Active Treatment of Fe-, Mn- and Coaldust Contaminated Mine Water as Part of the RAME-Project in Vietnam

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Abstract The RAME research project started its first activities in Vietnam at the end of 2005. The aim of the BMBF (German Federal Ministry of Education and Research) funded research and development project is to develop methods to reduce the environmental impacts due to hardcoal mining in Quang Ninh province / Vietnam by selected technical measures and enhancement of the environmental management. Based on a preliminary survey, dump stabilization and recultivation, mine water treatment, dust mitigation and post-mining landuse were identified as main research fields and are the subjects of subprojects. This publication highlights the RAME research on mine water treatment.

Key Words hardcoal mining; mine water treatment; manganese removal

The RAME joint research project

In 2005, the Research Association Mining and Environment (RAME) and the Vietnam National Coal – Mineral Industries Group (VINACOMIN) agreed on a collaboration in order to develop environmental concepts and measures for Quang Ninh hardcoal mining areas. RAME is coordinated by the Institute of EE+E Environmental Engineering+Ecology, Ruhr-University of Bochum (Prof. Dr. Harro Stolpe, Dr. Katrin Brömme) and is funded by BMBF (German Federal Ministry of Education and Research).

The subjects of the joint research project RAME are related to main environmental problems of hard coal mining in the Quang Ninh Province, Vietnam (Brömme *et al.* 2007). The RAME research project consists of 6 subprojects (fig. 1).

Subproject I. Environmental management, environmental information system, capacity development

Decisions on environmental measures require knowledge about emission sources, transmission paths, immission areas etc. Furthermore, knowledge about environmental technologies, hazards, legislation, the available budget and the costs of measures is required. In order to manage all these information, an environmental information system and annual environmental reports are developed. The annual environmental reports are instruments for environmental management. They contain information about the status of the environment and recommendations for monitoring and remediation measures.

The subproject (project start 2007) is carried

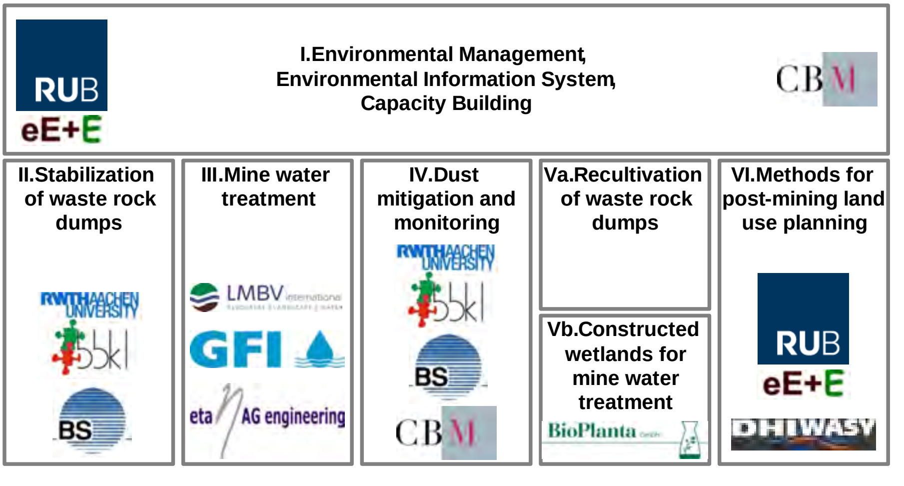

Figure 1 The RAME project structure.

out by the Institute of Environmental Technology and Ecology at Ruhr-University of Bochum and CBM GmbH, Aachen (capacity development).

Subproject II: Stabilization of waste rock dumps
The project site for dump stabilization (project start 2008) is a typical dump; it is filled with heterogeneous waste rock materials using the side-hill fill dumping method. Thereby, a segregation of waste rock particles occurs where fine particles stay at the upper part and coarse materials move towards the foot of the dump. Further stability risks are caused by mechanically labile material layers inside the dump and subsidence processes due to uncompressed materials. The task of the subproject is to investigate the dump in order to quantify the stability and to develop solutions to reduce the risks of landslides.

The research of the subproject has two main components. One is the investigation of the dump stability by monitoring of dump movements, other signs for failures, seepage water flows and geomechanical investigations by drillings and trial pits. This component also investigates the risk of acid mine drainage from the dump. The second component is a large scale test of a different dumping method in layers including compression by trucks under controlled conditions in order to develop technical guidelines for the dumping process in the future (Ahmad *et al.* 2009, Deissmann *et al.* 2008, Martens *et al.* 2009).

