Underwater Nozzle Pipelines (UNP) – A new Process for in-lake Liming

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Abstract In fall 2011, one of the largest pit lakes of Eastern Germany has been limed with a novel on-site process. Within 16 weeks of operation, its 110 Mm^3 of water could be shifted from the iron buffer to circumneutral pH-values. Due to a thorough consideration of the chemical and hydrodynamic parameters the method prevailed an 80 % efficiency. In this paper we will present the details of this novel UNP-process.

Keywords in-lake treatment, liming, technological solution, pit lake

Introduction

Usually, after open pit mining ceases, the open space fills and leaves back pit lakes. In the Eastern German Lusatian lignite mining area, this will result in Europe's largest artificial lake district. Many of those lakes comprise of large water volumes and surface areas and are therefore amongst the largest lakes in Germany (Nixdorf *et al.* 2001). The inflow of potentially acid groundwater from the adjacent overburden dumps results in sulphate dominated acidic conditions. Many of the newly developed pit lakes have a pH of around 3.0, in the range of the iron buffer (Geller *et al.* 1998).

Back in the 1970ies and 1980ies methods were developed to treat lakes acidified by acid atmospheric depositions (Nyberg 1988, Sverdrup 1985). However, the acidity of the acid sulphate pit lakes exceeds those of the Scandinavian softwater lakes by 2…3 orders of magnitude (Geller 2009). This results in a substantially larger amount of neutralizing agents needed to treat the pit lakes. To minimize the costs for creating and keeping pH-neutral conditions it is essential to apply the neutralising agents as efficient as possible. Current procedures, such as sprinklers (Benthaus and Weber 2012) or ships (Pust *et al.* 2010) that spread the suspension over the water surface, have weaknesses that inhere the procedures and are mainly a result of the hydraulic and logistical circumstances.

This paper presents our work that aimed in developing and testing a highly efficient procedure to lime the pit lakes.

Methods

Usually, lime products are used to neutralize acidified lakes. On-site they are mixed with water to produce a suspension which is then injected into the water body. In order to inject the neutralizing agent as efficiently as possible, it is necessary to disperse the suspension evenly in the lake volume with a minimum amount of energy.

This requirement is best met by applying the free jet principle (fig. 1). Velocity differences between the free jet and the ambient fluid generate exchange processes at the jet boundary (Schlichting and Gersten 1997). Fluid particles of the ambient fluid near the jet boundary are incorporated into the eddies and accelerated. Within the jet the fluid particles are decelerated as a result of turbulent conditions and eddies in the jet direction. Due to the incorporation of ambient fluid into the jet, the jet volume increases with length and the jet ve-

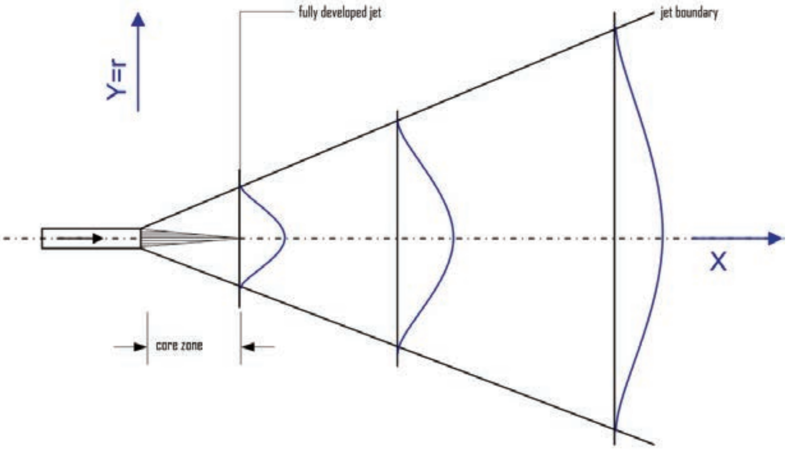

Fig. 1 *Velocity distribution inside a free jet flowing into a stagnant and homogenous surrounding fluid*

locity decreases while its momentum stays constant. Based on the investigations of Kraatz (Bollrich *et al.* 1989) it is possible to describe the jet’s velocity distribution and special development as a function of its initial velocity and length.

By using the free jet for injecting and mixing the lime suspension density differences between the particle loaded jet beam and the ambient fluid are induced. Permanent mixing of the ambient fluid over the length of the jet causes a continuous dilution and consequently a reduction in the suspension’s density. Those density effects superimpose the spreading of the free yet and determine the beam’s trajectory (fig. 2).

