Iron removal from the Spree River in the Bühlow pre-impoundment basin of the Spremberg reservoir

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Abstract

Due to its huge water body, the Spremberg reservoir plays an essential role in retaining the Spree's visible iron load upstream of Cottbus and the Spreewald, caused by rising groundwater levels. During the period from August through December 2014 repair work on the dam at the reservoir had to be done. These repairs became necessary because the damage to the eastern wing wall of the dam ascertained in 2013 had the potential to significantly impair the reservoir's flood control capability. In order to allow the work to proceed, the water level had to be lowered by some meters which involved a notable shortening of the residence time. That increased the risk that iron retention in the reservoir may no longer be ensured.

The preferred option was geared towards achieving iron retention in the pre-impoundment basin by means of sequential conditioning of the river Spree. Building on the results of flocculation tests a corresponding technical unit for a two-stage conditioning of the river Spree upstream of the pre-impoundment basin was designed and constructed. In order to allow for large-scale prefabrication and for ease of assembly, the project was implemented in the form of a mobile container plant. The plant went from design to completion in a couple of months.

The plant as a whole consists of two series-connected units. Located in Spremberg Cantdorf (ca. 1.5 km upstream of the pre-impoundment basin), plant unit 1 ensures production and tailor-made dosage of milk of lime. Production of the flocculating agent suspension and its tailor-made dosage are performed by plant unit 2 at the pre-impoundment basin inlet. A design capacity of 15 m^3/s was established for both plant units, which is equal to the average discharge of the Spree River at the Spremberg gauging station.

Except for a short interruption due to winter conditions in February, the conditioning plant has been in continuous operation since it came on stream in August 2014. Thanks to the efficiency of the conditioning plant, no significant exceedance of the visible iron plume limit of 2 mg/L total iron at the Bräsinchen reference gauge was recorded while damage to the dam was being repaired. Monitoring of the Spree River indicates load-based proportional daily mean iron retention at the Bühlow pre-impoundment basin varying between 30 % and 86 % as a function of concentrations in feed water and an average of ca. 50 %.

The final process step following iron separation from the aqueous phase consists in desludging the pre-impoundment basin and in doing so removing the generated iron deposition from the water body. GIP and project partner TWB are currently carrying out an initial operation intended to remove ca. 30,000 m^3 of sludge from the pre-impoundment basin using two specially equipped suction dredges. The sludge is dewatered on site by two high-performance mobile decantation plants prior to disposal. Following consultation with the proper regulatory authorities, LMBV envisages the continued tailor-made operation of the conditioning plant over the next five years until measures which are currently designed and implemented with a view to decreasing iron-bearing groundwater discharges into the Spree and Kleine Spree rivers will have the required impact. The objective is to achieve safe iron retention in the main dam even at low water storage level and a load-proportional elevated degree of iron retention in the pre-impoundment basin.

Key words: Iron removal, mine water, water treatment, river treatment plant

Background

Progressive groundwater resurgence in mine reclamation areas has resulted in a partial increase of iron concentrations in the Spree River. Current measurements performed at the Spremberg Wilhelmsthal gauging station show total iron levels (Fe_{total}) ranging on average from 5 to 6 mg/L with peaks of 15 mg/L. Concentrations at such a high level do not only cause damages to the watercourse as an ecosystem but also lead to a distinctly visible browning of the water.

Owing to its huge body of water, the Spremberg reservoir plays a crucial role in retaining the Spree's visible iron load upstream of Cottbus and the Spreewald. Iron precipitation measures implemented within the Bühlow preimpoundment and within the main dam reduce the iron load downstream of the Spremberg reservoir by some 75 % [IWB 2013]. Thereby the reservoir performs a crucial protective function for the benefit of the downstream riparian's (Spreewald, Cottbus) against ochre pollution.