The subproject is carried out by the Institute of Mining Engineering I, RWTH Aachen University and the company Brenk Systemplanung, Aachen.

Subproject III: Mine water treatment
The mine water treatment project is presented in more detail in chapters 3 and 4 of this publication.

Subproject IV: Dust Mitigation and Monitoring
The project site for the dust mitigation subproject (project start 2009) includes open pit mines, large waste rock dumps, coal and waste rock transport routes, coal screening areas and a coal processing plant as well as a coal harbour. Furthermore, the area is located very close to residential areas of Ha Long City which are especially sensitive to dust emissions. The task for the subproject is to perform an extended dust monitoring in the area following the production chains of the coal. As a result, the most relevant dust sources are identified. Subsequently, dust mitigation measures will be developed for these dust sources.

The subproject is carried out by the Institute of Mining Engineering I at RWTH Aachen University and the companies Brenk Systemplanung and CBM GmbH, both in Aachen.

Subproject Va,b: Plant based methods (Recultivation, Constructed Wetlands)
One task of this subproject (project start 2008) is to develop and test long-term stable and sustainable concepts for a recultivation of the dump site. The subsequent step includes recultivation measures aiming to assist nature by utilizing natural succession. Locally adapted plant species occuring already in the original natural vegetation are grown in distinct islands serving as colonization initials. The chosen methodology aims at developing a fully functioning, self-sustaining system that involves besides plants also natural processes of soil development and nutrient cycling.

In order to develop the method in detail, the subproject designed recultivation experiments. The experiments compare tree species and grass species as well as different ways of soil improvement. Furthermore, the recultivation results are compared with already established plantations using traditional recultivation trees (Kuka *et al.* 2010, Finkenbein *et al.* 2010).

The second task of this subproject is mine water treatment by constructed wetlands for an area where the acid water in a lake strongly affects the agricultural production downstream. Beside other mine influenced waters, seepage water drains a waste rock dump into the lake. The subproject has the task to test whether this kind of water can be treated successfully in a constructed wetland.

The constructed wetland was designed as a passive biological treatment facility with two treatment steps in two basins one after another. The first basin contains a limestone drainage passage covered by mixed manure. The second basin contains a planted gravel filterbed. The pilot scale constructed wetland has a designed capacity of 4.4 m^3/h (Gerth 2009).

The subproject is carried out by the Helmholtz Centre for Environmental Research – UFZ in Leipzig and the company BioPlanta GmbH in Leipzig.

Subproject VI: Methods for Post-Mining Land Use Planning
This subproject (project start 2011) has the task to develop an approach for planning of post-mining land use under consideration of the surrounding land uses and land use requirements. The project is carried out on two scales: overview scale (about 1:25,000) and detailed scale using the example of open pit mines to be closed soon. The post-mining land use shall also contribute to mitigate land use conflicts between mining / urban areas / conservation / tourism, etc. in this region. A planning and communication concept will be developed, which includes already existing and new ideas for post-mining land use.

The subproject is carried out by the Institute of Environmental Technology and Ecology at Ruhr University of Bochum and DHI-WASY, Syke.

Framework conditions for the development process of a mine water treatment plant

Within the framework of RAME subproject III, a mine water treatment plant for an underground anthracite mine in Northern Vietnam was developed by the three German partners LMBV-International, eta engineering AG and GFI Dresden. Limiting factors for the development of a suitable treatment process have been the rather limited financial resources, the limited size of the construction area, the tropical and humid conditions in Northern Vietnam and the prerequisite of the Vietnamese partners to run the plant with a low amount of additional chemical substances besides lime. The implementation planning was finished with great support of the Vietnamese partners in 2010. It was then supplied to the Vietnamese partners, who are now realizing the construction. The plant is currently set up in the field and it is planned to be put into operation in 2012.

The first step of the planning process was an elaborate monitoring program on the mine site to determine the concentrations of the main contaminants which turned out to be coal particles, partially oxidized Fe and Mn. Based on the monitoring results, it was decided together with the Vietnamese project partners to design a plant which would be able to treat raw waters with up to 50 mg/L Fe_{tot}, 10 mg/L Mn and coal particle loads up to 1.5 g/L TS. Current Vietnamese regulations for industrial waste water require runoff concentrations of less than 5 mg/L Fe and 1 mg/L Mn. The plant should be able to treat 800 m^3/h with an increase option up to 2400 m^3/h.

