Wastewater Management in Coal Mining Operations: A Geotextile-Based Semi-Active Treatment System in South Kalimantan, Indonesia

Adhika Catra Pradhana[1], Yudha Hadiyanto Eka Saputra[1]

[1]*Environmental and Reclamation Department, PT Borneo Indobara, South Kalimantan, Indonesia*

Abstract

High-TSS mine water at PT Borneo Indobara reduces pond capacity and increases sludge handling demand. This study evaluated an integrated geotextile pool and geotextile tube system under field conditions. Fine-grained sludge was characterized by high silt-clay content. The geotextile pool reduced TSS from 92,340–150,110 mg/L to 6,424–9,307 mg/L, while the geotextile tube reduced TSS from 6,016–8,386 mg/L to 55–149 mg/L. The pool reached specific gravity 1.40 after 14 d, whereas the tube reached 1.45 after 29 d. Both systems showed complementary roles in sludge dewatering.

Keywords: Mine water, sludge dewatering, geotextile tube, geotextile pool, TSS, coal mining

Introduction

Mine water management remains a major operational and environmental challenge in open-pit coal mining, especially in tropical regions with high rainfall and fine-grained overburden. Runoff from disturbed mine surfaces transports large amounts of suspended solids into treatment ponds, reducing hydraulic retention time and accelerating sediment accumulation. Under these conditions, conventional sediment ponds must treat water and store sludge simultaneously, which lowers their operational efficiency.

In Indonesia, mine water discharge must comply with regulatory limits, including a maximum TSS concentration of 200 mg/L before discharge to natural waterways. At PT Borneo Indobara, South Kalimantan, runoff from mining areas within the Warukin Formation commonly contains very high suspended solids. Fine-grained materials derived from siltstone, claystone, mudstone, and coal-bearing strata contribute to rapid sludge accumulation in ponds and increase maintenance demand (Jamal *et al.* 2021).

Previous work from the same regional setting described quartz, kaolinite, illite, and occasional pyrite as common minerals in clay-rich materials, with SiO_2 and Al_2O_3 as dominant oxides and Fe_2O_3 and CaO also present (Sira *et al.* 2021). Those findings are consistent with the field character of sludge observed in the present study.

Geotextile-based dewatering systems are increasingly used to reduce sludge volume before final disposal or further handling. Geotextile tubes are commonly used as confined filtration units, especially when combined with polymer conditioning (Muthukumaran and Ilamparuthi 2006). At IMWA 2017, Kim and Kim (2017) reported that geotextile tubes, geotextile bags, and gunny bags could be used for mine drainage sludge dewatering through flocculation and self-filtration, and that sludge characteristics strongly influenced dewatering behaviour. Geotextile-lined pools can serve as open dewatering basins with simpler operation and easier excavation. Field-scale information comparing their operational roles within one integrated treatment train is still limited in coal mine water management.

This study aimed to evaluate the field performance of an integrated geotextile pool and geotextile tube system for sludge handling in high-TSS coal mine water treatment at PT Borneo Indobara. The objectives were to: (1) characterize sludge properties along the treatment train, (2) evaluate TSS reduction by both geotextile systems, (3) assess dewatering behaviour using specific gravity, water content, and solid content, and (4) describe the operational role of each method in the treatment sequence.

Methods

Site Description and Treatment Process

The study was conducted at PT Borneo Indobara, an operating open-pit coal mine in South Kalimantan, Indonesia. Water and sludge from active mining areas are collected in a sump area and pumped to Karuh Pond. From there, slurry enters a geotextile-based treatment stage before passing to Sediment Pond 06 GRM and then being discharged to the receiving stream (Fig. 1).

Two geotextile systems were used in complementary roles. A geotextile pool was operated as an open pre-treatment and bulk dewatering unit without chemical addition. A geotextile tube system was operated as a secondary dewatering unit with polymer injection. In the geotextile tube arrangement, sludge was pumped from Sediment Pond 06 GRM through a dredging pump and booster pump to a mixing chamber. Polymer solution was prepared in a dosing unit using recycled filtrate water and injected into the mixing chamber during pumping. The conditioned slurry then flowed through a DN350 HDPE PN 16 pipeline into geotextile tube bags (Fig. 2).

