fed with a higher loading rate with a mean value of 63.4 Kg TSS/m²*year, than the other two beds (Bed 1 and 3) with a mean SLR of 31 Kg TSS/m²*year. Cumulative solids retention in each bed is also presented in Figure 9.

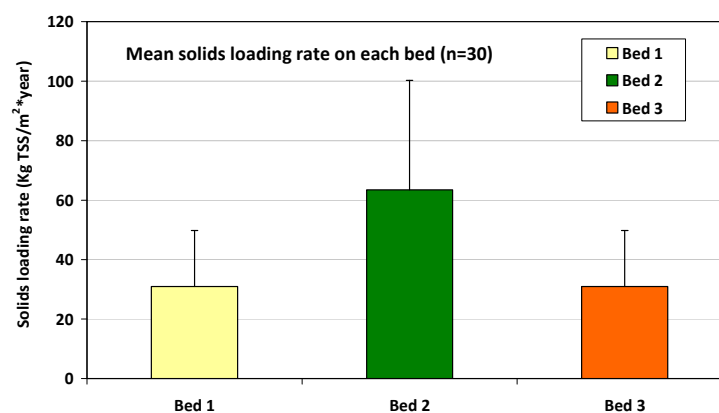


Figure 8: Mean solids loading rate (SLR) on each bed during the on-going operational period

This result indicates that until now a total of 48.4 Kg of TSS mass has been accumulated on Bed 2 after starting the sludge loading, as compared to the Beds 1 and 3 with a TSS mass retention of 23.6 Kg. The higher the accumulated solids content on the bed without causing any hydraulic problem (clogging etc.) or without any stressful plant-growth situation means the better the dewatering efficiency of the system.

The efficiency of the SDRBs for sludge dewatering can be evaluated by the increase in total suspended solids (TSS) concentration within the accumulated sludge. In general, TSS concentration increases from 0.5 – 3% in influent sludge to 30–40% in the accumulated solids within the first 3 days after applying the sludge on the beds.

During the first phase of the experiment (0–504 days, Phase I), the average sludge loading was 500 L/week on bed 1 & 3 and 1000 L/week on bed 2. After day 504 (Phase II), only the sludge loading rate on Bed 2 was increased to 1500 L/week (HLR 15 cm/week). Bearing in mind that the Bed 2 has the highest sludge thickness and sludge loading rate as compared to the Bed 1 and 3, therefore it was expected that the sludge dewatering will be decreased in Bed 2, but until now no unwanted situation has taken place or occurred.

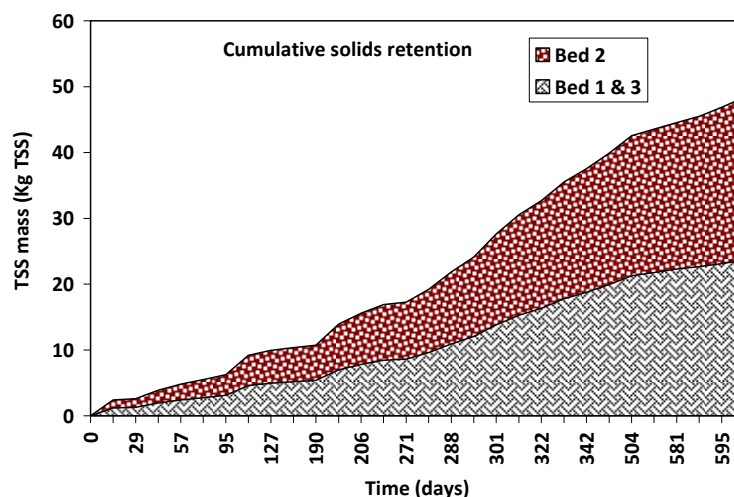


Figure 9: Cumulative solids mass retention on the bed 1, 2 and 3 during the on-going operational period

The efficiency of SDRB systems can also be observed by the decrease in volatile solids (VS) concentration within the settled sludge. During sludge treatment within the SDRBs at Fuhais, a VS reduction of 25–30% can be achieved. VS removal yields depend on influent sludge VS concentration. Since the quality of the secondary sludge collected from the nearby WWTP is changing frequently because of their sludge thickening methods, maintenance and sometimes lack of available sludge at the sludge thickener, therefore it is hard to control over the VS content of the influent sludge and also to the mineralized sludge on the SDRBs on a regular basis. Also because the quality of wastewater is highly variable through the week (oil, grease and blood in the weekends) might be a reason for a frequent change of sludge quality.

