

Treatment of communal sewage sludge: quantities, recent and future technologies, heavy metals and costs

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Abstract

In the light of the valid EU directives the sludge produced in communal waste water treatment plants and industrial waste water works becomes a more and more costly problem, because during the forthcoming years the simple and low cost land-filling will be forbidden.

In the article the whole issue from sludge production, sludge treatment to sludge disposal is covered from the view of an engineering consultant, in other words bound to practical experience. Several technologies are presented and costs and ecological impacts are assessed.

1 Amount and Composition of sewage sludge in Slovenia

The sewage sludge quality is determined by the presence of pathogenic organisms and concentrations of heavy metals and is dependent on the wastewater characteristics and the type and quality of treatment. The concentrations of heavy metals such as arsenic, cadmium, copper and cobalt in sewage sludge vary depending on the contributions from industries and households to the sewer system and the efficiency of wastewater/sludge treatment system. Table 1 shows the composition of an average sewage sludge after pre-treatment at a wastewater treatment plant (Data representing an average sewage sludge in Austria).

In Slovenia 53 percent of the households are connected to wastewater treatment plants. About 87,3 million m³ wastewater is treated at these plants each year and produce therefore an estimate of 27.000 Mg (dry matter) of sewage sludge.

The ingredients, especially the amount of heavy metals are of course dependent on the industrial and communal facilities connected to the sewer system.

In Austria these “indirect” waste water producers are regulated by appr. 60 special water regulations. One of the most important pollutants in respect to heavy metals and persistent

organic compounds are communal landfills. Therefore the regulation for landfills are even stricter than for communal waste water.

Most of the Austrian landfill leachate is cleaned on site and discharged directly to a river by the use of reverse osmosis, the heavy metals and persistent compounds remain in the concentrate, which is reinjected to the landfill in order to “boost” the organic degradation within the landfill.

Parameter	unit	value
pH	[1]	7,7
Dry matter	[mass - %]	30,50
NH ₄ -N	[g/kg dry matter]	1,60
NO ₃ -N	[g/kg dry matter]	0,17
Organic Nitrogen	[g/kg dry matter]	14,18
Total Nitrogen (Nges)	[g/kg dry matter]	25,19
Calcium (Ca)	[g/kg dry matter]	70,98
Potassium (K)	[g/kg dry matter]	2,63
Magnesium (Mg)	[g/kg dry matter]	9,17
Phosphorus (P)	[g/kg dry matter]	31,00
Arsenic (As)	[mg/kg dry matter]	6,05
Lead (Pb)	[mg/kg dry matter]	53,82
Cadmium (Cd)	[mg/kg dry matter]	1,19
Chromium (Cr)	[mg/kg dry matter]	43,4
Cobalt (Co)	[mg/kg dry matter]	6,53
Copper (Cu)	[mg/kg dry matter]	197,10
Manganese (Mn)	[mg/kg dry matter]	220,86
Molybdenum (Mo)	[mg/kg dry matter]	3,90
Nickel (Ni)	[mg/kg dry matter]	27,69
Mercury (Hg)	[mg/kg dry matter]	1,00
Zinc (Zn)	[mg/kg dry matter]	809,52
organohalogen compound content (AOX)	[mg/kg dry matter]	147,00

Table 1: composition of a sewage sludge (Lit. 1)

2 Technology

The first step in the “mechanical” wastewater treatment process is the removal of large solids

and grits through screening. The screening by-products are treated separately from other wastewater sludge.

The second “mechanical” step involves the use of clarifiers and sedimentation tanks to settle particles in the wastewater. This treatment removes approximately 50 to 65 percent of the suspended solids and 30 to 40 percent of the biochemical oxygen demand (BOD) from wastewater. Therefore, the “primary” sludge removed from this process contains a high amount of organic matter that is highly degradable.

During the biological treatment aerobic micro – organisms are used to remove the remaining BOD, Ammonia and suspended solids. Overall, this “secondary” sludge is consisting of nearly 90 percent organic matter and is composed of approximately 2 to 4 percent solids.

Both sludges from mechanical and biological wastewater treatment are mixed together and undergo further treatment.