Sludge Sampling and Characterization

Sludge samples were collected from the sump area, Karuh Pond, and Sediment Pond 06 GRM. A total of 9 samples (Tab. 1) were analysed for natural water content, specific gravity of solids, wet density, dry density, void ratio, saturated density, submerged density, degree of saturation, and grain-size distribution.

Specific gravity was measured using a density cup. Water content was calculated from the ratio between wet sample mass and oven-dried sample mass after drying at 105 °C. Grain-size analysis followed ASTM procedures. TSS was measured using a Hach DR900 instrument following the manufacturer's method and applicable international standard practice.

Geotextile Pool

The geotextile pool functioned as an open dewatering basin without chemical addition. One pool had a radius of 16 m and a height of 2.5 m, with a solid capacity of up to 1,500 m^3. The operational target was specific gravity (SG) 1.40, at which the material could be blended and excavated. Under field operation, this condition was reached after 14 d.

The geotextile pool used nonwoven polypropylene geotextile with a nominal mass of 300 g/m^2. The characteristic opening size was 0.12 mm. Manufacturer data indicate a permittivity of 0.4393 s^{-1}, UV resistance of 70%, tensile strength of 14.20 kN/m in the machine direction and 30.10 kN/m in the cross direction, and puncture resistance of 3,160 N.

During operation, slurry from the upstream treatment stage was pumped into

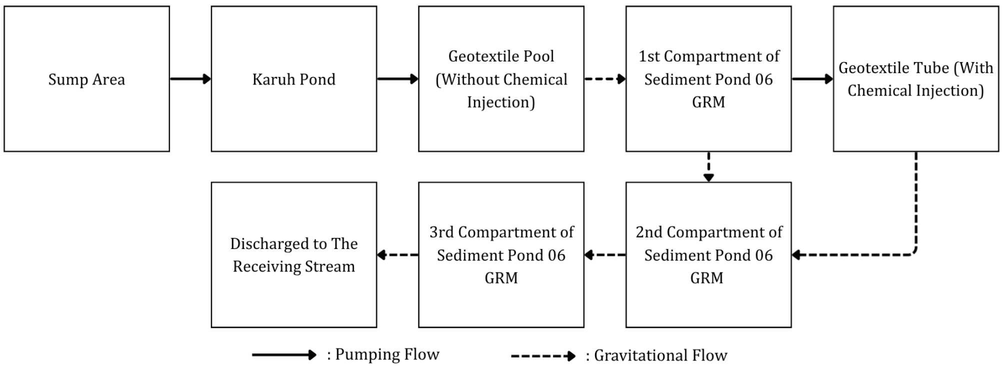

***Figure 1** Integrated mine water treatment train from sump area to discharge area.*

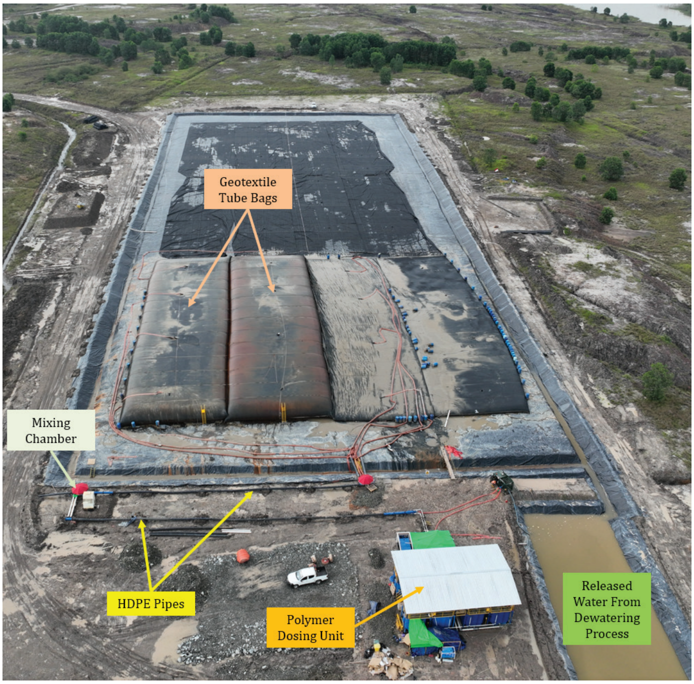

Figure 2 *Geotextile tube operating arrangement.*

the geotextile pool over one filling period. No flocculant or other chemical additive was introduced into this system. Solids settled and accumulated within the lined basin, while water gradually discharged through the geotextile and by surface drainage under gravity. Because the pool was fully exposed to field conditions, its dewatering behaviour was influenced by rainfall, evaporation, drainage capacity, and the progressive self-weight consolidation of the deposited sludge mass.