We will get more data on the sludge stabilisation after the termination of sludge loading on the beds at the end of our investigation period. The result of sludge dewatering and stabilisation processes is a final product (biosolids) that is suitable for land application, either directly or after additional composting.

Due to some design constraints with only one drainage outlet for three beds, it is also not possible to estimate the water loss from each individual bed in this study. Therefore, we considered three individual beds as one-single bed unit and a quantitative approach was taken to estimate the water balance within the beds. In general, after 7 days of sludge loading, about 58-64% of percolated leachate was recovered. Around 42-36% of the influent water was lost during the 7-day resting period, thus corresponding to a daily water loss of approximately 25.6 mm/ (m²*day). Water loss can be attributed to plant evapo-transpiration or storage in the top sludge layer, adsorption to the filter media surface or to interstitial water.

During dewatering, rainwater due to several rainfall events at the site increased the water content of the sludge, especially when the sludge was freshly discharged on the beds. Rainfall during dewatering generally prolonged the dewatering process. Therefore, in principle, SDRBs are more efficient as dewatering units in the dry season with no or minimal amount of rainfall.

3.1.2 LEACHATE ANALYSIS

Figure 10 shows the concentrations of the selected parameters which are monitored within the collected leachate from the drainage outlet tank of the SDRBs. A high COD with a mean value of 638.3 ± 167 mg/L is observed, which is nearly close to the septic tank effluent concentration in case of wastewater treatment. The mean concentrations of NH₄-N and NO₃-N are obtained as 0.6 ± 0.4 and 937.7 ± 80 mg/L, respectively. The low level of NH₄-N and high level of NO₃-N indicate the establishment of stable aerobic conditions and high oxygen transport within the SDRB systems. This transformation of NH₄-N into NO₃-N (nitrification) can also be considered as a guarantee of sludge stabilisation by microbial processes. Oxygen transfer by diffusion via the porous medium and by the aerenchyma of the plants in the rhizosphere creates aerobic microsites in the bulk sludge layer and thus ensures appropriate conditions for aerobic degradation processes and other oxygen dependent reactions like nitrification.

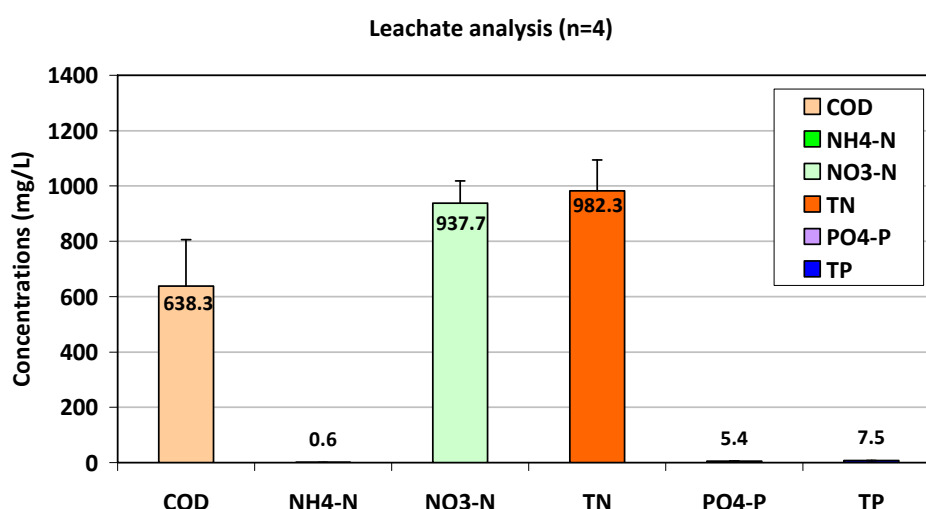


Figure 10: Mean concentrations of parameters monitored within the leachate of the SDRBs

Total nitrogen (TN) of 982.3 ± 112 mg/L within the leachate is mainly analyzed as $\text{NO}_3\text{-N}$, which can also be used as a potential liquid fertilizer, if not treated further. The low $\text{PO}_4\text{-P}$ and TP with a mean concentration of 5.4 ± 0.8 and 7.5 ± 0.3 mg/L, respectively, clearly suggest that most of the phosphorous is retained within the accumulated dried biosolids of the SDRBs and will be available for plant growth if used as organic fertilizer or soil conditioner suitable for agricultural crop fields or land reclamation. However, the accumulation of organic and inorganic pollutants in the sludge may impede such applications due to the environmental and health hazards that it may involve. Thus, the assessment of some potential pollutants (i.e. heavy metals, fecal microbial indicators, etc.) is needed before land application of the treated sludge.