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figure 1: Membrane bioreactor system

The recent development of membrane bioreactorsystems (MBR – see <http://www.envicare.at/research/kommeng.pdf>, Lit. 2 - 5) seems to be very promising to reduce the amount of the “secondary” sludge. These systems operate with a dry solids concentration from 8 – 20 g/l and ensure an aerobic stabilisation during the treatment.

2.1 Sludge pretreatment in waste water treatment plants

2.1.1 Storage

A volume reduction of approximately 30 – 80 % can be reached with sludge thickening before a further treatment. At smaller wastewater treatment plants, where the sludge is driven off regularly, thickening usually takes place directly in the sludge storage tank. The sludge is compressed at the tank bottom only by the force of gravity, while above the sludge a cloudy water layer is formed, which is taken off and led back into the inlet.

On larger plants separate thickening basins exist. These basins are equipped with slow rotating mixers, which create micro canals in the sludge for a better dewatering. Also pure machine thickening is gaining more significance with e.g. non-stabilised sludge, that could rot during the storage.

2.1.2 Aerobic stabilization

Aerobic stabilisation can be performed simultaneously in an activated sludge plant whereby primary and secondary sludge are continuously aerated for long periods of time. In aerobic digestion the micro – organisms extend into a respiration phase where materials previously stored by the cell are oxidized, resulting in a reduction of the biologically degradable organic matter. Thus, aerobic stabilisation of the entire excess sludge (including primary sludge) is energy consuming. Additionally, it calls for extra reactor volume.

Usually this system is applied at WWTP's smaller than 20.000 PE. The main reason is that up to this size the utilization of biogas in cogeneration units is not economically feasible and that an aerobic stabilisation is relatively cheap in terms of investment costs.

2.1.3 Anaerobic digestion

An anaerobic treatment system is a complex and costly bioprocess that produces methane gas from the biological digestion of sewage sludge (see figure 2). This process is most efficiently done using either an anaerobic activated sludge system or a submerged media anaerobic reactor. The production of methane gas is a sensitive process because it requires specific environmental conditions for the growth of methanogenic bacteria. These bacteria need temperatures (appr. 38 °C, mesophilic) and can only digest effectively at a pH of 6.6-7.6.

After cleaning and purifying (sulphur, siloxane) the methane gas, it can either be burned by direct firing to produce process heat or within a cogeneration unit to provide electric power and heat.

Due to the relatively high investment costs and due to safety regulations anaerobic systems are commonly used at WWTP's larger than 20.000 PE. From the energy point of view the production of biogas is ecologically sound, a renewable energy source.



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figure 2: digester (left) and cogeneration unit (right)

2.1.4 Dewatering

A further reduction of the sludge quantity is commonly applied after the thickening. The liquid sludge is dewatered and forms a dry and porous residue while the water from the press is fed back to the WWTP. For a good dewatering, size and firmness of the sludge agglomerates are important, they have to remain porous during the compression. Flocculants are often used to achieve a high as possible dry material content and must be specifically fitted with the specific sludge. For the choice of the correct dewatering process it is important to consider a multiplicity of further boundary conditions: Quantity, structural situation, disposal, regulations, availability, personnel etc.

Dewatering can be done naturally (dry beds), however this is only possible during a long period of time. Faster and smaller, but also more cost intensive, are machine processes such as pressing (filtration by vacuum and pressure filters) and centrifugation (decanter centrifuge).



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figure 3: chamber press filter (left) and decanter-centrifuge (right)

2.1.4.1 Chamber filter press (filtration by pressure filter)

This pressing technique is the most widespread despite its intermittent operation and its high investment cost. Chamber filter presses (see figure 3) are one of the most efficient ways to dewater and compact sludge into solid cakes.

The sludge slurry is pumped into the press, fills the chambers and dewatered via the pressure from the feed pump. Filtrate passes through the media/filter cloth and continues out of the press. Depending on the nature of the slurry, chamber filter presses are capable of dewatering sludge up to 30%-60% solids.

