Technical and Economic Aspects of Recent Achievements in Mine Water Management in the Mines of Quang Ninh Coal Basin, Vietnam

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Abstract Vietnam National Coal and Mineral Industry Holding Corporation Limited (VINACOMIN) had to overcome two main challenges in order to achieve an efficient mine water treatment in the mines of the Quang Ninh Coal Basin, Vietnam: (i) low investment capacity for mine water treatment, and (ii) variation in mine water quantity and quality due to climate conditions. Solutions included equalizing reservoirs for a stable quality of the mine water inflow and parallel treatment lines for treatment capacities varying with seasonal changes. Furthermore, VINACOMIN established a joint environmental fund in order to mobilize financial resources for investment into mine water treatment plants.

Keywords coal mine, mine water treatment, Vinacomin Central Environmental Fund, changing weather conditions, equalizing reservoir

Introduction

The Quang Ninh Coal Basin is situated in the North East of Vietnam, near the coast of Halong Bay, which has been recognized as World Natural Heritage by UNESCO. Almost all coal mining activities in this area are controlled by Vietnam National Coal and Mineral Industries Holding Corporation Limited (VINACOMIN).

The main sources of mine water are surface water and groundwater running into the mines. Additionally, there are other waters contaminated by mine related processes, such as wastewater from workshops or coal screening stations.The average quantity of mine water discharged from coal mines is from 1.9 to 2.1 m³ per ton of raw coal (VITE 2014). The two primary types of water pollution are physical and chemical (inorganic). The mine water isacidic and contains coal sludge (SS), iron (Fe) and manganese (Mn) which are considered to bemajor pollutants (Kurtz 2009; Bilek et al.; 2011) andusually exceed permitted limits. The concentration of metals such as As, Pb, Hg, Cd is below the permitted limits as shown in Tab. 1.

Table 1 *Averagevalue ranges and limits of the main pollution parameters in mine waters in Quang Ninh according to the National Technical Regulation on Industrial Wastewater No.40 (QCVN 40:2011/BTNMT)*

	pH	SS (mg/L)	Fe (mg/L)	Mn (mg/L)	Hg (mg/L)	As (mg/L)	Pb (mg/L)	Cd (mg/L)
Range of measured values	2.6-6.8	70-1,714	2.3-247.4	0.85-24.6	0.0005	0.0005	0.0019	0.0033
QCVN40*	5.5-9	100	5	1	0.01	0.1	0.5	0.1

* basic values which have to be adjusted further in case of wastewater discharge into a water body used for water supply purposes and depending on volume parameters of the receiving water body and the wastewater flow

The climate of Northern Vietnam has 4 seasons but one year can be divided into 2 main seasons regarding the rainfall: the rainy season that lasts from April / May to October / November and the dry season that lasts from November / December to the following April / May. The annual rainfall in Quang Ninhvaries from 2,200 mm to 2,400 mm and mainly concentrates in July, August and September. These seasonal changes affect both mine water quantity as well as mine water quality.

The quantity of mine water reaches the highest values in the 3rd quarter of the year with up to 2 – 2.5 times for underground and 4 – 5 times for open pit mines in comparison with the 1st and the 2nd quarters. The mine water volume in the 3rd quarter is also higher than in the 4th quarter, up to 1.2 – 1.3 times for underground and 1.1 – 2 times for open pit mines. The average quantity of mine water in the rainy season is 1.33 – 2.05 times higher than in the dry season (VITE 2014).

The mine water quality in the rainy season is characterized by less acidity (pH) but higher contents of suspended solids (SS) and metals (Fe and Mn) as shown in Tab. 2.

Table 2 *Variations in raw mine water quality due to seasonal changes at VangDanh underground coal mine*

Items	pH	SS (mg/L)	Fe (mg/L)	Mn (mg/L)
Monitoring results from February to October 2015	5.2 - 7.4	39 - 210	4.07 - 13.33	0.71 - 2.42
Monitoring results after a big rain in August 2015	6.74	633	96.4	6.71

Aside from interdependent factors (Marcus 1997), the mine water quality in Quang Ninh is also influenced by the depth of mining and the geological conditions including endosmosis of surface water into galleries through fissures on the surface.

Mine water is discharged into rivers and small streams as well as directly into coastal waters of Ha Long Bay.

During a very long period (1955 – 1994) the mine water was discharged untreated into the environment and has impacted the receiving water courses seriously. In the period 1994–2009, mine water was treated using a very simple technique for mine water neutralization and sludge settling (Fig. 1). Other parameters were not treated at all.