From August through December 2014, the State Office of Environment, Health, and Consumer Protection (LUGV) had repair work carried out on the dam of the reservoir. These repairs became necessary because the damage to the eastern wing wall of the dam which had been ascertained in 2013 had the potential to significantly impair the reservoir's flood control capacity. In order to allow the works to proceed, the water level had to be lowered to 89 m a. s. l, which meant a drawdown of ca. 3 meters. According to [IWB 2013], the associated significantly shorter retention time gave reason to expect an essentially lower retention of iron. As early as 2013, a water level drawdown of 2 meters made for reasons of maintenance then led to cutting the retention time in half and significantly diminishing the retention of iron [IWB]. In the process of iron precipitation the area of the Spremberg reservoir was used to its maximum. In case of a significant further water table drawdown like the one that became necessary in the summer of 2014, detection threshold exceedances in the main dam outlet and, by implication, potential restrictions on the use of water had to be expected.

Thereupon, relevant water management competencies (LMBV, Vattenfall Europe Mining AG) were pooled in an ad hoc task force on the initiative of the Brandenburg State Office for Mining, Geology and Natural Resources (LBGR) and in co-ordination with the LUGV Brandenburg with a view to planning and implementing a viable concept which would ensure iron retention within the reservoir under the boundary conditions of dam wall rehabilitation.

Measures to remove iron from the Spree River

Process technological concept

The members of the above-mentioned ad hoc task force studied various measures aimed at enhancing the efficiency of iron retention within the preimpoundment basin. Their preferred option was geared towards a sequential conditioning of the Spree River in order to achieve iron retention within the preimpoundment basin involving the following process stages:

1. pH increase to accelerate iron (II) oxidation;
2. Mixing and contact time within a predetermined flow channel;
3. Flocculation aid addition to enhance flocculation;
4. Preferred settlement of the iron hydroxide sludge (IHS) in the Bühlow preimpoundment.

Based on experience gained from mine water treatment by Vattenfall Europe Mining AG, the Brandenburg University of Technology BTU Cottbus conducted flocculation tests for process optimisation [IWSÖ / BTU COTTBUS 2014]. The efficiency of pH increase and the adjustment of an optimum pH value were considered as a start.

Further tests served to select a flocculation aid suitable for the Spree River water. During these tests, 3 different anionic flocculation aids as well as a dual flocculation process combining cationic PolyDADMAC with anionic flocculation aid were studied.

Additional studies with regard to treatment sequence included:

- Combination of pH increase by way of lime slurry addition and subsequent addition of flocculation aid,
- Impact of contact time between pH increase and addition of flocculation aid, and
- Impact of mixing turbulence at pH increase of addition of flocculation aid, respectively.

Subsequently, the process stages of sequential conditioning were refined as follows:

1. pH adjustment to pH > 8.0 by addition of lime slurry;
2. Mixing channel with minimum contact time of 30 minutes, and
3. Addition of the Koaret PA 3230 T flocculation aid.

In the framework of a technological concept, GIP GmbH Dresden investigated ways to implement the process at short notice.

Planning and technological implementation

Building on the above results, GIP GmbH Dresden designed and constructed a corresponding technological unit for a two-stage conditioning of the Spree River upstream of the preimpoundment basin [GIP 2013].

One standout feature of the project was the very short period of time available for its implementation. Planning work started in April 2014 on the understanding that the unit would come on stream not later than in August 2014. This tight deadline was met thanks to excellent co-operation among all parties involved in the project and partial integration of individual planning stages.

In the light of these circumstances, the following key principles had to be observed in terms of engineering design:

- Complete adaptation of the unit to site conditions;
- use of existing infrastructure;
- to the greatest extent possible, use of available structural conditions in order to pare time and effort at the construction site.

Nonetheless the plant‘s subsystems had to be designed in a way to make sure they would not be affected by flood nor constitute flow channel obstacles in the case of a flood event.