Geotextile Tube

The geotextile tube functioned as a confined secondary dewatering unit with polymer conditioning. Each tube had dimensions of 61.4 m × 18.3 m and a maximum height of about 2.4 m. One layer consisted of 12 bags. The operational target for stacking was SG 1.45, which was reached after 29 d.

The geotextile tube used woven polypropylene geotextile GT500D. Material properties provided by the manufacturer include an opening size of 0.3 mm, water permeability of 25 L/m^2/s, tensile strength of 100 kN/m in the machine direction and 125 kN/m in the cross direction, CBR puncture strength of 10 kN, and seam strength of 75 kN/m.

After the pumping stage, the geotextile tube entered a relaxation or passive dewatering stage. During this period no additional slurry was pumped, and the retained material was allowed to consolidate under self-weight while water continued to discharge through the geotextile. SG, water content, and solid content were monitored over time in order to assess densification of the sludge mass. Unlike the geotextile pool, the operational criterion for the geotextile tube was not excavation readiness but stacking readiness. The target condition was SG 1.45, which represented a denser and more stable sludge condition suitable for supporting a second layer. Under the monitored field conditions, this criterion was reached after 29 d.

Polymer Dosing and Operating Records

The geotextile tube system used Flopam AN 934 SH as flocculant. Polymer was blended with recycled filtrate water in the dosing system and injected into the mixing chamber during pumping. Daily records included flow rate, influent TSS, chemical consumption, daily slurry volume, chemical dosage per cubic metre of slurry, and filtrate TSS.

Monitoring Datasets

Geotextile pool performance was evaluated using 10 single observations collected within one pumping batch on the same day at different hours. Each observation included influent TSS, influent SG, flow rate, and effluent TSS.

Geotextile tube performance was evaluated using 30 single observations collected from 12 bags in layer 1 on different dates during one month of operation. One zero-flow day was excluded from efficiency calculations because no slurry entered the system. Daily dewatering after the pumping stage was monitored separately using SG, water content, and solid content, together with rainfall.

The datasets represent operational field observations rather than replicated laboratory experiments. Therefore, the reported mean and standard deviation values describe field variability under actual operating conditions, including changes in flow rate, sludge condition, rainfall, and bag operation. No statistical hypothesis testing was conducted, and the comparison between systems is interpreted as a field-performance evaluation rather than a controlled experimental comparison.

Data Analysis

TSS removal efficiency was calculated as:

$$\eta = \frac{C_{in} - C_{out}}{C_{in}} \times 100$$

where C_{in} is influent TSS and C_{out} is effluent TSS. Mean, standard deviation, and range were calculated for the main TSS datasets to describe field variability. Since the observations were operational field measurements rather than replicated laboratory trials, the results are interpreted as field-performance indicators.

Results and Discussion

Sludge Characteristics

The sludge was dominated by fine material. Gravel was negligible, sand was minor, and most samples consisted mainly of silt and clay. Passing No. 200 values were generally high, commonly exceeding 90%. These results indicate that the treatment train handled fine-grained sludge that would be difficult to settle efficiently in conventional ponds alone. The observed particle-size distribution is consistent with clay-rich detrital material derived from the Warukin Formation.

Geotextile Pool Performance

The geotextile pool received highly concentrated sludge, with influent TSS ranging from 92,340 to 150,110 mg/L. Effluent TSS ranged from 6,424 to 9,307 mg/L. Mean influent TSS was 107,286.4 ± 19,753.0 mg/L, while mean effluent TSS was 7,424.4 ± 992.4 mg/L. Average TSS removal efficiency was 93.02 ± 0.46% (Tab. 2).

These results show that the geotextile pool acted effectively as a bulk solids reduction unit without chemical addition. Although the effluent remained above the final discharge criterion, the pool substantially lowered solids loading before downstream treatment. That role makes it suitable as a pre-treatment and dewatering step rather than a final polishing unit.