The free jet’s spread is either limited by the jet reaching the lake’s floor or a layer of water with a higher density. Those layers might be a result of thermal stratification during the summer stagnation (thermocline) and the suspension will then spread horizontally along this boundary layer.

In order to neutralize the acid pit lake, the lime suspension’s dilution at the end of the jet beam’s length must possess the chemically necessary application rate. Best neutralisation results will be obtained if the liming is conducted during the lakes full vertical circulation periods because the complete length of the jet beam can be used for the mixing of the lime suspension (fig. 2). An adequate number of

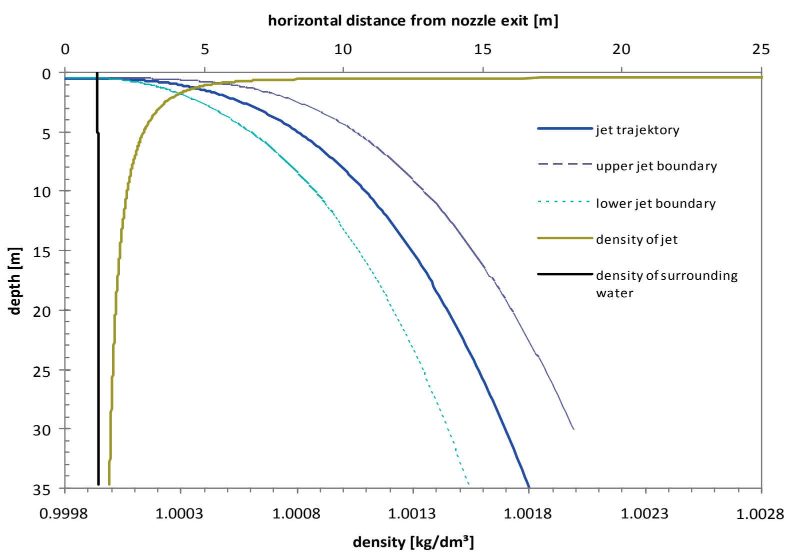

Fig. 2 *Jet trajectory and change in density over the whole jet run length*

nozzles assures that the ambient lake water mixed into the free jet spreads into the whole lake volume at least once during the application period. The method works on a 24–7 basis and consequently even in the case of large water bodies a relatively short period of time is necessary for the liming.

Each pit has an individual chemical composition and morphology. Consequently, the UNP-process requires a configuration specifically designed for each water body. The parameters to be considered include the maximum concentration of the lime suspension, the best treatment period and the location of the nozzles to produce the free jet.

Area of Investigation

A first pilot test of the UNP liming process was conducted within the pit lake *Scheibe*, which has a volume of 110 Mm^3 and a water surface of 6.8 Mm^2. With its length of 5.2 km and a maximum width of 1.7 km it belongs to the largest pit lakes in the Lusatian lignite mining area. As a result of the lignite mining technology used, the lake's morphology is characterised by two distinct features: the eastern part of the lake consists of the former pit's inner dump with a shallow water area of 2… 6 m depth and the western part with a water depth of 35 m (fig. 3). Lake *Scheibe* is characterised by dimictic conditions with full circulation phases in spring and fall.

A determining aspect for the water composition of lake *Scheibe* are the groundwater inflows into the lake: from the south, from the mother rock a slightly acidic groundwater with an acidity of approximately 1.0 mmol/L and from the inner dump water with an acidity of 9.0 mmol/L. Initial lake water conditions used for predicting the treatment of lake *Scheibe* were an acidity of 3.4 mmol/L, a pH of 2.9, as well as calcium and sulphate concentrations of 150 mg/L and 550 mg/L, respectively.

Pilot Project Implementation

Prior to the pilot test, various potential lime products were investigated in the laboratory to determine if they can be used to neutralize lake *Scheibe* with the UNP-process. It could be shown that a quicklime (CaO) provided by Fels-Werke GmbH has the best performance characteristics resulting in a necessary application rate of 150 g/m^3 at an efficiency of 70 %. Con-