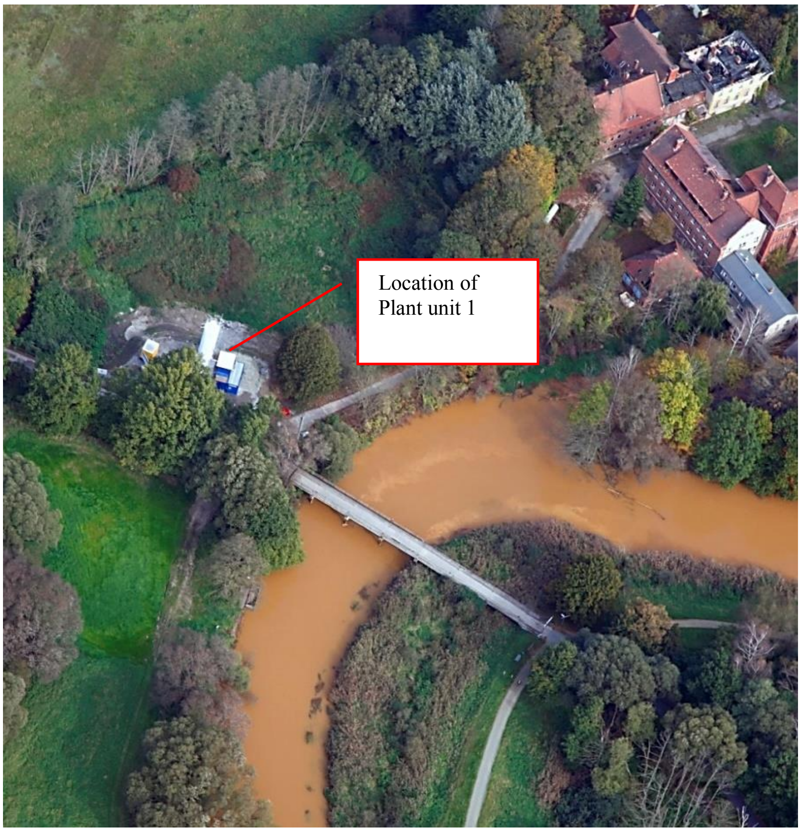

Figure 1 *View of plant unit 1 in Spremberg Cantdorf and in-stream lime dosing*

Two plant units were designed and erected for the two process stages, namely addition of lime slurry (1st process stage) and addition of flocculation aids (2nd process stage) to ensure preparation and tailored dosing. The engineering design was that of a container-based mobile plant with a view to enabling extensive preconstruction and rapid assembly. It was only a matter of months from design to completion.

Plant unit 1 is located in Spremberg Cantdorf, approximately 1.5 km upstream of the preimpoundment basin. At this site, an existing bridge across the Spree River was available for lime slurry supply and blending into the river water. Lime slurry blending is preceded by dilution in a motive water stream and is performed by means of three pairs of nozzles. In doing so, uniform pH distribution can be achieved in the Spree water only a short distance away downstream.

***Figure 2** Container-based mobile plant providing tailored lime slurry dosing (Plant Unit 1)*

Weighing of the batching tank ensures accurate lime slurry preparation. Tailored dosing depending on the flow in the Spree River is performed by a frequency controlled hose pump. In coordination with all parties involved in the project, the plant was designed for a flow rate of 15 m^3/s which corresponds to the Spree River's average discharge flow. Making full use of the facility's design capacity, the maximum dosing is limited to a flow rate of 17 m^3/s.

Preparation and tailored dosage of flocculation aid suspension are ensured by plant unit 2 at the preimpoundment basin inflow. Existing training wall structures (triple intake fan) upstream of the preimpoundment basin were used to provide access to the Spree River (see Figure 3). The flocculation aid suspension was also mixed into a motive water stream, and dosing into the Spree water was channelled by means of three pairs of nozzles. Following completion of horizontal directional drilling, the dosing pipe runs directly from plant unit 2 to the training wall structure within the Spree riverbed. Such taking advantage of site conditions allowed to keep impact on the waterbody‘s channel geometry to a minimum.