As for many years, the domestic coal selling price in Vietnam was fixed below the actual coal production costs in order to prevent cost increases in some key industrial branches such as

power supply, cement, paper and fertilizer production, the coal mines were left without any profit. Therefore, internal financing for an improved mine water treatment in the coal mines was not available.

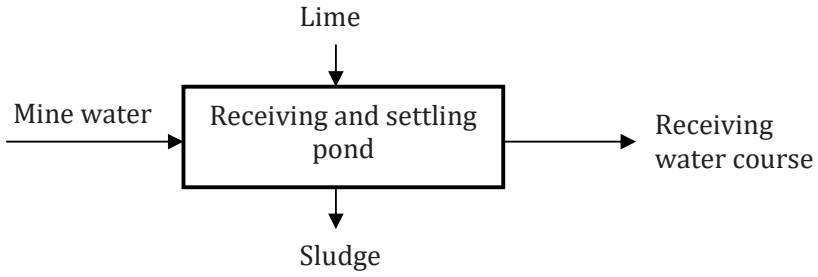

Figure 1 *Outline of mine water treatment before 2009*

Methods

A good combination of economic and technical solutions was necessary in order to achieve an effective solution for mine water treatment in Quang Ninh.

Setting up a financial source for mine water treatment

In 2009, the VINACOMIN Central Coal – Mineral Environmental Fund (VCEF) for investment into environmental measures including mine water treatment was established. The fund receives an annual financial contribution from all coal mining companies as a proportion of the coal production costs. Currently the rate is fixed at 1.5%. It is annually defined by the Members Board of VINACOMIN. The payment of contribution to VCEF is recognized under the coal production costs of every coal mining company. With regards to mine water treatment, VCEF is used for mine water treatment plants (MWTP) investment as well as the costs for maintenance of MWTP. Through the fund large as well as small mining companies get the chance to invest into environmental measures and especially mine water treatment solutions.

Furthermore, VINACOMIN set up a company specialized in environmental measures named Vinacomin - Environmental Company Limited (VEC) in order to enhance step-by-step the capacity through experiences made in the projects and to centralize the operation of mine water treatment plants in one unit. The company is responsible for the construction of MWTP as well as managing, operating and maintaining MWTP as a non-profit enterprise. The relation between the stakeholders in VCEF and their responsibilities are shown in Fig.2.

Adaptation of mine water treatment technology to seasonal variations

With the establishment of VCEF the first MWTP were implemented. The treatment steps consisted of neutralization and reaction, flocculation, sedimentation and manganese filtration (Fig. 3).

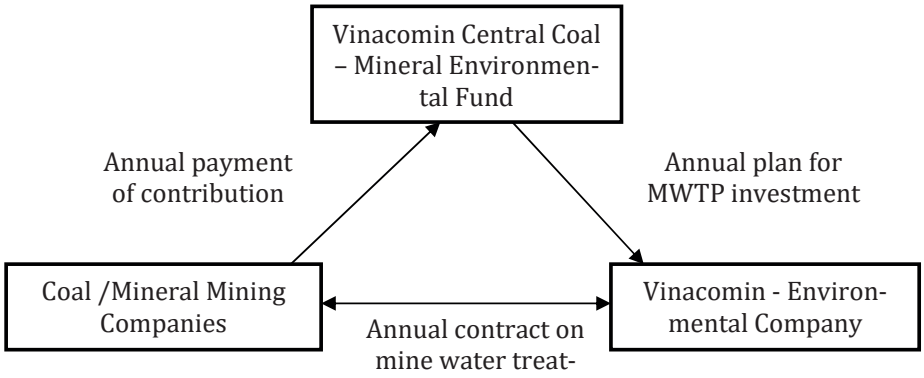

Figure 2 *Relationbetween the stakeholders in VCEF and their responsibilities*

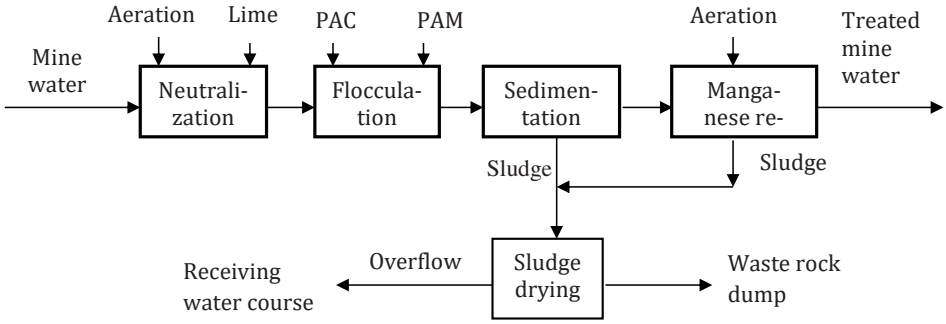

Figure 3 *Outline of mine water treatment applied for the first MWTP in the period 2009 – 2010 (Abbreviations: PAC –Poly Aluminium Chloride, PAM - Polyacrylamide)*