Because of the high volume fluxes and the very limited space, only active treatment was an option. While Fe and coal particles can be removed by classic oxidative mine water treatment (neutralisation by lime, oxidation, flocculation, sedimentation) (Aubé 2004, Coulton *et al.* 2003), Mn removal is more demanding (Martin 2005). Thus, most effort was spent on developing a suitable Mn removal. Preliminary tests showed that oxidation by ozone had to be ruled out due to high costs and interference with the organic coal dust particles. Also extensive increase of the pH was dropped because of high lime consumption, increasing calcite precipitation (Kurtz 2011) and sludge volumes as well as the violation of the Vietnamese runoff requirements (pH 9.0). Thus, sorption to parallelly precipitating iron hydroxides and catalytic oxidative Mn removal was investigated in more detail.

Development of the mine water treatment process

To support the planning process and to test and optimize possible Mn removal technologies, a bench scale treatment plant (fig. 2) was set up at the Groundwater Center in Dresden to test the whole treatment process in one line and also single parts of the whole process. Laboratory tests

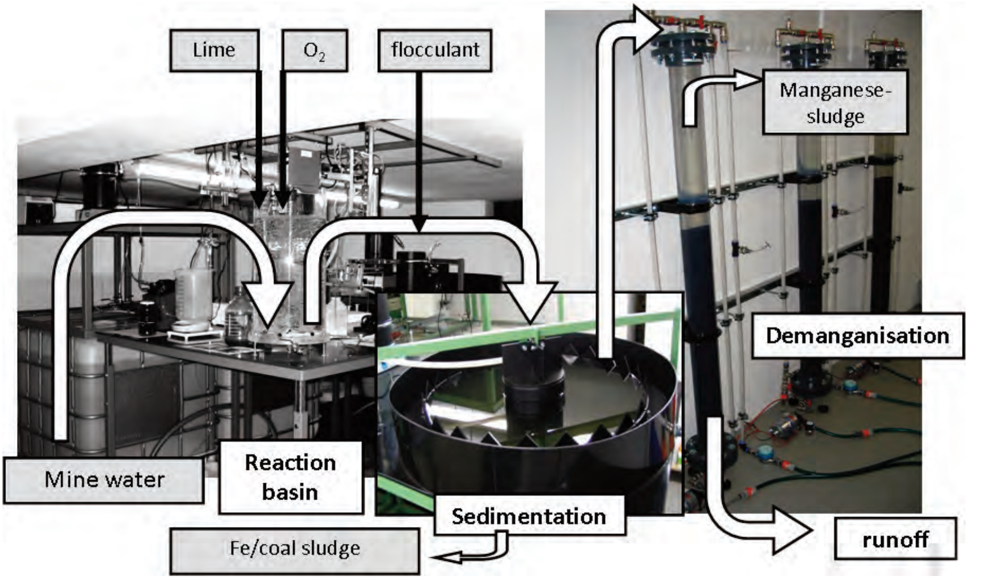

Figure 2 *Bench scale mine water treatment plant, which was used to parameterize most of the relevant processes.*

were performed to investigate the rather special sludge settling behaviour of the coal-iron-hydroxide aggregates and the Mn oxidation kinetics under the specific conditions of the reaction basin in the presence of iron hydroxides and coal dust (Kurtz *et al.* 2010).

Bench scale tests showed that about 50% of the Mn load could be removed in a first step at a pH of 9.0 by sorption and oxidation in the reaction basin with an economically reasonable use of neutralising agents. The remaining Mn load above 1 mg/L has to be removed in a second step by additional catalytical oxidation which was performed in fixed bed manganese oxide filters (Kurtz *et al.* 2011,

Schlenstedt *et al.* 2010) (fig. 3). The two treatment steps are dependant on each other because of several reasons:

1 The removal of suspended solids and part of the metal-hydroxides is a prerequisite for the Mn removal in the second step in order to avoid clogging and extensive periods of filter flushing.
2 Mn-sorption to Fe(III)-hydroxides as well as catalytic Mn oxidation is vastly accelerated at elevated pH-values due to higher sorption capacities (Davies & Morgan 1989). Thus, the pH-increase to 9.0 in the reaction basin supports all three removal processes: *sorption in the reaction basin, heterogeneously catalyzed Mn-oxidation at ferric-hydroxide surfaces and heterogeneously catalyzed Mn-oxidation at the surfaces of manganese oxides*. In the latter operation, the actual pH-level can be adjusted to the actual Mn-inflow concentration and mine water flux to minimize lime use.
3 By using the coal dust and the freshly formed iron hydroxides as adsorbent in the first step under the conditions of high Mn-concentrations, the mine water´s inherent sorption potential can be utilized best. In that way, the hydraulic retention time in step 2 can be minimized. This also reduces the amount of Mn-sludges, and minimizes the volume of the (expensive) Mn-oxide filter material.

Using this technology, the amount of lime has to be increased by about 30 to 40% compared to pure Fe removal at pH 7.5 (Kurtz 2011).

Transferring the mine water treatment process to the field

The mine water is transferred to the plant by two pipelines which collect the water from 5 adits. After measuring its flux, the water is transferred to a reaction basin with a volume of 275 m³. The residence time of 10 to 20 minutes allows for significant Mn-sorption and -oxidation. Both processes turned out to be time-dependant in the bench scale tests. The pH is raised to 9.0 by adding lime slurry. The turbulence and mixing energy is created by five airlifts which transfer high amounts of finely dispersed gas bubbles to the water body. The airlifts are also used to distribute the lime slurry and to add the oxygen to the water which is used in the second treatment step.

This technique does not make use of moving parts within the reaction basin and thus represents a rather robust solution. The hydrated lime is stored in two closed silos and added to the basin via two separate dosing stations. For the mechanical separation of its solids, the water is then transferred via a plenum to a sedimentation unit, which consists of a basin with high turbulence where a flocculant is added, a paddle chamber to allow for the growth of flocs and a sedimentation basin which is equipped with lamella separators.

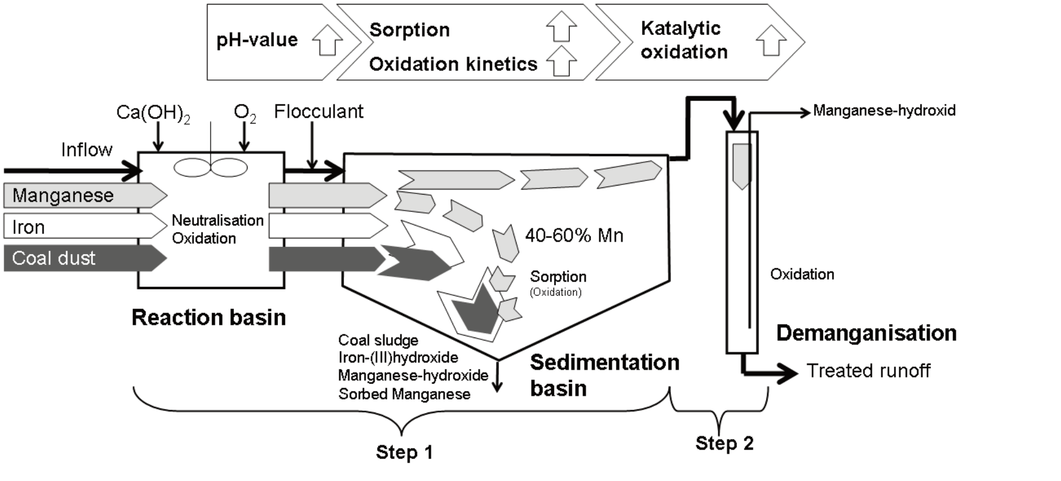

Figure 3 *Scheme of the treatment process.*

Mobile pumps transfer the sludge to a thickener and then to a decanter for further dehydration.

The solid-free but still Mn-containing water is transferred to the demanganization unit. A group of 25 parallel filters with a total filter area of 100 m^2 and a retention time of 7.5 minutes is used to remove the remaining Mn. As catalytically active filter material, a fixed bed of natural Mn-ore is used. Its Mn removal capacity was tested in long-term bench scale tests of several months. The Mn sludge is collected in a separate sludge basin, dried and removed periodically for disposal on a waste rock dump.

Currently, most of the constructions in the field are finished (fig. 4) and the equipment has to be installed. The German partners will accompany the further construction process and the start-up phase of the plant. It is intended to continuously proceed with the monitoring which will include all process steps when the plant is complete. An extensive capacity building program is currently accompanying the whole program and will be focussing in the near future on running the treatment plant. Selection of the future staff by VINACOMIN is in progress.