3.1.3 PLANT GROWTH AND SHOOT DENSITY

The changes in environmental conditions induced by sludge applications on the SDRBs certainly influenced the multiplication rate of the plants. As a result of secondary sludge applications, shoot density was almost 2-3 times higher in the dewatering beds within the first 2 months of sludge application, especially *Arundo donax* on Bed 2 and 3. *Phragmites australis* were also growing with a faster rate on Bed 1. This high density can be attributed to the plants' adaptability, allowing for growth in sludge treatment beds, but also to the availability of sufficient nutrients, especially nitrogen and phosphorus contained in sewage sludge. With regard to sludge dewatering, this high plant density is beneficial as it helps to accelerate the high amount of water loss by infiltration and evapo-transpiration. This high plant density also leads to an increase in oxygen transport to the below-ground parts of the rhizosphere contributing to aerobic sludge mineralisation, the complex plant-root system aggregates the medium and thereby builds up porosity and drainage pathways.

In addition, during a resting period, accumulated sludge forms a dry surface film that is cracked due to the movement of plants. The fractures on the sludge layer enhance water percolation and oxygen

transfer, which promotes a more uniform porosity along the bed and sludge mineralisation at the bottom level (Nielsen, 2003). Figure 11 shows the dried sludge with cracked surface on a SDRB at Fuhais.



Figure 11: Dried sludge with cracked surface on a SDRB at Fuhais, Jordan

3.2 ANAEROBIC BIOREACTOR

3.2.1 PHYSICO-CHEMICAL ANALYSIS OF TREATED SLUDGE

As mentioned earlier that the sludge analysis facility at the local Al-Balqa University is not optimum, therefore a few of the sludge samples from the anaerobic bioreactor (inflow and outflow) were carried to the UBZ laboratory for sludge quality analysis of the most important parameters. For example, Table 3 shows the analytical results of the sludge influent and effluent sample which was analysed on 23.11.2011.

Table 3: Inflow and outflow sludge sample analysis at the UBZ, UFZ laboratory

Parameter	Unit	Sludge inflow	Sludge outflow
TS content	%	1.53	3.87
COD	mg/L	704	216
TOC	mg/L	235	35
TN	mg/L	1231	2274
Organic acids	mg/L	332	31.4
<i>E. coli</i>	MPN/100 mL.	2,85,1000	10,000

Increasing the TS content suggests the volume reduction and mineralisation of sewage sludge under the running conditions of the bioreactor. The sample from the outlet has nearly 90% reduction of organic acids, 85% of TOC, 70% of COD and almost 2-log reduction of *E. coli* as compared to the inflow secondary sludge during a slow and stable bioreactor operation. Accumulation of TN indicates the beneficial reuse of this effluent as organic fertilizer, if not treated further.

3.2.2 PRODUCTION OF BIOGAS

The results of the gas production rate monitored from the attached 'gas-counter' of the anaerobic bioreactor at Fuheis from the beginning of the sludge operation period is shown in Figure 12. The gas production rate is fluctuating with a mean value of 42.8 ± 26 L/d as recorded from the gas-counter. We haven't disturbed the set-up of the feeding substrate in order to achieve a stable operating condition inside the bioreactor. As we are using secondary treated sludge (not the raw sludge from the primary settling tank), therefore to boost-up the microbiological activity a little bit and for a higher gas production rate, a batch of fresh cow dung was included at one stage inside the bioreactor.

The fluctuating dynamics of the gas production rate curve clearly suggest that the biological process collapses on a regular basis of every three months inside the reactor. Nevertheless, without knowing the organic acids and pH-value from the reactors on a regular basis, it is not possible to make any remarks on this characteristic.