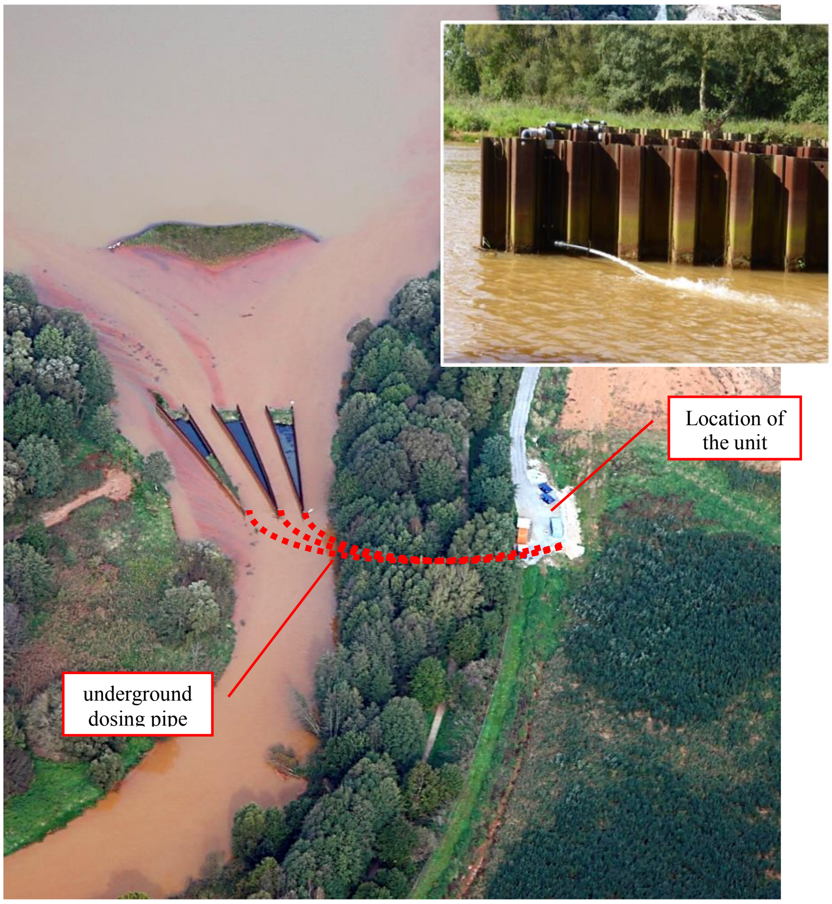

Figure 3 *Plant unit 2 located in preimpoundment basin inflow and nozzle-controlled dosing of flocculation aid*

Results achieved so far by the operation of the conditioning plant

Except for a short downtime due to winter conditions in February 2015 (February 03 to March 04, 2015), the conditioning plant has been in continuous operation since it came on stream in August 2014.

During the period of operation, the Spree River discharge varied from 6 to 31 m³/s. Lime slurry dosing rate was in the order of 0.25 mol/m³, with an average lime consumption of 9 t/d. The consumption rose to 19 t/d at maximum capacity utilisation. Average daily consumption of flocculation aids was 200 kg/d with dosing in the 0.1 to 0.2 g/m³ range.

In connection with this measure, intense monitoring of the Spree River performed since 2012 at three sampling stations was enhanced by an additional measuring point located right in the inflow to the Bühlow preimpoundment basin in order to comply with a regulatory requirement to perform environmental monitoring [IWB].

Long-term monitoring data establish an average iron load (with regard to Fe_{total}) of approx. 7,100 kg/d with mean concentrations in the order of 5 to 6 mg/L in the inflow to the preimpoundment basin. In this connection, the iron levels are essentially a function of discharge rates. Increased discharges induce dilution. However, the increase in stream velocity, which is inevitably connected with an increase in discharge rates, in the first instance, brings about a mobilisation of iron hydroxide sludge deposited along the watercourse. This implicates concentration peaks of up to 15 mg/L.

As a result of the conditioning, the average natural iron retention within the preimpoundment basin was raised from approximately 2,000 kg/d by up to 50 percent to 3,000 kg/d; under optimum conditions, it rose even by 100 percent to 4,000 kg/d (see Figure 4).

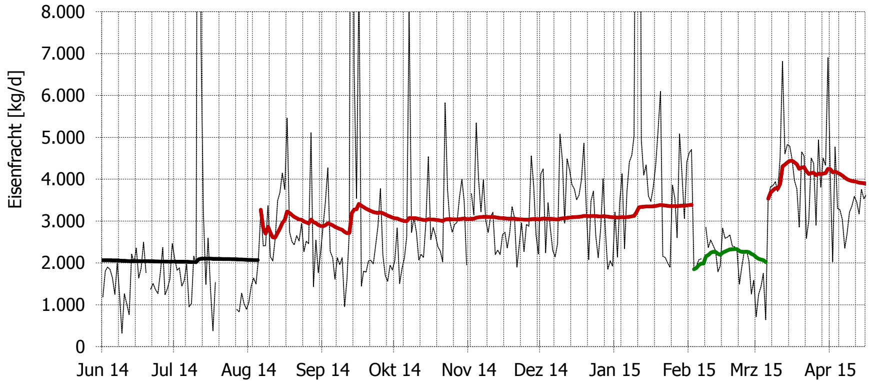

Figure 4 *Daily values (thin black line) and moving average of iron retention in the Bühlow preimpoundment basin from June 2014 to April 2015 (Source: [IWB])*