Conclusions

In the course of the RAME project, a solid mutual trust was built between the German planners and developers and the Vietnamese decision makers. Without this, international projects are not successful. Especially the permanent on-site presence of members of the RAME network leadership proved to be very helpful. For a successful project progress, it turned out to be critical to integrate the Vietnamese side in all planning steps and decision processes. From today's point of view, the offer of a „turn-key plant" would not have been accepted by the local project partners. Only by the willingness of the German developers and planners to accept and organize „numerous German-Vietnamese interfaces" in planning, funding and realizing the construction, the joint project was realisable.

References

Ahmad S, Martens PN, Pateiro Fernández JB, Fuchsschwanz M (2009) Mine Waste Dumping and Corresponding Environmental Impacts at Chinh Bac Waste Dump in Vietnam. Securing the Future and 8th ICARD, 23–26 June 2009, Skelleftea, Sweden

Aubé B (2004) The science of treating acid mine drainage and smelter effluents. http://www.infomine.com/publications/does/Aube.pdf, Download am 16.03.2007

Brömme K, Stolpe H, Tran M (2007) Developing Environmental Concepts for Vietnamese Coal Mines. SWEMP 2007, 10th International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production, 10—14 December 2007, Bangkok, Thailand

Coulton R, Bullen C, Dolan J, Hallett C, Wright J, Marsden C (2003) Wheal Jane mine water active treatment plant – design, construction and operation. Land Contamination & Reclamation 11(2):245—252

__Figure 4__ Erection of the sludge thickener in Vang Danh (sedimentation basin in the background).

Davies SHR, Morgan JJ (1989) Manganese(II) Oxidation on metal oxide surfaces. Journal of Colloid and Interfaces Science 129(1):63—77

Deissmann G, Pateiro-Fernandez JB & RAME Project Team (2008) Improvement of environmental conditions in coal mining areas of the Quang Yen Basin, Quang Ninh Province, Vietnam. Proceedings 86th Annual Meeting of the German Mineralogical Society, 14th – 17th September 2008, Berlin, S15P05

Finkenbein P *et al.* (2010) A succession based technology for reclamation of coal mining areas in Northern Vietnam. 12th International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production SWEMP 2010, May 24—26, 2010, Prague, Czech Republic

Gerth A (2009) Usage of passive biological water treatment technologies in Latin America, Vietnam and Hungary (in German), Symposium „Wasser: Lebensquell und Wirtschaftsbasis", TerraTec – Internationale Fachmesse für Umwelttechnik und –dienstleistungen, Leipzig

Kuka K, Finkenbein P, Franko U (2010) Increase of substrate quality on dumps in open cast mining areas to enable plant growth. International Mining Conference and Exhibition 2010 – Advanced Mining for Sustainable Development, 23—25 September 2010, Ha Long, Vietnam

Kurtz S, Bilek F, Kochan HJ, Denke P (2011) Mine drainage water treatment in Vietnam. Water Wastewater Technology. Special Issue 2011:20—23

Kurtz S (2011) Untersuchung der Prozesse der Mn(II)-Entfernung bei der Behandlung von Abwässern aus einem Kohlebergbau in Vang Danh (Vietnam) und Entwicklung eines Verfahrens zur Entmanganung von Grubenwässern. PhD-Thesis at the BTU Cottbus, Proceedings des Dresdener Grundwasserforschungszentrums e.V., Heft 46

Kurtz S, Denke P, Bilek F, Kochan HJ (2010) On-Site-Monitoring and Process Investigations on the Prognosis of Sludge Characteristics in a Vietnamese Mine Water Treatment Plant in case of Mine Waters rich in Coal Dust, Iron and Manganese (in German). Tagungsband im Rahmen des 61. Berg- und Hüttenmännischen Tages am 10./11.06.2010 in Freiberg

Martens PN, Rattmann L, Pateiro Fernández JB, Ahmad S (2009) Opportunities for a sustainable development at Chinh Bac mine waste dump in Vietnam. SDIMI 2009 – Sustainable Development Indicators in the Minerals Industry 2009 Conference, 6–8 July 2009, Gold Coast QLD, Australia

Martin SC (2005) Precipitation and Dissolution of Iron and Manganese Oxides. Environmental Catalysis, CRC Press, Boca Raton