Passive Treatment of Minewater at the Schlema-Alberoda Site

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Abstract. A pilot scale constructed wetland for treatment of seepage water from uranium mining was planned, built and operated. The pilot plant was designed for treatment of 5 m³ per hour. The system consists of 4 basins and 1 lagoon. The objective of the project was the investigation of the long-term stability and robustness of passive water treatment systems. The feasibility of treatment of seepage water from uranium mining in constructed wetlands was proven by the operation of the pilot plant. A series of robustness investigations was conducted; including the operation during long lasting frost periods, under increased hydraulic load and under high carbon load. By using a tracer the hydraulic characteristics of the basins was tested. The control of the wetland is very complex due to different redox condition necessary for removal of arsenic (aerobic) and uranium (anaerobic). Additional information for an increased robustness of the system was derived from the operational results.

Introduction

During and after closing of uranium mining sites in Thuringia and Saxony, contaminated water from mine flooding and seepage occurs. This water usually contains, besides uranium and radium, other metals like arsenic, iron, and manganese. This water is treated by conventional technologies like precipitation, coagulation and ion exchange. The use of passive technologies based on biological, physical and chemical processes could be a cost-saving alternative. Constructed wetlands are such a passive water treatment technology.

BioPlanta and WISUTEC investigated the feasibility of a long-term, stable and reliable treatment of seepage water being contaminated with uranium, arsenic and nitrate in a constructed wetland.

Based on small-scale studies, a pilot plant was built and is operated at the site of mine shaft 371. The constructed wetland system, also referred to as "planted reactor", was designed for the treatment of 5 m^3/h. Treatment objective is the removal of uranium, arsenic, radium, nitrate and traces of heavy metals. Defined target concentrations are: uranium 0.3 mg/l, radium 0.2 Bq/l, arsenic 0.1 mg/l and nitrate 10 mg/l. The proof of the long-term stability of the treatment performance and the robustness against external disturbances is a prerequisite for the administrative approval of the technology.

The conduct of the system towards external influences and disturbances was studied by monitoring the reaction to applied targeted failure situations, technical problems and seasonal influences. From these results a statement about the conduct of the system in continuous duty as well as under long-term performance and about measurements to be taken in case of failures to restore the operational state was deducted.

Fundamentals of Metal Removal in Wetlands

Since the 1980s, constructed wetlands have successfully been used for the treatment of acid mine drainage (AMD) and for the removal of iron in Great Britain, USA, Australia and Canada. Studies in natural wetlands showed that in many cases dissolved uranium is removed from the water and accumulated in the wetland sediments. The reproduction of these processes in pilot-scale constructed wetlands has been tested in the USA and in Australia since 1995.

The fundamental process of uranium immobilization is the reduction of the mobile U(VI)-species to insoluble U(IV). The anaerobic wetland sediment has the right conditions for this reaction. Other processes that can lead to an immobilization include: sorption on organic (humic substances) and inorganic (Fe- and Mn-oxides) material, co-precipitation and plant uptake.

Sulphate reducing bacteria (SRB) like *Desulfovibrio* spp. show the effect of enzymatic uranium reduction (Neal et al. 2004). A comprehensive overview of microbial uranium reduction is given by Lutz et al. (2002). The process of reduction and precipitation of uranium is reversible, i.e. under oxidizing condition remobilization can occur.

A removal of arsenic can be achieved by co-precipitation with iron as well with aluminium- and manganese oxides/hydroxides under aerobic conditions. A reducing environment leads to a dissolution of the oxides/hydroxides and thus a mobilization of bound arsenic. Because the water on the investigated site has a low iron content, iron arsenate can only be precipitated to a minor extent.

The conditions in wetlands and the hydraulic, geochemical and biological processes connected with metal removal are extensively reviewed by Younger and Wolkersdorfer (2002). Younger states, that it is yet unknown to which extent temperatures in autumn and winter influence the vitality of sulphate reducing bacteria in wetland sediments.

Bio sorption processes, which also play an important role in the treatment of mining waters, are reviewed by Ondruschka and Bley (2002). The complex formation of U(IV) phosphates and arsenates has been investigated by Geipel et al. (2002). Uranium complexes formed by microbial processes are discussed in Merroun et al. (2002).

Different uranium valences in a nutrient solution and in the biomass of plants cultivated in this solution have been found. Uranium is bound in plants mainly in form of uranyl phosphate groups (Günther et al. 2002).

In column and small scale studies BioPlanta has proven the effective removal of arsenic and uranium by a biological system consisting of a gravel filter, plants, and microorganisms.

The experiments have shown that the carbon supplied by plant roots and detritus is insufficient to reach the required low redox potential in the wetland. So a readily available carbon source was needed for uranium removal. Since the carbon release from compost, straw or other organic solids cannot be controlled, a liquid carbon source was needed, which could be dosed according to the variable demand under changing temperature and hydraulic conditions. Molasses was chosen due to its non-toxicity, low price and content of micro-nutrients, which have shown to have a positive effect on the development of the microflora.

Based on the results of the experiments, the pilot system at the site of shaft 371 was planned and built.