In particular during the winter months, a significant drop in Fe (II) concentration due to lime addition was observed downstream of the preimpoundment basin (see Figure 5). The nearly complete oxidation of Fe (II) achieved in this way provided the required preconditions for more efficient iron retention within the preimpoundment basin. Hence, total iron concentrations downstream of the preimpoundment basin decreased on average to approximately 2.5 mg/L.

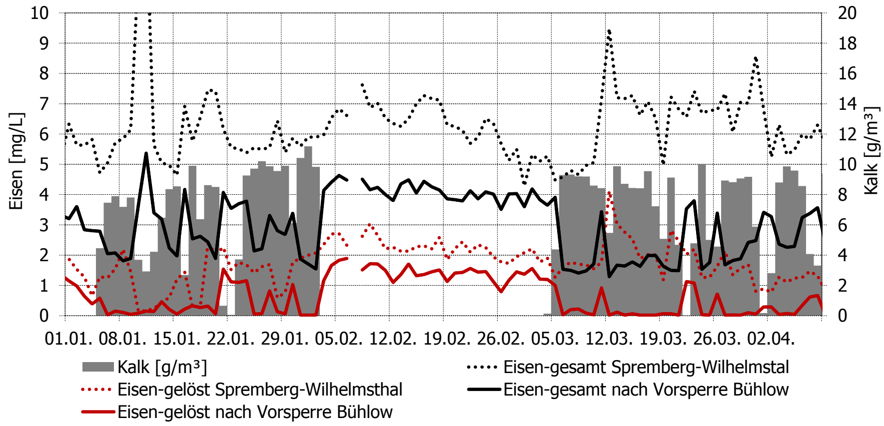

Figure 5 *Time course of concentrations of dissolved iron Fe(II) and total iron - Fe(II) and Fe(III) – upstream and downstream of the Bühlow preimpoundment from January to April 2015 (Source: [IWB])*

Efficiency of lime addition during the first process stage (Plant unit 1) is illustrated by the time course of the individual iron concentrations within the preimpoundment as depicted in Figure 5. During plant downtime in February 2015 Fe (II)-concentrations jumped up to levels of 1.5 to 2.0 mg/L with total iron concentrations rising to approximately 4 mg/L. During that period, iron retention within the preimpoundment basin was notably down.

Thanks to the efficiency of the conditioning plant according to [IWB], no significant exceedance of the visibility threshold of 2 mg/L total iron at the Bräsinchen reference gauge was recorded while damage to the dam was being repaired.

Measures to remove iron hydroxide sludge from the preimpoundment basin

Measures aimed at the sequential conditioning of the Spree River are intended to enhance the settling capacities of iron hydroxide flocs and in doing so to remove iron from the aqueous phase. Iron hydroxide sludge (IHS) generated in this way settles and forms a sludge layer within the preimpoundment basin.

Since there is strongly uneven flow through the preimpoundment basin, as a consequence sludge settlement is also uneven. Measurements accompanying the measure as well as a two-dimensional flow calculation revealed that under current conditions approximately 75 percent of total flow through the preimpoundment basin follows a short circuit pattern through the eastern sector. At the time of sounding on March 13, 2015, the sludge layer in that sector had a thickness of up to 1.9 meter while sounding results ranged from 0.5 to 1 m in the other sectors. Total sludge volume within the preimpoundment basin amounted to 86,510 m³. The settled IHS undergoes a number of aging processes which contribute among others to a progressive thickening of the deposited IHS. While the uppermost sludge layer typically shows dry matter contents in the range from 2 to 5 percent by mass, the dry matter content of low-lying sludge layers rises up to 40 percent by mass.