Geotextile Tube Performance

The geotextile tube treated slurry with influent TSS ranging from 6,016 to 8,386

***Table 1** Summary of sludge physical and grain-size characteristics by sampling location.*

Sampling Location	n	Water Content (%)	Gs	Silt (%)	Clay (%)	Passing No. 200 (%)
Sump Pit	3	13.19 ± 1.90	2.63 ± 0.01	46.98 ± 1.93	44.77 ± 5.20	91.76 ± 3.39
Karuh Pond	3	15.09 ± 5.08	2.59 ± 0.09	39.56 ± 3.10	38.66 ± 18.07	78.22 ± 19.04
Sediment Pond 06 GRM	3	13.72 ± 4.12	2.63 ± 0.04	30.88 ± 1.28	67.17 ± 2.46	98.05 ± 1.80

mg/L, excluding the zero-flow day. Filtrate TSS ranged from 55 to 149 mg/L. Mean influent TSS was 6,992.9 ± 653.6 mg/L, and mean effluent TSS was 100.9 ± 27.6 mg/L. Average TSS removal efficiency was 98.56 ± 0.34% (Tab. 2).

These results show that the geotextile tube produced much cleaner filtrate than the geotextile pool. Filtrate remained below 200 mg/L during valid monitored observations. The combined effect of woven confinement and polymer conditioning appears to be responsible for this low filtrate TSS. In operational terms, the geotextile tube served as a secondary dewatering and polishing unit.

Dewatering Cycle and Sludge Condition

The water content values in Tab. 1 are lower than those shown in Fig. 3 because they represent different material conditions. Tab. 1 summarizes laboratory characterization results from collected sludge samples, whereas Fig. 3 shows the evolution of water content in the bulk sludge mass during post-filling dewatering. Immediately after pumping, the sludge body remained highly saturated and contained large amounts of pore water, resulting in initial wet-basis water contents above 60% in both systems. This behaviour is consistent with the fine-grained nature of the sludge, which is dominated by silt and clay fractions and therefore retains water strongly. During the relaxation stage, drainage and self-weight consolidation progressively reduced water content and increased solids concentration. The geotextile tube reached a lower final water content than the geotextile pool because polymer conditioning, confined geometry, and longer dewatering time promoted denser final sludge formation.

The observed dewatering behaviour can be explained by three main mechanisms: filtration, flocculation, and consolidation. In the geotextile pool, solids were retained mainly through settling and filtration by the nonwoven geotextile layer, while water discharged by gravity and surface drainage. Because no polymer was used, fine clay-silt particles were more likely to remain dispersed, which explains why the pool reduced bulk solids effectively but still produced higher effluent TSS than the tube. In the geotextile tube, polymer conditioning promoted flocculation before the slurry entered the bag. Larger flocs were more easily retained by the woven geotextile and by the filter cake formed inside the tube. After filling, self-weight consolidation gradually reduced water content and increased solid content. This process is consistent with previous observations that sludge characteristics and polymer-assisted self-filtration influence geotextile tube dewatering performance (Kim and Kim 2017; Muthukumaran and Ilamparuthi 2006).

Post-filling monitoring showed different operational cycles for the two systems. The geotextile pool reached SG 1.40 after 14 d, which was the criterion for blending and excavation. At that stage, water content was 53.57% and solid content was 46.43% (Fig. 3).

The geotextile tube required 29 d to reach SG 1.45, which was the criterion for stacking. At that stage, water content was 49.57% and solid content was 50.43% (Fig. 3). The tube therefore required a longer dewatering period, but it produced denser final solids than the pool.

Differences in operating cycle indicate that the geotextile pool is more suitable for faster excavation readiness, whereas the geotextile tube is more suitable for staged stacking and higher final solids concentration. Rainfall during the monitoring period did not prevent gradual densification in either method, although short plateaus in SG and water content were observed.