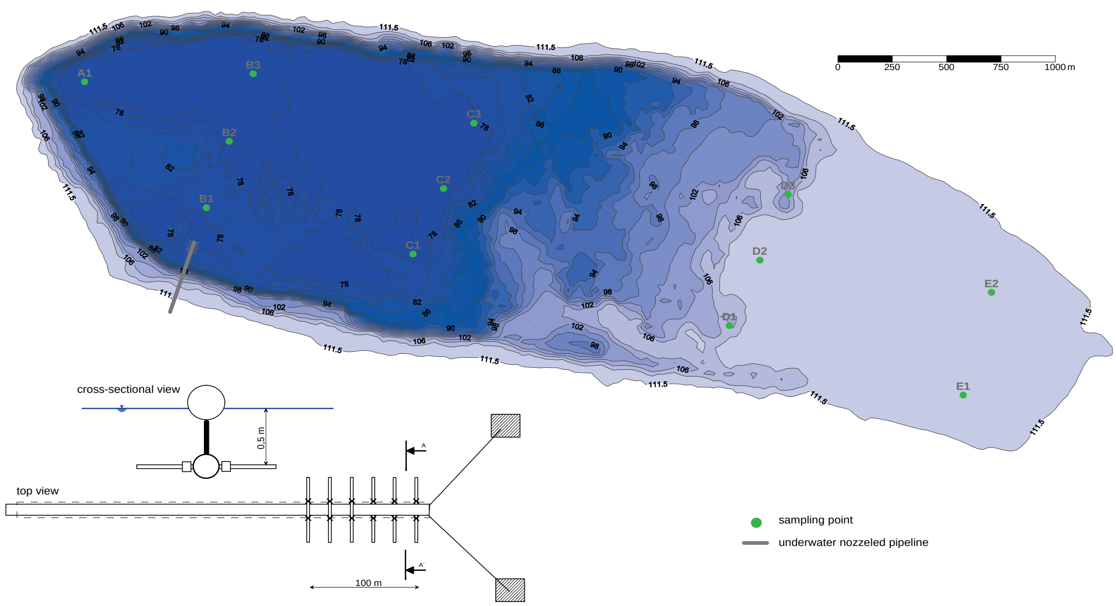

Fig. 3 Morphometrics of lake Scheibe, *sampling points, and a detailed view of the UNP-process*

sequently the necessary amount of lime to be added was 16.5 kt.

Technologically, the UNP-process is kept very straightforward: A submersible pump draws water from the lake and supplies the mixing station with this water by ways of a pipe. Two lime silos are dosing the neutralization agent into a mixing tank. From there, the lime suspension is pumped into a maturation tank and finally into a submerged floating pipe transporting the suspension into the lake. At the end of the pipe the lime suspension mixing nozzles are installed in pairs. Lake *Scheibe* had a nozzle configuration with 6 pairs at a distance of 20 m, which can be considered to be a punctiform injection in relation to the lake's size (fig. 3). On October 4, 2011 the treatment of lake *Scheibe* started and could be finished successfully on January 25, 2012, after just 16 weeks of operation and two short operation interruptions of the liming installation (fig. 4). For monitoring the liming, 33 water samples were taken on a weekly basis at 12 sampling locations (fig. 3).

Based on the changes of the water quality, the specifications for the further operation of the neutralisation plant were determined. An additional monitoring of the hydraulic conditions of the lake provided the basis for validating a 3D lake model (MOHID-Water Modeling System). Both data were used to verify the previously used design calculation algorithms. In addition, the 3D modelling aimed in identifying the fraction of the momentum input, density driven flow, and wind induced flow responsible for the overall water treatment.

Results

At the beginning of the treatment, lake *Scheibe* was characterised by stratification with the thermocline being located at a depth of 12 m. Liming started initially with a 10.4 t/h mass flow, equivalent to 250 t/d. Such an application rate makes high demands on the logistics of the lime supply as up to 10 silo trucks were needed on a daily basis. As expected, the application of the suspension was restricted to the epilimnion, but wind induced currents during this phase of the injection supported a uniform distribution of the concentrations throughout the whole epilimnion. Consequently, a treatment effect could already be observed at the two farthest measurement points E1 and E2 in the first week of operation (fig. 3).

A certain proportion of the neutralising agent is stored as a result of its horizontal spreading along the thermocline. Since the samples were always taken from the same depths, part of the injected neutralisation agent is therefore not detected and thus, the average effect in the entire lake is temporarily