Sludge removal from the preimpoundment basin and hence the elimination of iron depositions from the waterbody is the final process stage required. During the period from April to August 2015, GIP and their project partner TWB will proceed to perform an initial desludging of the preimpoundment basin. This partial sludge removal is aimed at producing appropriate new volume for the settlement of IHS along the preferred flow path in the eastern sector of the preimpoundment basin. According to a 3D-volume balance based on sounding data, the volume of this partial sludge removal was put at approximately 30.000 m³. Sludge removal from the preimpoundment basin is performed by two specifically equipped suction dredges. Prior to disposal, the dredged sludge undergoes dewatering on site in two mobile decanter units, each with a capacity of 100 m³/h.

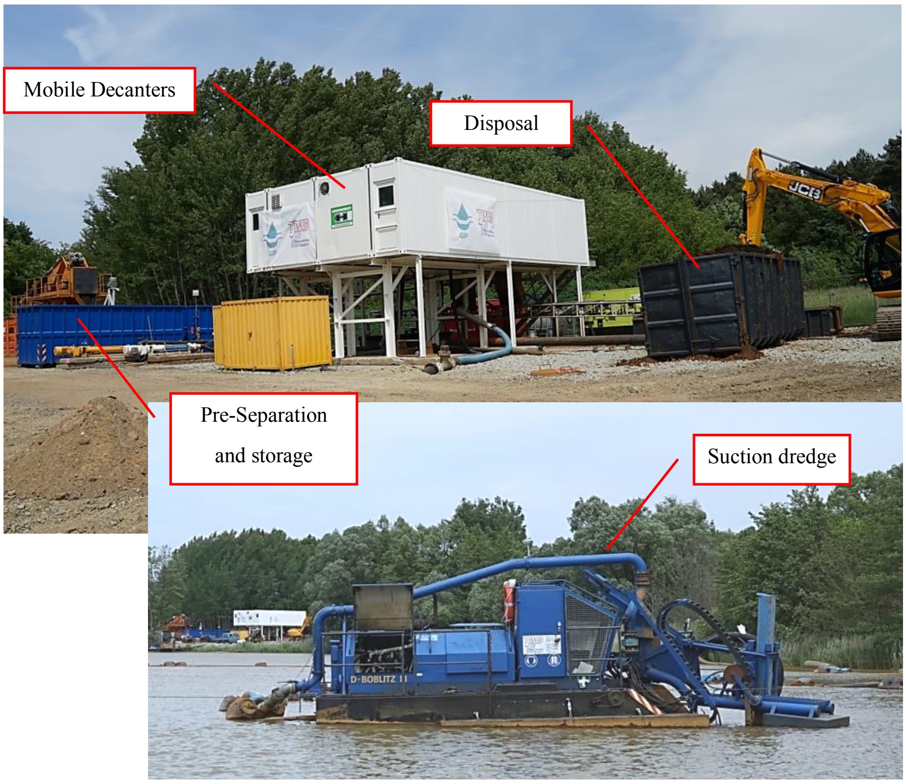

Figure 6 *Desludging the Bühlow preimpoundment basin*

Continuation of iron removal measures

After consultation with the competent regulatory authorities, LMBV envisages to continue the tailored operation of the conditioning plant in the coming five years until a point is reached when the currently planned and implemented measures which are targeted at diminishing the impact of iron-bearing groundwater onto the Spree and Kleine Spree Rivers are beginning to take effect.

Protection of the town of Cottbus and of the Spreewald against visible iron pollution is the primary goal of this measure. A visible browning of the water begins at a total iron concentration of approximately 2 mg/L (visibility threshold). At a total iron concentration of less than 1 mg/L, water presents a slightly appearance.

Analysis of monitoring data from 2012 through 2014 reveals average iron retention in the preimpoundment basis of approximately 2,000 kg/d or ca. 30 percent. A vast special area of protection (SAC) extends along the inflow to the main dam. Therefore, a further objective of the conditioning plant's continued operation is the best possible iron load in the preimpoundment basin. The planning target aims at a load proportional iron retention rate of ≥ 50 percent.

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