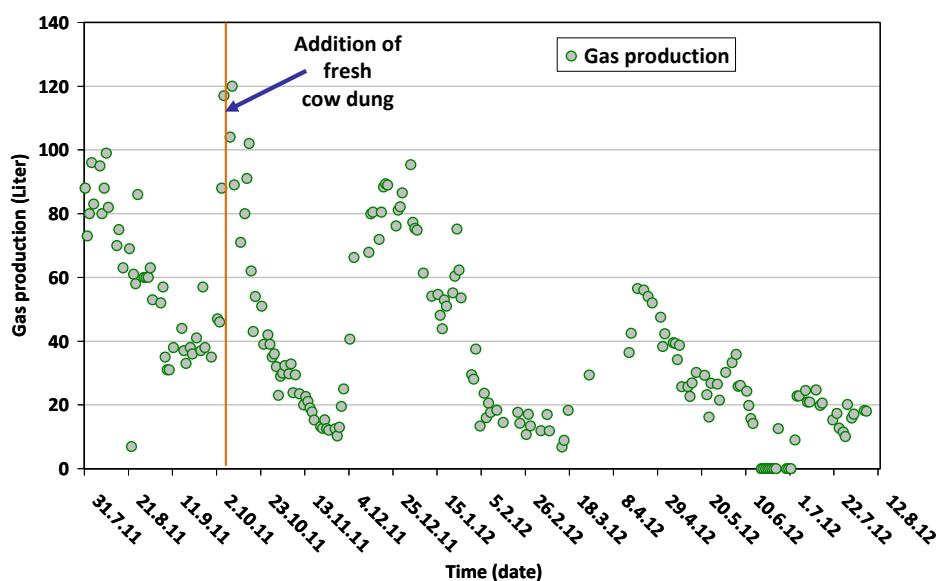


Figure 12: Gas production rate of the bioreactor investigated from the beginning of the sludge operation

Using of concentrated sludge fractions (e.g. septage from a septic tank) or mixing a co-substrate (e.g. olive-mill sludge) with the supplied secondary sludge might be giving a better biogas production rate. These options will be considered within the running time period of the project.

3.2.3 ANALYSIS OF PRODUCED BIOGAS

The analysis of the produced gas (% vol.) at the reactor outlet was carried out by using a simple gas analyser (Ansyco, GA94). The short-term experimental results clearly shows that the majority (>55%)

of the produced gas from the anaerobic bioreactor is methane (CH_4). Table 4 shows the analytical results of the produced gas during different investigation phases of the reactor operation.

Table 4: Analysis of biogas produced during different investigation phases of the reactor operation

Parameter	CH_4	CO_2	O_2
	%	%	%
During mixing inside	68.4	30.4	1.1
During resting period	62.7	22.3	2.4
Before batch loading	55.9	26.1	5.6
Immediately after batch loading	65.8	27.5	2.7

The analysed values of CH_4 and CO_2 clearly show the anaerobic process inside the reactor and also supporting the values found in other literatures. Directly after the batch loading and during the mixing phase the CH_4 -values are higher due to fresh CH_4 is leaving the sludge phase. Only the concentration of oxygen (O_2) is a little bit too high for an anaerobic process. It should be lower than 1-2% as suggested by other literatures. This might be due to the fact that the oxygen is able to enter the reactor through the effluent outlet. More results are needed before making any concluding remarks on this biogas analysis.

4 CONCLUSION

Investigation on the sludge dewatering from the SDRB ecotechnology under local Jordanian climatic conditions reveals that evapo-transpiration might be the major dewatering process. The presence of plant within the SDRBs assists aerobic biological mineralisation of the sewage sludge and hence makes the technology more attractive (e.g. less odors) as compared to the conventional sludge drying beds without plants. Demonstrating the beneficial reuse of leachate and dried biosolids (final product) as organic fertilizer in agriculture and for soil improvements will also be carried out at the end of the investigation period.

For deriving the necessary design criteria for a full-scale implementation of the SDRB technology, we are evaluating the technical components of each process unit. The suggested solutions will be comparatively evaluated not only by technological criteria but also by analyzing the economic and social viability. The results of these investigations will be used to assess the overall potential of the SDRB ecotechnology as a decentralised sludge treatment solution for arid/semi-arid regions, especially in WWTPs of small communities.

A laboratory based experiment with the secondary treated sludge and olive mill sludge is currently carrying out at the UBZ laboratory in order to assess the potential of biogas production from concentrated sludge fractions (like olive mill sludge) and to use it as a co-substrate in the anaerobic bioreactor at Fuhais. Several trial experiments by mixing olive mill sludge and the secondary treated sludge with different ratios are investigating the suitable ratio of these two combinations of sludge

that can boost up the anaerobic microbial process and produce more biogas. The results will be accumulated in the next project proceeding report in future.