Description of the Pilot System

The pilot system at shaft 371 consists of the following components: storage lagoon, constructed wetland and a polishing lagoon. The wetland system is made up of 4 serially connected cells. The flow in the cells is horizontal. The base area of the cells is 19 m^2 (cells 1, 2, 4) and 15 m^2 (cell 3).

The wetland cells are 1.2 m deep earthen basins with PE-lining, filled with washed gravel (2-8 mm) to a layer depth of 0.9 m. The total volume of the planted gravel filter sums to 1,226 m^3.
The in- and outflow areas of each cell were constructed of coarse gravel (16-32 mm). Water passes through the cells by gravitational flow. The outflow of each cell connects to shafts for sampling and the control of the water level in the wetland.

The inflow to the wetland system is controlled by a valve and measured by an inductive flowmeter. The cells are planted with reed (*Phargmites australis*) and sedge (*Carex gracilis*).

Fig. 1. Cells 1 and 2 of the pilot system on the site of shaft 371.

To reach anaerobic conditions in the first two cells, molasses is added to the inflowing water and the cells 1 and 2 are operated with a constant water level just slightly below the gravel surface. After the passage of the first two cells, the water reaches cell 3, where the water level is periodically changed (fill-and-drain) by means of a time-controlled valve in the outflow of cell 3. During the fill cycle, the water is enriched in oxygen and so aerobic processes for the removal of excess carbon and precipitation of arsenic can take place.

The system started operation in October 2002. Until today investigations of the performance and operation stability were undertaken.

Results of Operation

Problems with administrative permissions and technical problems (clogging of drainage tubes) caused a delay in the start of operation with the configuration as described above. The fully operational state of the system could be established in June 2004. Before that date the system was operated without molasses and without the fill-and-drain system in cell 3.

With the start of the molasses allowance, intentionally planned as an overdose to saturate the first cell with molasses, the outflow concentrations for COD exceeded the permitted level. Reducing conditions were established in all 4 cells, re-

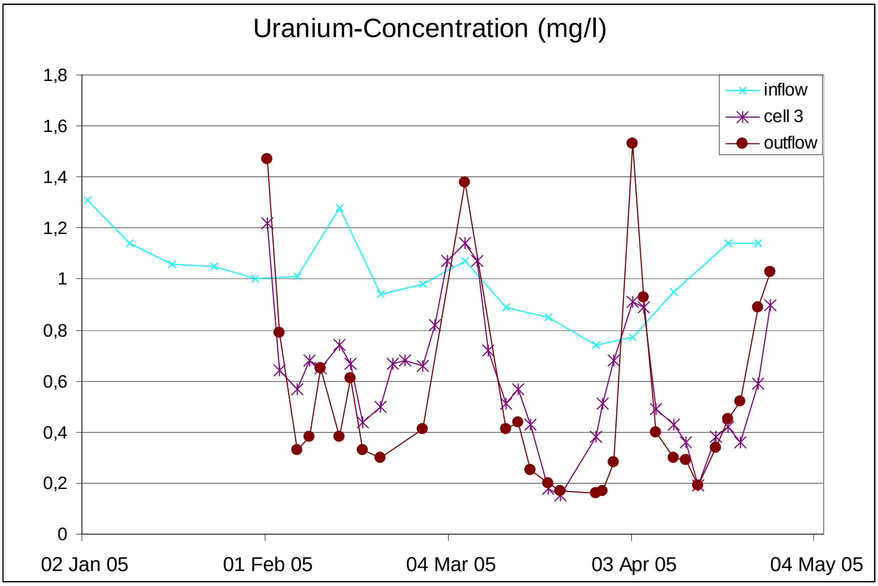

Fig. 2. Results of operation from 2005, uranium concentrations.

sulting in a good uranium retention and nitrate reduction, but also in an unacceptable mobilization of arsenic. So the system had to be operated in closed circuit. Starting from October 2004, the normal operation was restored and the system was operated with varying hydraulic loads and molasses dosages between 70 l/d and 180 l/d. Uranium retention was low until November 2004, when for the first time sulphate reducing reactions were proven by decreasing sulphate concentrations in the outflow.

The peaks in the outflow uranium concentration, which can be seen in figure 1, occurred during phases of short circuit operation, forced by exceeding permitted COD-concentration in the outflow. Overall it can be seen, that the target value of 0.3 mg/l uranium can be reached under optimal operational conditions. The conditions required for a stable operation have been reached in 2005.

The same holds true for arsenic. In optimal conditions an outflow concentration below 50 µg/l was achieved, but during phases of excess COD input it could reach several times the inflow concentration, which means that arsenic is very easily and fast remobilized.

Conclusions

It could be shown that passive systems as a constructed wetland are a possible solution for treating uranium-contaminated water. The operation under properly controlled redox conditions is essential to reach low arsenic levels at the same time. The design of the pilot-scale system needs to be slightly improved to provide a better aeration of the basins 3 and 4. With these changes stable removal rates of uranium and arsenic are expected without exceeding permitted COD-levels in the outflow.

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