2.1.4.2 Centrifuge

Centrifuges are occasionally used to reduce the volume of stabilized sludge (see figure 3). The goal of centrifugal dewatering (thickening) is to obtain a solids concentration of approximately 20%.

Sewage Sludge is fed at a constant feed rate into a rotating bowl and the solids are separated from the liquid by the centrifugal forces created by the rotating bowl. The solids are compacted to the bowl wall and the liquid and fine solids exit the unit through the effluent line. An internal screw conveyor removes the dewatered sludge out one end of the bowl while water leaves the other end. Although the solid content is still low, it is possible to transport the “pudding” like sludge.

2.2 Off-site treatment of the dewatered sludge

2.2.1 Composting

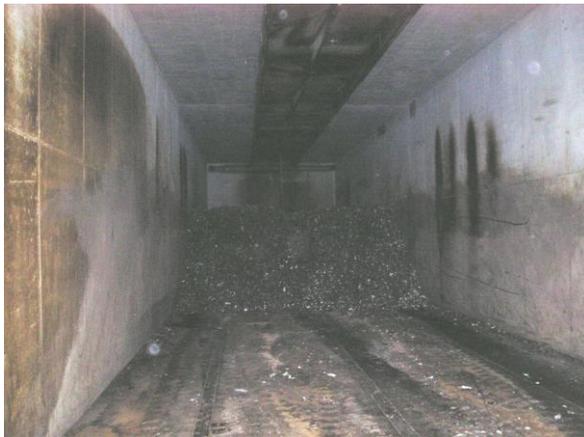
Composting is a method for managing sewage sludge wherein the organic components of the sludge are biologically decomposed under controlled conditions to a state where the resulting composted material can be handled, stored and/or applied to land without adversely affecting the environment. The resulting compost will be drier and more stabilised than dewatered, raw or digested sewage sludge, thus emitting less odorous compounds and attracting fewer vectors (e.g. rats, flies).

Composting works by mixing the sludge with a bulking agent to make sure that the mixture can be aerated for an accelerated aerobic degradation process. The problems are that much energy is required to aerate the composting material, and the end product, the compost, must be disposed of to suitable land and it is not attractive to farmers due to a low fertiliser value.

The sludge is dewatered to approximately 35% DS. This allows the sludge to be self-supporting in a pile or stack and so facilitate composting. It is then mixed with a bulking

agent to dry out the blended mix. Bulking agents can be sawdust, leaves, paper and solid waste, however wood chips are the most common. It is mixed in a ratio of three parts wood chips to one part sludge to achieve 55% DS.

Composting technologies vary from simple, open wind - row facilities (elongate piles) to more controlled reactor systems such as aerated static pile and in vessel (vertical flow reactors and inclined reactors).



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figure 4: technical and controlled process in closed boxes or “low-tech” in open rows

2.2.2 Anaerobic treatment

See chapter 2.1.3. The off-site treatment of communal sewage sludge only makes sense in case that there is no anaerobic treatment on the WWTP.

2.3 Drying

Sludge drying is used to reduce both pathogens and the water content of sewage sludge, thus a reduction of the sludge weight is the main goal.



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figure 5: technical drying or “low-tech” solar drying

2.3.1 Technical Drying

Technical Sludge drying procedures are based particularly on contact or convection procedures.

Large amounts of air are not necessary during the contact drying, because the warmth is supplied by the contact between the damp product and a heated wall. Only a minimum gas flow is often planned for the evacuation of steam. The advantage is that the expenditure for exhaust air purification is small.

Convection drying obtains its effect by treating the sludge with hot-air. In addition ambient air is heated to a high temperature with a burner or steam heat exchanger and brought in contact with the sludge in a drum or belt dryer.

2.3.2 Solar Drying

Agricultural and other products have been dried by the sun and wind in the open air for thousands of years.

A solar drying process is based on the fact that evaporation takes place also at lower temperatures than 100 °C. Anyhow energy is required, the source is the freely available solar energy.

A precondition is that the sludge has to be dewatered to a dry solids concentration of > 20 w%.