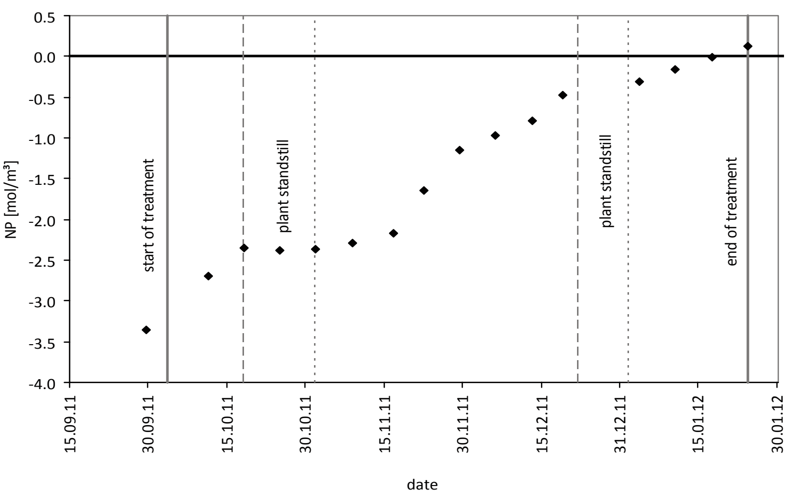

Fig. 4 *Temporal progress of the lake* Scheibe *treatment*

underestimated. In view of a full lake circulation and the subsequent homogenisation of the lake's conditions, eventually, the treatment effect is correctly represented. During the continuation of the water treatment, the thermocline gradually disappeared and the expected treatment effect could fully develop over the entire water depth. This phase of the treatment is purely controlled by momentum input and the density driven flow in the lake.

Fig. 4 shows the temporal development of the average lake's conditions. As a measure of the acidity and alkalinity the modified neutralization potential NP of Schöpke (2008) is used

As planned, at the end of the water treatment, lake *Scheibe* exhibited pH-neutral conditions with a 0.16 mmol/L buffering capacity. The amount of lime used was 15.2 kt, which is less than calculated and the chemical efficiency with 80 % was above the pre-determined value. All project objectives agreed with the client were met and the financial framework was not exhausted. With treatment costs of less than 0.01 €/mol the UNP-process is well below other lake treatment costs with lime.

Various boundary conditions for the lake treatment could be identified by the 3D modelling. Wind induced currents are supportive only within the epilimnion. Yet, the main treatment effect is controlled by the momentum input and the density driven flow (fig. 5). Moreover, the pre-determined parameters for predicting the process could be proved to be sufficiently accurate.

Conclusions

As the LMBV pilot test for neutralising lake *Scheibe* showed, a stationary, continuously working liming installation can treat large pit lakes within a relatively short period of time. The UNP-process described in this paper combines chemical and hydrodynamic conditions within its design calculation algorithm. In order to achieve an optimum treatment, the process is fitted into the natural circulation period of the water body. To our knowledge it was the first time that 15.2 kt of lime were applied within a 16 weeks operation period. The chemical efficiency of 80 % exceeds the expected efficiency obtained during preliminary tests and the treatment costs of less than 0.01 €/mol extraordinarily prove that the UNP-process is a highly efficient treatment option.

Acknowledgements

This pilot project was conducted on behalf of the LMBV (Lusatian and Central German Mining Administration Company). The authors appreciate their financial contribution.

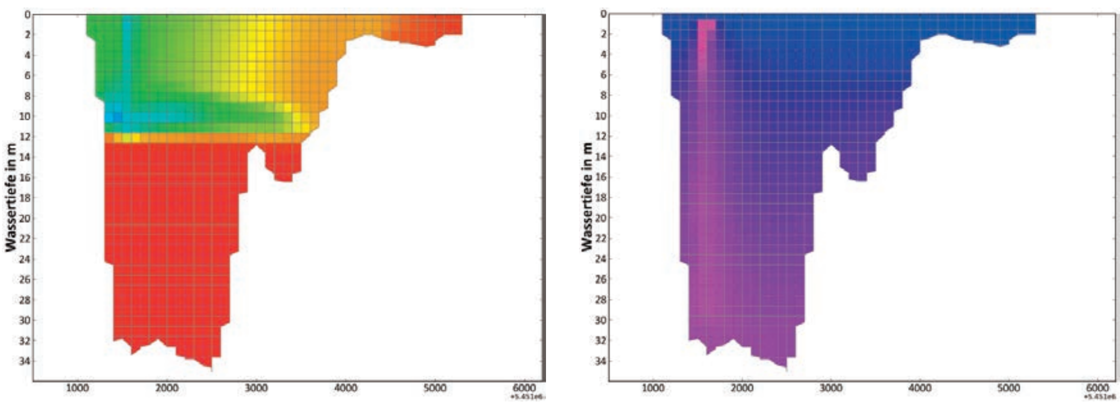

***Fig. 5** Longitudinal section of lake* Scheibe *with discharge of lime suspension under stratified conditions (left) and while full circulation is completed (right) [dimensions in m]*

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