1 Introduction

During the last decades, the conventional treatment of municipal wastewater has reached a very high standard. Current developments are concentrating on the optimisation of treatment techniques, such as energy reduction or treatment alternatives. However, the treatment and reuse or disposal of the sludge that is produced during the wastewater treatment is of greater concern, due to high costs and public awareness. For that reason, in the last years research has focused on alternative water treatment technologies (e.g. Ecological Sanitation) and the treatment of sewage sludge.

In a wider context, it should be realised that natural resources are scarce and that their distribution across the world is unequal. Does it make sense to import huge amounts of nutrients from other continents, to flush them down after consumption and burn what is left over after treatment? Is it fair to waste phosphorous that will be lacking in many countries very soon, only because we can afford it? As long as our urban drainage systems mix nutrients and pollutants and transport both towards an end-of-the-pipe treatment, we have to handle these shortcomings and develop techniques that help close the loop of nutrients, if they are safe for the environment and human health. A reuse of high quality sewage sludge can contribute to this recycling, if it is accepted by the population. Alternative sludge treatment processes with a "green" image, such as composting or humification may help to regain the acceptance of sludge recycling that was lost as a consequence of scandals in the agricultural practice and disinformation in the press.

In Germany, common conventional treatment options for stabilised sludge are:

- gravity thickening
- mechanical thickening with centrifuges, gravity-belt thickeners or rotary-drum thickeners
- mechanical dewatering with centrifuges, belt-filter presses or recessed-plate filter presses
- heat drying, based on convection, conduction or radiation

All mechanical methods for thickening and dewatering require, beside the equipment, energy, manpower and chemicals, such as precipitants and flocculation agents.

The necessity for the dewatering of sewage sludge is caused by economical considerations. It is estimated that the costs for the agricultural use of liquid sludge are 70% higher, related to the total solids, compared to the agricultural use of dewatered sludge. This estimation does not yet regard the transportation costs. [ATV, 1999]

As an alternative to these mechanical treatment options, the sludge treatment in reed beds was developed in the 1960's by Seidel. [SEIDEL ET AL., 1984] These reed beds are similar in appearance to subsurface flow constructed wetlands. The difference is that the liquid sludge is applied to the surface of the beds and the filtrate flows through the gravel to underground drains. The purpose of the reed beds is to dewater the sludge by drainage and evapotranspiration and to allow a longer time for biological processes with the result that the stabilisation and mineralisation proceeds, that pathogens numbers decrease and that the mass attenuates through degradation of organic matter.

In the middle of the 1990's a new variation to this nature-oriented technique was developed. Instead of reed, grass is used to support the treatment process and instead of an almost permanent flooding of the beds, the sludge is applied twice a year in thicker layers. The effect on the sludge is similar, the sludge dewaters, organic matter is degraded and pathogen numbers decrease. The product is free of offensive odours and obtains an appearance at first glance, which is similar to soil rich in humus. The process is applicable for aerobically stabilised sludge as well as for digested sludge.

As a consequence of this high content of humic substances, the term "humification" was introduced., for the whole process the term "Batch Humification of Sewage Sludge in Grass Beds" is suggested. The final product of this process is named "substrate" in this work.

In this work, a number of important aspects of the sequential humification in grass beds were investigated:

- grade of dewatering that can be achieved in certain time periods
- distribution of the leachate amount
- progress of the organic matter, grade of stabilisation
- balances of nitrogen and phosphorous, which part remains and which part drains, which part is converted into which compounds, uptake by the grass and emission to the atmosphere
- fate of heavy metals and organic pollutants

- development of pathogens
- emission of the greenhouse gases methane and nitrous oxide
- required grade of stabilisation before humification
- operational aspects e.g. maximum surface load, number of cycles per year and in total
- comparison between mechanical dewatering devices and a humification plant, investment and operation costs, approximate estimation of a carbon dioxide balance

To examine these aspects, a pilot scale humification plant was constructed and operated for 3½ years. Furthermore, the operation data from several full scale humification plants were collected and analysed.

The main scope of this work is to give an overview over the various aspects that are of interest, regarding the Batch Humification of Sewage Sludge in Grass Beds. Since the spectrum is very broad, the level of detail had to be reduced, but the work points out subjects that are worth a closer look in further investigations.