The following principles apply:

- Installation of a proper rain protection
- Thermal insulation
- High evaporation rate like in a green house
- Controlled ventilation
- Controlled and periodic turning of the sludge

According to the mean solar radiation in Austria/Croatia of 1.000 to 1.100 kWh/m² a mean evaporation of 850 l_{H₂O}/(m²*a) is likely to achieve under the above mentioned guide lines.

It is useful to include a certain puffer volume/area for storing the sludge, since during the cold period (December – February) the DS content may not be reached completely. If this is done properly, a dry solids content from 70 – 80 % is ensured.

The total electric energy consumption equals ~ 25 kWh/t_{H₂O} evaporated.

2.4 Final treatment

2.4.1 Agriculture

The disposal of (dewatered) sewage sludge on agricultural surfaces was predominant through

the last decades.

Application of treated sludge to agricultural land was considered to be the best practicable environmental option for most sewage sludge (Department of the Environment, 1995). Care must be taken that applying the sludge will not pose any health or environmental hazard due to its content of pathogens and heavy metals. Furthermore, the sludge should be applied according to the fertiliser requirements of the crops grown on the land to prevent leaching of the nutrients, especially nitrogen.

Due to hygienic problems and also because of accumulation of heavy metals in the soil authorities in Europe became more and more concerned about these issues recently. Today there are strict European regulations which prohibit the deposition of sewage sludge on most agricultural regions, in Austria this is depending on the steepness of meadows and on the kind of public funding.

In general it can be stated that today nearly all sludge from communities larger than ~ 2.000 PE is not disposed on agricultural soil, but incinerated.

Figures in mg/kg _{DS}	Value from table 1	Germany – current status (AbfKlärV)	Values under discussion	EG-Ökolandbau-VO, 2002/91
Cd	1.2	10	0,5 - 1,4	0,7
Cu	197	800	50 - 80	70
Ni	28	200	25 - 60	25
Pb	54	900	40 - 80	45
Zn	810	2500	330 - 450	200
Hg	1	8	0,2 - 0,8	0,4
Br	--	900	25 - 70	70

Table 2: Limit values for sewage sludge utilisation

2.4.2 Landfill

In Austria land filling of dewatered sludge was the most important option for the final treatment until end of 2003. Since 2004 the new landfill regulation “Deponieverordnung” is valid which prohibits the disposal of organic material, therefore the land filling of sewage sludge is not possible any more.

A similar regulation is valid since 1.7.2005 in Germany (Technische Anleitung Siedlungsabfall) and the EU guideline is under way as well.

2.4.3 Incineration/gasification

In view of the inherent problematic of pollutants it is evident that there is no alternative to the thermal treatment of the dried sewage sludge. However, sewage sludge is not only consisting of pollutants. It also has contents which are of value.

Incineration

The calorific value of dewatered and dried sludge is approximately equivalent to brown coal. It can be burned either in lime or cement factories, but of course also in waste incineration plants.

Due to the inorganic fraction about 1/3 of the input will remain as ash.

Another option is a small incineration facility on-site. Some demonstration plants were built recently, one of them by TECON Engineering in Bad Vöslau, Austria. The basic flow diagram is shown below.