When taking the MWTP into operation, it was found that the seasonal variation of mine water quantity and quality leads to a very unstable operation of MWTP. The following factors are affected: (i) in the dry season the treatment capacity of the MWTP reached only 40 – 50% compared with its design capacity. In the rainy seasonthe MWTP were usually overloaded due to the large volumes of mine water which led to partial discharges of untreated mine water into receiving water courses. In some cases the MWTP were operated with 120 –160% of the design capacity during rainy season, which led to reduced treatment qualities. The treated water often did not fulfil the environmental standards. (ii) The design parameters of the technological process failed due to constantly changing mine water characteristics, which led to additional demand for treatment chemicals, such as lime, PAC, PAM. (iii) Increased sludge amounts and demand for equipment repairs due to overload led to increased operation costs.

One solution approach for quantity variation was the design of multiple treatment lines. While the first generation of MWTP (11 MWTP put in operation in the period of 2009 – 2010) was only designed with one treatment line the following MWTP had 2 – 4 parallel

treatment lines (Fig. 4) which can be operated independently. The number of treatment lines operated at the same time depends on the mine water volume. The operation of treatment lines in accordance with the seasonal volume of mine water led to a reduced consumption of energy and treatment chemicals. Furthermore, during dry season the treatment lines can be maintained easily without stopping operation (VITE 2014).

Figure 4 *VangDanh MWTP:capacity of 3,000 m³/h, designed with 3 treatment lines*

In an attempt to further homogenize the inflow to the MWTP with regards to quality and quantity equalizing reservoirs have been studied and applied. An equalizing reservoir is a reservoir constructed by reinforced concrete or natural stone masonry (Fig. 5). In some cases abandoned settling ponds of coal preparation plants were reused. The reservoir is located outside the boundaries of the MWTP near the points of mine water drainage. The main tasks of equalizing reservoirs are: (i) homogenization of different mine water sources before flowing to the MWTP, (ii) prevention of overflow of untreated mine water into receiving water courses during intense rainfall events, (iii) partial sedimentation of coal particles contained in raw mine water for a general reduction and homogenization of the suspended solids concentration in the input to the MWTP.

Figure 5 *Equalizing reservoir in Nui Nhen MWTP, Quang Ninh*

Equalizing reservoirs were designed and constructed based on the analysis of the mine water volume and the available area at the mine site. The minimum required volume of the reservoir is defined as the total volume of mine water discharged within 4 hours. If possible, the retention time should be increased to 8 or to the maximum of 12 hours in order to ensure that no untreated mine water is discharged into receiving water sources.

Through laboratory experiments it was found that the raw mine water from open pit mines reaches a suspended solids concentration in the reservoir outflow of 100 mg/L (allowed limit according to QCVN40, see Tab. 1) after a settling time of 1.5 to 2 hours. For raw mine water from underground mines the corresponding settling time with 2 to 3 hours is slightly longer. The settling of coal dust also affects the concentrations of Fe and Mn. For open pit mine water the concentration of Fe is decreased by ⅔ and for Mn by ½. For mine water originating from underground mines nearly no reduction in Fe and Mn concentrations was found (VITE 2014).

Results

The setup of the VCEF as source for investment into mine water treatment led to the construction of 41 mine water treatment plants in the Quang Ninh coal mining area between 2009 and 2015 where currently a total amount of 565,000 m³/day istreated. The total investment amounts to 47 million USD. In a period of only 6 years a mine water treatment ratio of 75% was achieved for the Quang Ninh coal mining area.

Based on the experiences made the general design for any new MWTP under the control of VINACOMIN includes an equalizing reservoir and 2 or more parallel treatment lines. The design follows the structure as shown in Fig. 6.