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2 Production, Use and Acceptance of Sewage Sludge

Sewage sludge, or biosolids, which is a term that has become widespread in Northern America in recent years, is an obligate product of any biological treatment of municipal or industrial wastewater, from centralised treatment plants or decentralised systems (septic sludge). It consists of bacteria, protozoa and multicellular organisms which have grown on the dissolved and solid components of the wastewater, as well as of inorganic and organic solids from the inflow which are not degraded under the conditions in the treatment plant.

According to the type of wastewater treatment, the quantity and characteristics vary. Before the sludge is treated, the water content is very high and organics make up more than 2/3 of the total solids. To prevent the production of offensive odours during handling or utilisation, sewage sludge is stabilised either aerobically (e.g. extended aeration or autothermal thermophilic aerobic digestion) or anaerobically.

Per population equivalent (PE), an average quantity of 50 gTS/d for well-digested or fully stabilised sludge [IMHOFF, 1999] and 56 to 60 gTS/d for simultaneously stabilised sludge [ATV, 2003] is produced under German conditions. However, different sewer systems, regional customs and economical standards can cause high variations, especially among different countries. In all German municipal treatment works, in 2001 about 2.4 million MgTS were produced. [DESTATIS, 2003]

Sewage sludge contains important nutrients and undesirable pollutants. If used in agriculture, the organic matter improves the soil by forming humus and the nutrients make the sludge a valuable fertiliser. In Lower Saxony the following average contents of nutrients were determined:

- *nitrogen:* 5.6 % N of TS
- *phosphorous:* 6.4 % P_2O_5 of TS
- *potassium:* 0.66 % K_2O of TS
- *magnesia:* 0.77 % MgO of TS

Based on the maximum application of 5 MgTS*ha^{-1} in 3 years, which is allowed in Germany, these average nutrient contents cover the demand of phosphorous completely for the crop rotation winter rape, winter wheat and winter barley. The demand for nitrogen and potassium fertilisers is reduced to 50% and 83%, respectively. [GUNREBEN, 2000]

The organic matter, which is applied with the sludge, increases the activity of microorganisms, the soils ability to hold water and nutrients and improves the soil energy balance, which influences the germination, growth and nutrient uptake positively. [BLUME, 1990]

An important aspect about phosphorous is that worldwide resources are limited. Depending on the definition of "economically exploitable" the estimations for the time until the resources are used up, vary between 30 [WENDENBURG, 2002] and 1,000 years [BÜCHEL et al., 1999]. Most authors estimate periods of about 100 to 200 years. In addition, the known resources are widely contaminated with natural sources of cadmium and uranium. [HOOGENKAMP, 1992] Therefore, the reuse or recovery of the phosphorous from sewage sludge is essential for the future agriculture and world nutrition.

On the other hand, the contents of pollutants in the sewage sludge are of a matter of concern. In table 2-1 the average concentrations of sewage sludge in Lower Saxony and the German threshold values are given. The 3rd column contains the relation between the average concentration and the threshold value. [LWK, 2003]

Table 2-1: Average Concentration of Organic Pollutants and Threshold Values in Lower Saxony [LWK, 2003]

Substance		Average Value	Threshold Value	Relation
heavy metals				
lead	mg/kgTS	30	900	3%
cadmium	mg/kgTS	1.08	10 (5)	11 % (22%)
chrome	mg/kgTS	28.31	900	3%
copper	mg/kgTS	244.97	800	31%
nickel	mg/kgTS	23.16	200	12%
mercury	mg/kgTS	0.65	8	8%
zinc	mg/kgTS	620.3	2,500 (2,000)	25% (31%)
organic pollutants				
AOX	mg/kgTS	198.35	500	40%
PCDD/ PCDF	ngTE/kgTS *)	7.34	100	7%
PCB 28	mg/kgTS	0.002	0.2	1%
PCB 52	mg/kgTS	0.002	0.2	1%
PCB 101	mg/kgTS	0.005	0.2	3%
PCB 138	mg/kgTS	0.011	0.2	6%
PCB 153	mg/kgTS	0.013	0.2	7%
PCB 180	mg/kgTS	0.007	0.2	4%

*) TE = toxicity equivalent