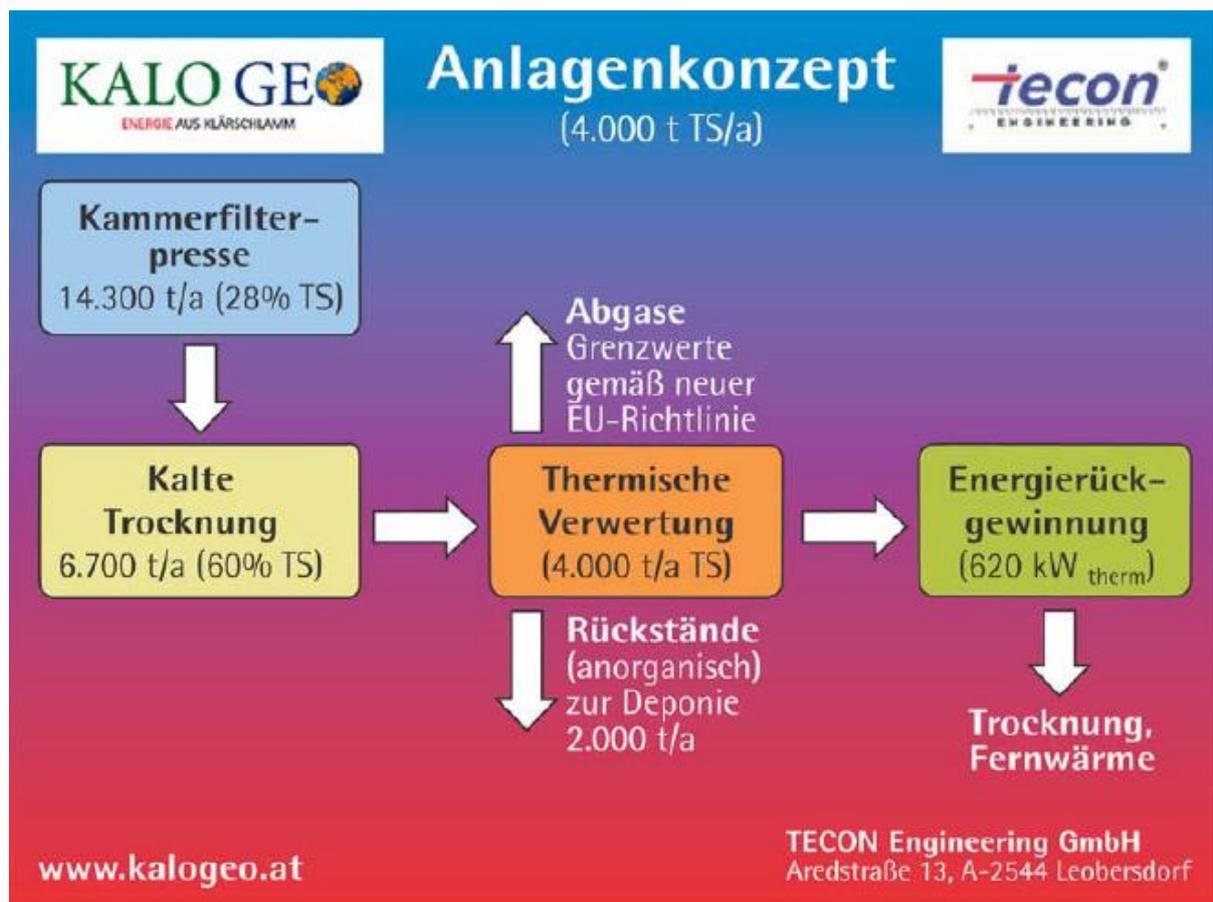


figure 6: mass balance of drying and incineration process (TECON)

Gasification

The gasification is nowadays working in demonstration scale and offers the proper process which removes the pollutants and at the same time leads to a wholesome valorisation of the sludge. Valorisation takes place directly at the sewage works, without transports stressing the environment.

The process transforms sewage sludge into electricity, heat and a mineral granule suitable for a wide variety of applications.

Additives are not required. The gasification process needs no external fuels and the gas fed to

the post combustion chamber is self-burning. The cold gas efficiency is between 65 and 70 % depending on the degree of drying which means that about two thirds of the energy contained in the sewage sludge are becoming combustible gas. The gas engine produces electrical energy, of which about 20 % are required for the process itself.

The mineral granule it is used in an Asphalt mixing plant as admixture.