Table 2 *TSS reduction performance of geotextile pool and geotextile tube.*

System	n	Influent TSS mean ± SD (mg/L)	Influent TSS Range (mg/L)	Effluent TSS mean ± SD (mg/L)	Effluent TSS Range (mg/L)	Removal efficiency (%) mean ± SD
Geotextile pool	10	107,286.4 ± 19,753.0	92,340–150,110	7,424.4 ± 992.4	6,424–9,307	93.02 ± 0.46
Geotextile tube	29	6,992.9 ± 653.6	6,016–8,386	100.9 ± 27.6	55–149	98.56 ± 0.34

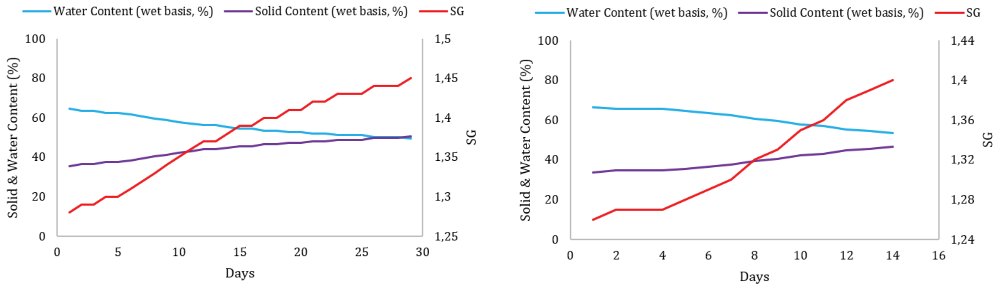

Figure 3 *Changes in specific gravity (SG), water content, and solid content during post-filling dewatering for the geotextile tube (left) and geotextile pool (right).*

Operational Role of Both Systems

The two systems are best understood as complementary rather than competing. The geotextile pool handled very high TSS feed and reduced solids loading rapidly, which supports its use as an open pre-treatment and bulk dewatering unit. The geotextile tube generated lower filtrate TSS and denser solids, which supports its use as a secondary dewatering unit after initial solids reduction.

From an operational perspective, the integrated system can reduce sludge-management-related cost by up to 44% compared with a conventional approach. Absolute cost values are not presented because of company confidentiality. This cost reduction is associated with lower solids loading to the main treatment ponds, reduced sludge handling frequency, and better control of concentrated material.

Conclusions

This study evaluated an integrated geotextile pool and geotextile tube system for field-scale sludge handling in high-TSS coal mine water treatment at PT Borneo Indobara.

The sludge was dominated by fine silt-clay material, which explains the difficulty of relying on settling ponds alone. The geotextile pool reduced TSS from 92,340–150,110 mg/L to 6,424–9,307 mg/L and provided an average removal efficiency of 93.02%. The geotextile tube reduced TSS from 6,016–8,386 mg/L to 55–149 mg/L and provided an average removal efficiency of 98.56%.

The geotextile pool reached excavation readiness after 14 d at SG 1.40, while the geotextile tube reached stacking readiness after 29 d at SG 1.45. Final solids concentration was higher in the tube system than in the pool system. These observations show that the geotextile pool is suitable for faster bulk dewatering and excavation, whereas the geotextile tube is suitable for lower filtrate TSS and denser final solids. Integrated use of both systems provides a practical field-scale approach for mine water sludge management under high TSS conditions.

Acknowledgements

The authors thank PT Borneo Indobara for operational support, field access, and technical data used in this study. Appreciation is also extended to site personnel involved in sampling, monitoring, and field operation.

References

Jamal J, Rijani S, Maryanto S, Cita A (2021) Clay minerals identification on Warukin Formation at Kandangan area, South Kalimantan Province based on ASD testing method. Jurnal Geologi dan Sumberdaya Mineral 22:1–7

Kim DM, Kim DK (2017) Assessment of dewatering process using flocculation and self-filtration according to the characteristics of mine drainage sludge. In: Wolkersdorfer C, Sartz L, Sillanpää M, Häkkinen A (eds), Mine Water and Circular Economy, IMWA 2017, Lappeenranta, Finland, pp 1178–1184

Muthukumaran AE, Ilamparuthi K (2006) Laboratory studies on geotextile filters as used in geotextile tube dewatering. Geotextiles and Geomembranes 24(4):210–219

Sira R, Sufriadin, Widodo S, Jaya A (2021) Analisis mineral matter dan kualitas batubara Blok Batulaki, Kecamatan Satui, Kabupaten Tanah Bumbu, Provinsi Kalimantan Selatan. Jurnal Geomine 9:206–217