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Technology of the Biological Treatment of Mine Water at the Kohinoor II Mine †

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Abstract: The aim of this work was to assess the effectiveness of the treatment process in the mine water treatment plant in Mariánské Radčice that pumps mine water from the MR1 pit and to evaluate whether this biotechnological unit is satisfactory in its treatment process with regard to the set limits for the discharge of treated mine water into watercourses, or whether this water can be discharged into Lake Most in the future, which is intended for recreation, and also with regard to the ecosystem that exists there.

Keywords: mine water; mine water pollution; biological treatment of mine water; root system; plant functions; elimination of ammonium ions

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1. Introduction

The water around us is an essential natural resource from which we benefit on a daily basis. It is essential for the life of millions of species of plants and animals—from the largest inhabitants of the oceans to the smallest microorganisms. Water is a necessary need of the human body; it is also a resource that we use every day in households, industry, agriculture, transport and, last but not least, for recreation. Through our daily activities, we change the quality and availability of water, we threaten it with overuse, with various types of pollution, and we change its properties.

One of the sectors that fundamentally changes the quality and properties of surface and underground water is mining, whether it is coal mining or the mining of other natural resources. Mine water from surface coal mining is characterized by a low pH value, high hardness, high iron ion content, high concentrations of dissolved and suspended substances, and extremely low organic matter content. Such water must be purified.

Mine water can have quite a serious impact on the hydrological regime, and it is therefore necessary to address this problem and look for optimal solutions and possibilities for its reuse. Both conventional and alternative methods can be chosen for mine water treatment. Conventional methods include water treatment using wastewater treatment plants or sedimentation tanks, alternative methods include the use of wetland ecosystems or reed bed plants, with regard to the specifics of particular mine water sources [1].

2. Reed Bed Plants

Reed bed plants are passive methods of water treatment that use not only natural processes, but also natural materials. These treatment plants are built mainly from the natural building materials found in the surrounding area and the filtration areas are planted with wetland vegetation. Biological stabilization tanks are most often used for water accumulation, water treatment, and additional water purification. Tanks may be aerobic or anaerobic in nature as well as aerated or non-aerated. Various final treatment ponds and aquaculture tanks are included. The most commonly used ones are aerobic biological tanks, where mechanical (sedimentation, adsorption), chemical (oxidation/reduction, decomposition of substances), and biological (decomposition, nutrient uptake, and metabolic processes) processes take place [2,3].

Passive systems for mine water treatment effectively treat even strongly diluted water and show a relatively high efficiency in removing pollution according to BOD_5, COD, suspended solids, and heavy metals. They cope well with the uneven inflows and even allow for intermittent operation. They are very simple in construction, require minimal maintenance, and are energy efficient. Also, the acquisition costs are usually lower than in the case of a conventional treatment plant. From an ecological point of view, they have a positive effect on the surrounding microclimate and have a certain landscaping function. Compared to the intensive systems, however, they are more demanding on land use, are partly dependent on climatic conditions, remove some nutrients, especially ammonia pollution, in a limited way, and have a low ability to regulate ongoing processes. In addition, the root systems of reed bed plants need to be permanently flooded [4–6].

Purified water passes through fields with wetland vegetation and lingers on them for some time. The main purpose of wetland vegetation is the filtration and then the insulation of the filter field, especially in the winter season. Filtration takes place in the soil and subsoil of the vegetation with the help of the root system. As the water passes through the vegetation, the impurities are collected directly in the natural filter, while the purified water flows further. It is necessary for vegetation stands to be designed with a sufficiently large area that takes into account the volume of treated water to effectively remove the required substances before the water returns to the watercourse. Passive settling lagoons and areas planted with wetland vegetation are the most environmentally friendly way of treating mine water. In addition to mine water treatment, wetlands built in this way are a rare habitat and are home to many different species of insects and birds [7,8].

Suitable wetland plants have an important role in the application of the passive method of water treatment. They tolerate constant and periodic flooding, the lack of oxygen, high salt content, and sudden changes in the pH values of the environment. Water rich in nutrients and waste products suits all plants that are appropriate for reed bed plants such as broadleaf and narrowleaf cattail (*Typha latifolia*, *Typha angustifolia*), great manna grass (*Glyceria maxima*), reed canary grass (*Phalaris arundinacea*), *Schoenoplectus lacustris*, lakeshore bulrush (*Sparganium erectum*), common reed (*Phragmites australis*) and common rush (*Juncus effuses*). Other plants include yellow flag (*Iris pseudacorus*), marsh-marigold (*Caltha palustris*), purple loosestrife (*Lythrum salicaria*), and meadowsweet (*Filipendula ulmaria*). It is recommended to mow the plants in the early spring (late February). It is possible to mow and harvest *Glyceria maxima* and *Phalaris arundinacea* even during the growing season and then use the harvested biomass for composting [9].

3. Mariánské Radčice Mine Water Treatment Plant

The treatment plant for mine water pumped from the MR1 pit of the Kohinoor II mine is located 0.8 km from the village of Mariánské Radčice. It is adjacent to the active Bílina mine, which is drained into the MR1 pit of the Kohinoor II mine. The Kohinoor II underground mine ceased its production in August 2002. In the Bílina mine, brown coal is still mined using the open-pit mining method [10,11].