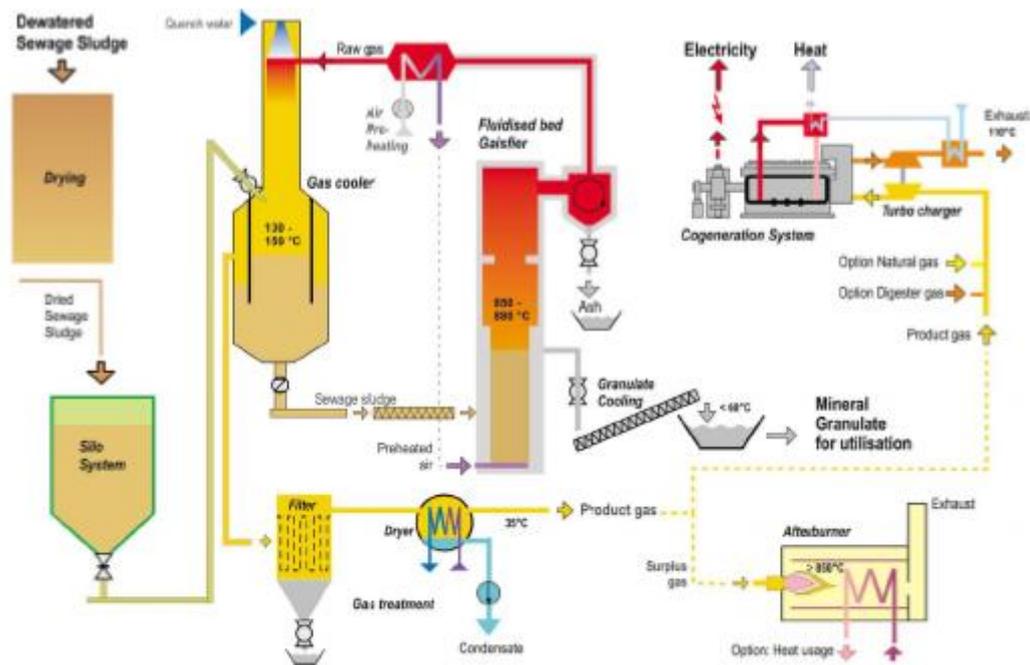


figure 7:gasification process (KOPF AG Umwelt- und Energietechnik, Germany)

3 Costs and ecologic aspects

3.1 Agricultural use

The costs for an agricultural disposal vary in a wide range, sometimes the operator of the WWTP even gains a slight profit.

As a mean value costs between € 100,- - 500,-/Mg_{DS} are realistic.

From the ecologic point of view this method is only acceptable if a tight monitoring of the sludge quality and the soil conditions are enforced. A pre-condition is that the sludge is hygienic, in other words treated thermophilic or heated prior to dewatering.

3.2 Composting and use of the earth like material in landscaping

According to Lit. 6 the costs for composting sewage sludge vary in the range from € 250,- - 350,-/Mg_{DS}. A survey at operators of Austrian composting facilities gave slightly lower prices

€ 180,- - 300,-/Mg_{DS}.

Generally the technical composting in closed boxes is of course more costly than the one in open stack.

During a technical composting process the products are well hygienised due to temperature and residence time. Monitoring of heavy metals content is obligatory prior to use in landscaping operations.

3.3 Mono incineration in large scale (off-site)

The costs for the external incineration of dewatered sewage sludge (30 % DS) in Austria varies in the range from € 150,- - 600,-/Mg_{DS}. (Lit. 1).

Due to modern techniques the processes are well controlled and the exhaust gas is treated in order to fulfil all valid directives, the remaining ash might be land-filled or used for construction works. The thermal energy within the sludge is used for heating, the overall process has to be classified as ecologically sound.

3.4 Co-incineration in existing industrial furnaces

In Austria the incineration of one ton of dewatered sewage sludge costs around € 150 - 400,-/Mg_{DS}. Commonly the costs in cement factories are the lowest, slightly higher are the costs in coal power plants.

The highest costs result if the sludge is disposed in waste incineration plants, here we find figures of € 300,- – 1.100,-/ Mg_{DS}.

Depending on the industrial furnace system the overall process has to be looked at before a judgement on the ecologically suitability can be given. E.g. a high content of heavy metals in the sludge might be blended to a low concentration if a lot of other input materials are processed in the same furnace system. It is generally agreed that a simple dilution is not environmentally friendly.

3.5 Treatment of sludge with high contents of heavy metals (electroplating industry, leather industry)

In general that kind of sludge has to be dewatered to a maximum degree since this decreases transportation costs and eases further reuse.

A close analytical examination is always necessary to evaluate the best recovery or disposal option. Often highly loaded sludge can be recycled directly in production facilities of metals works. If there is an undefined mix the incineration in a treatment plant for hazardous waste might be the only possibility.

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