On possibilities of the post-treatment of anaerobic digester effluents with high H_2S loads in constructed wetlands

PhD thesis of
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Summary and Conclusions

Energy saving lowcost technologies for wastewater treatments are highly needed as well in developing as in industrialized countries. Especially the anaerobic methanogenic fermentation technology for wastewater offers a high energy saving potential – even a useful biogas is produced. So, already in many countries, especially in the tropics, domestic sewage treatment is often realised by an anaerobic fermentation step such as a septic tank, an anaerobic filter etc. By such a treatment step the biochemical oxygen demand (BOD) of the wastewater is considerably reduced, but it contains still relatively high residual BOD, ammonia and sulphide formed by the bacterial dissimilatory sulphate reduction. Because of this H_2S content and the poor effluent quality (relatively high BOD and ammonia) the anaerobic fermentation of wastewater needs a further post-treatment step.

Sulphide toxicity

Descriptions of sulphide toxicity were mainly done in stagnant waterlogged soils like paddy fields were the concentration gradients around the helophyte roots are more or less undisturbed. Contrary to these stagnant waterlogged soils in constructed wetlands the water with its ingredients is streaming through the "rooted soil filter". By this, the oxygenated "protection" layer of the helophyte roots is permanently disturbed especially in case if the streaming water contains highly toxic H_2S. That is why, toxicity tests should be executed under conditions were the roots are directly exposed to the actual toxicant concentration like in hydroponic culture.

In this study, the physiological responses of *J. effusus* according to the effects of different concentrations of sulphide on its growth and constitution, was investigated under controlled laboratory hydroponic conditions. Concentration limits for all the evaluated parameters i.e. relative growth rate, water uptake, and chlorophyll fluorescence were defined for this species. Such laboratory experiments are necessary to optimise the design and operation of constructed wetlands for the treatment of H_2S containing waters. Unfortunately, no comparable data are available for other wetland species under similar conditions.

The most striking result is that there are no big differences between the sensitivity of relative growth rate, the efficiency of photosynthesis and water uptake in *J. effusus*. These parameters were found not to be influenced by concentrations of sulphide lower than 10 mg L^{-1}. By this, *J. effusus* is well suitable for the application in constructed wetlands to treat sulphide loaded wastewater as effluents from anaerobic digestion of domestic sewage.

Post-treatment model experiments in a laboratory-scale macro-gradient-free Wetland system (Planted fixed Bed Reactor)

Previous methods for the investigation of rhizospheric processes are limited in their use for further development in application of treatment wetlands. The usual inflow/outflow characterization of more or less large systems with internal gra-

dients has to be supplemented by small-scale gradient-free model investigations. This methodical requirement has been addressed by the “Planted Fixed Bed Reactor“. The principle of the reactor ensures macro-gradient-free conditions for investigating redox processes inside the rhizosphere. Using *Juncus effusus* plants, gravel as soil material and a hydraulic retention time of 5 and 10 days, long-term investigations were carried out treating synthetic anaerobic reactor effluent of domestic sewage. Long-term (over month) effects on removal of contaminants and the variability of the redox conditions were monitored.
Under these model conditions for subsurface flow constructed wetlands the possibility to treat sulphide containing effluents (like they are generated in case of anaerobic treatment of domestic sewage) under distinct conditions was shown. Aerobic processes (ammonia and sulphide oxidation) and anaerobic processes (denitrification, sulphate respectively thiosulphate reduction, etc.) occur within the rootzone simultaneously.
The sulphide removal is influenced by various factors like concentration of DOC, nitrogen compounds, sulphide, sulphate and other sulphur species, by loading conditions and as it was shown in these model experiments also by the plantation (density and surely other plant related factors). In case of post-treatment of effluents from anaerobic reactors in subsurface constructed wetlands especially the balance of sulphide, sulphate and residual organic carbon of high bioavailability have to be considered because these systems work simultaneously as an anaerobic and aerobic reactor. The formation of sulphide concentrations toxic to the plants have to be prevented by variation of loading rate for instance. The apparently differing observations regarding the role of wetland plants with respect to sulphur removal signify the need for more studies on this aspect.

Treatment of artificial sulphide containing wastewater in planted and unplanted subsurface horizontal flow laboratory-scale constructed wetlands
In general higher dynamics of the sulphur transformation with concomitant higher sulphide and thiosulphate removal than in the unplanted control bed could be observed in the planted wetlands. Furthermore the results show the suitability of constructed wetlands for the removal of reduced respectively partly oxidized sulphur compounds (sulphide, thiosulphate); consequently an increase of the sulphate concentration can be expected.
The plants affected a clear stimulation of the sulphide and ammonia removal rates. Sulphide concentration in the range of 1.5 - 2.0 mg L^{-1} were tolerated by the plants and completely removed in the planted model wetlands; sulphide concentration of > 2.0 mg L^{-1} caused instabilities in sulphide and nitrogen removal. Area specific sulphide removal rates of up to 94 mg sulphide m^{-2} d^{-1} were achieved in the planted beds at hydraulic retention times of 2.5 d. Sulphate affected the sulphide removal. While in the unplanted control bed an almost stable removal in the range of 150 – 300 mg N m^{-2} d^{-1} was observed variations of hydraulic retention time, sulphide and sulphate concentrations influenced the ammonia removal rate within the planted beds in a broader range (600 - 1,400 mg N m^{-2} d^{-1}).
It was shown that sulphide removal in planted horizontal flow constructed wetlands is limited by the sulphide tolerance of the plants. *Juncus effusus*, for example, is not suitable for the treatment of water with sulphide concentrations of ≥ 10 mg L^{-1}. The achieved sulphide removal rates in planted beds were considerably higher than in the unplanted control beds. However, the maximum specific sulphide removal rate of 94 mg sulphide m^{-2} d^{-1} in the planted beds achieved so far is lower compared to the carbon and ammonium removal rates. It should be noted that sulphide removal was effected by the sulphate concentration in the influent water.

Only for TOC a relatively stable and linear removal rate, in correlation to the loading rate, in a range of 400 to 1,500 mg m^{-2} d^{-1} in the planted beds was observed.

Concluding remarks

The results showed that sulphide oxidation, nitrification, denitrification and sulphate reduction occur simultaneously in the rhizosphere of treatment wetlands caused by dynamic redox gradients (aerobic-anaerobic) conditions. For a detailed understanding, the effects of sulphur transformation on the removal performance in constructed wetlands should be investigated in future experiments, particularly in terms of biotical or abiotical of oxidation of reduced sulphur compounds, competition for oxygen due to oxidation of reduced species, changes of micro-environmental conditions in the rhizosphere due to redox potentials and sulphur deposits, nutrient mobilization or immobilization, and biofilm formation.

In general, the results of the experiments substantiate the suitability of post-treatment of anaerobic reactor effluents in subsurface horizontal flow constructed wetlands.

In comparison to ponds and surface-flow wetlands this type of wetland ensures considerable lower toxic and smell intense H_2S emmision into the atmosphere.

In the laboratory-scale system high treatment efficiency concerning sulphide removal was shown. The model system was relative shallow (25 cm) in comparison to full-scale systems. Nevertheless, there is to expect that a deeper bed will not improve the treatment efficiency concerning sulphide removal. The deeper zones with less root density function more or less only as an "anaerobic filter".

In general sulphide inflow concentration should be controlled on a regular basis and should not exceed 5 mg L^{-1}; if neccesary, by wetland effluent recirculation for diluting the sulphide inflow concentration this crucial parameter can be guaranteed.