The Mariánské Radčice mine water treatment plant, whose construction began in October 2018 and trial operation started in January 2021, is the largest biotechnological mine water treatment plant in Europe. Its area is 2.5 ha. It works on the principle of the biological treatment of mine water, similarly to natural reed bed plants. However, it is not a purely biological treatment plant; it has additional technological elements used especially for aeration and the pumping of water [12].

The entire biotechnological unit can be described as a system of wetlands; its aim is to ensure a stable method of mine water treatment using the physicochemical and biological processes that occur spontaneously in natural wetland systems. The system is designed so that its operation requires minimal service and maintenance, i.e., the lowest possible operating costs in the long term. The operation of the treatment plant is planned for the duration of pumping mine water from the MR1 pit, i.e., for the entire period of mining at the Bílina mine.

During 2021, a trial operation of the biotechnological mine water treatment plant in Mariánské Radčice took place. This process was closely monitored and evaluated in early 2022. The aim of the operation of this unit is to ensure such a quality of discharged water so that, with regard to the valid legislation of the Czech Republic, it is possible to discharge it into the recipient, which is the Radčický stream, or into Lake Most, if the standards for bathing water are reached after treatment [13].

The biotechnological system of this treatment plant consists of the following basic parts: a supply aeration object (pipe system, aeration cascade), seven tanks with an area of more than 2.5 ha, connecting troughs and pipes between individual objects, aeration piping system, blowers, pumps for pumping mine water, eventually a suction dredger for pumping sludge. The biotechnological treatment plant includes two electrical distribution stations, an outlet from the treatment plant to the recipient, and a sludge field. The site is divided into four height levels, the flow of mine water is ensured by gravity.

The whole system is populated with wetland plants (macrophytes). The main share consists of common reed (*Phragmites australis*), reed canary grass (*Phalaris arundinacea*), great manna grass (*Glyceria maxima*), cattail (*Typha*), and gradually associated self-seeding herbs from the surroundings. The surrounding areas were planted with shrubs and trees, partly fruit, and grassed. The entire mine water treatment plant is relatively well integrated into the surrounding landscape without a disturbing effect. During the construction, natural materials of local origin were used to the maximum extent (after previous mining activity).

An absolutely essential element of the biotechnological system, where the process of mine water treatment takes place, is a system of seven tanks. Six of them are settling and purifying tanks and are located in two lines next to each other. Tanks A1, B1, and C1 are located to the left of the entrance to the treatment plant. Parallel to them in the second line (to the right) there are tanks A2, B2, and C2. From a technological point of view, the A1 and A2 tanks differ; the others are identical in pairs (B1, 2 and C1, 2). The seventh tank is the tank marked D. Here the overall water treatment (Fe, Mn, and total N) and stabilization of the outflow parameters before discharge into the Radčický stream take place. Tank D has the function of final purification, mixing (incoming water from the previous 6 tanks), and stabilizing (Figure 1).

Mine water is pumped from the MR1 pit in the Kohinoor II mine site. Originally, it was a wind shaft of a mine into which mine water from the Bílina mine, where mining is still taking place, is drawn. The pit is 300 m deep. At present, the water is pumped from the pit by one or two 6 m long pumps. Depending on this, water flows to the water treatment plant at a speed of 60 to 120 L/s through the piping system. The pipe supply of pumped water has the parameter DN400, the gravity drainage pipe DN500, and a length of up to 605 m. The maximum design flow rate of the biotechnological system is 180 L/s.

On the inflow of mine water to the treatment plant there is a shaft made of concrete rings DN1000, a height of 3 m, with a steel lockable entrance. The concrete outlet has a capacity of 2.5 m^3 of water. From there, water is led through a DN400 pipe with a length of 40 m to the aeration cascade, which consists of a continuous staircase (1 pc). There is a considerable aeration of water and release of ammonium ions into the air on this cascade. The stairs are strongly coloured with sedimentary Fe particles (Figure 2). From there, mine water flows through concrete gutters to the first reservoirs A1 and A2.

Figure 1. Aerial view of the biotechnological unit of the water treatment plant. Tanks A1, B1, C1 in the left line, A2, B2, C2 in the right line, retention tank D in the upper right.

Figure 2. Cascade (staircase) behind the inflow of mine water to the treatment plant.

The vegetation sludge field (VSF) is part of the technological unit of the treatment plant. It serves to significantly reduce the volume of the sludge, which will later be disposed of as a waste. If necessary, the sludge will be pumped from the area of settling tanks using a suction excavator. The VSF is dimensioned so that the volume of the sludge is reduced to 1/3 of the original volume by dewatering and drying. This is done mainly by evaporation of water from the sludge and through evapotranspiration by wetland plants.

The biotechnological treatment plant has an active aeration system.