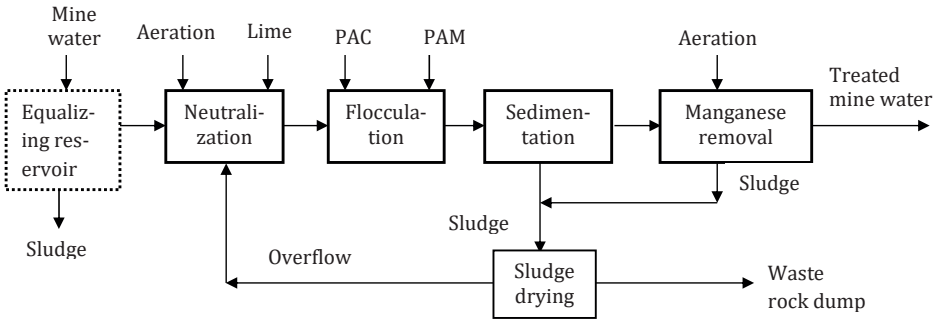

Figure 6 *Outline of mine water treatment with equalizing reservoir*

The 11 MWTP which were equipped with an equalizing reservoir showed an improved operation efficiency. Tab. 3 shows the example of Mao Khe MWTP (VITE 2014, 2015).

Table 3 *Operational efficiency of Mao Khe MWTP designed with a capacity of 1,200 m³/h, 2 treatment lines and an equalizing reservoir of 3,700 m³ which was added in 2012*

Items	2011	2012	2013	2014	2015	2016
Achieved max. monthly output [m³/h]	594	769	1,025	1,054	997	980
Achieved max. monthly output compared with the design capacity [%]	49,5	64,0	85,4	87,8	83,1*	81,7*
Consumption of Lime [g/m³]	no data	no data	200	200	190	170
Consumption of PAC [g/m³]	no data	no data	6	6	6	6
Consumption of PAM [g/m³]	no data	no data	1	1	1	1

* The operational efficiency decreased due to an extraordinary heavy rain event in Quang Ninh (1,600 mm within 10 days, July/August 2015) that flooded the whole MWTP. The repair works lasted until 2016.

Conclusions

Mine water and mine water discharge in the Quang Ninh coal mining areas were not controlled during a very long period. Although legal regulations for mine water treatment and quality standards for mine water discharge were in place, the mine operators did not comply with the regulations due to financial and technical constraints. Finally, the mining industry defined the target of 100% mine water treatment before discharge into water bodies and the issue became the top priority with regards to environmental measures.

The VINACOMIN Central Environmental Fund as a form of "joint responsibility" was an appropriate solution which has helped the coal mining companies in the Quang Ninh Coal Basin to overcome their lack of investment capacity. Nowadays, almost all coal mining companies in theQuang Ninh Coal Basin have been equipped with at least one MWTP, some mines even with two, such as the Mao Khe and the Nam Mau Underground Coal Companies. Seasonal changes of weather conditions and especially tropical rain events require special solutions in mine water treatment. If this is not taken into account, the treatment results cannot fulfil the environmental standards during operation. The combination of several parallel treatment lines with an additional upstream equalizing reservoir seems to be an appropriate solution for mine water management in Vietnamese coal mines.

The example on mine water management in Quang Ninh has shown that only the combination of suitable economic and technical solutions lead to a successful implementation of mine water treatment for all mines. Under the new regulations of the Law on Water Resources of Vietnam, the use of surface and underground water sources is controlled even more strictly. With an annual amount of tens of millions of cubic meters the treated mine water is an important potential reserve for the surface water resources in Quang Ninh.

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References

Kroll A, Amézaga JM, Younger PL and Wolkersdorfer C (2002) Regulation of Mine Waters in the European Union: The Contribution of Scientific Research to Policy Development. Mine Water and the Environment 21:193 – 200 © IMWA Springer-Verlag 2002

Doll B (2012) Mine Water Treatment Solutions for Discharge and Re-Use. Pall Corporation

Dvořáček J et al. (2012) Economics of mine water treatment, J. S. Afr. Inst. Min. Metall.vol.112n. 2Johannesburg

Bilek F, Broemme K, Stolpe H (2011) Active Treatment of Fe-, Mn- and coaldust contaminated Mine Water as Part of the RAME-Project in Vietnam. "Mine Water – Managing the Challenges" IMWA, Aachen, Germany

Marcus JJ (1997) Mining Environmental Handbook: Effects of Mining on the Environment and American Environmental Controls on Mining.Imperial College Press, London

Kurtz S et al. (2009) Treating Mine Water contaminated with Iron, Manganese and high solid Carbon Loads under Tropical Conditions.Securing the Future and 8th ICARD, June 23-26, 2009, Skelleftea, Sweden

Nippon Koei Co. (2014) Environmental Planning of Quang Ninh Province to 2020, vision to 2030, Final Report

VITE (2014) Project "Evaluation of the effectiveness of technology, techniques and management for the existing mine water treatment plants and orientations of application for the next ones" (Vietnamese)

VITE (2015) Project "Plan of treatment and reuse with mine water and surface water sources towards business and production purposes of VINACOMIN at Quang Ninh coal area" (Vietnamese)