4. Evaluation of the Efficiency of the Purification Processes at the Treatment Plant

As part of ongoing research, samples of raw water were taken in the months of March–December 2021. The following parameters were evaluated: sulphates, iron, manganese, ammoniacal nitrogen, chemical oxygen demand by permanganate, pH values, undissolved substances, dissolved annealed substances, and benzo(a)pyrene. The limits for the discharge of treated mine water are set by Government Regulation No. 401/2015 Coll., on the indicators and values of permissible pollution of surface water and wastewater, the requirements for permits for the discharge of wastewater into surface waters and sewers, and on sensitive areas, as amended [14,15].

Based on the measurements and identified pollution parameters, respectively, the assessment of their values at the inflow and outflow at the biotechnological mine water treatment plant in Mariánské Radčice, the effectiveness of the treatment processes was evaluated with regard to the monitored parameters set by the legislation and the water management regulation of the Regional Authority of the Ústí nad Labem Region.

Based on the obtained measurements of water at the inflow to the treatment plant, it was found that mine water from the MR1 pumping pit does not show above-limit values of sulphates, manganese, COD_{Cr}, dissolved annealed substances, and undissolved substances, even at the input to the treatment process. These pollutants are therefore not a problem for these particular mine waters. On the other hand, the values of iron and ammoniacal nitrogen were unsatisfactory and high, the acidity of the waters was high and therefore the pH values were low, and the values of benzo(a)pyrene at the inflow were also exceeded. However, during the treatment process, it was effectively possible to reduce the values of all monitored substances to the values required for treated water currently flowing into the Radčický stream. The treated mine water fully complies with the legislative requirements imposed on it. The pollution values of sulphates were reduced by almost 30%, iron by 86%, manganese by almost 78%, and ammoniacal nitrogen by more than 89%. COD_{Cr} pollution increased slightly by less than 3% during the treatment process, which was negligible with respect to the satisfactory inflow values. The pH value increased by more than 22% to values between 7.85 and 8.26, thus the acidity was significantly reduced. The values of dissolved annealed substances decreased by almost 62% during the treatment, benzo(a)pyrene up to a hundredfold to the required below-limit values. Other monitored parameters were already satisfactory in the raw water.

The biotechnological unit for mine water treatment in Mariánské Radčice works very efficiently, and the treated water fully complies with the set limits with regard to its current use—outflow to the recipient. However, if the treated water should be drained into Lake Most, which is a locality for recreation and bathing, some of the permitted pollution in the treated water has been exceeded. The regulation in question sets stricter limits for bathing water, namely which would be exceeded for COD_{Cr} pollution and $N\text{-}NH_4^+$. For COD_{Cr} this is the permissible value of 26.2 mg/L, the annual limit average is 26 mg/L, but this limit was exceeded during 2021 only once. For $N\text{-}NH_4^+$, the permitted pollution level is 0.64 mg/L, but on an annual average this limit is only 0.23 mg/L. Compliance with this limit seems to be the biggest problem in the treatment process of the biotechnological unit of Mariánské Radčice.

If the treated mine water was to be drained into Lake Most, it would be necessary to monitor some other pollution parameters that are not currently under supervision. These include, namely: saturation of water with oxygen, biochemical oxygen demand (BOD), total organic carbon (TOC), total phosphorus, total nitrogen (nitrogen nitrate, nitrogen nitrite, nitrogen ammoniacal), total chlorides, and magnesium and calcium content. For bathing waters, the parameters of contamination by *Escherichia coli* bacteria, the intestinal enterococci, the thermotolerant coliform bacteria, radioactivity indicators, and possibly other values are also monitored. Since wastewater from human settlements is not treated at the treatment plant but only mine water, the biological indicators of bacterial pollution by *Escherichia coli* bacteria, the intestinal enterococci and the thermotolerant coliform bacteria do not appear to be problematic.

5. Conclusions

The biotechnological mine water treatment plant is at the very beginning of its existence, it has completed the first year of the trial operation, in the following years the improvement of the functioning of the entire system and its stabilization can be expected, as well as the improvement of the state of the still young vegetation, some parts of the fields are not covered by vegetation yet, and a fully developed, rich root system also cannot be expected.

During the one-year trial operation of the mine water treatment plant in Mariánské Radčice, it was found that purely biological natural processes should be supplemented with technological elements to the necessary extent, as these significantly affect the treatment process at the treatment plant. In particular, these are the elements of the active aeration of the tanks (root fields), blowers and oxygen distribution pipes. These elements were shut down in October 2021 for their inspection and maintenance, and immediately this fact had a negative impact on the quality of the treated water. The shutdown of the aeration system and the subsequently measured values constitute clear evidence that this element is desirable at the treatment plant and its inclusion is necessary.

The biotechnological treatment plant can undoubtedly be described as a functional unit in mine water treatment, which also takes into account the trend of using biological treatment plants where possible. At the same time, the nature and location of the mine water treatment plant fits very well into the surrounding landscape and is completely undisturbed in connection with the surrounding inhabited part of Mariánské Radčice. In addition, treated mine water could, if necessary, be used to irrigate agricultural areas in its immediate surroundings, especially in the event of the lack of natural moisture.

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