Partners in Sustainability: The Benefits of a Collaborative Relationship Between a Mine, Consultant, and Supplier in Water Management

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Abstract

Water treatment in mining is crucial for environmental sustainability, as untreated water can harm ecosystems, which can affect permitting. A Swedish metal mine exemplifies innovation and collaboration in tackling water treatment challenges. Key elements of concern include metals, which seems common yet is complex for efficient application. Designing of an effective process involves selecting appropriate precipitation mechanisms and solids removal technologies, which has proven to be effective and robust for the presented case study, delivering high-quality effluent. By adopting proactive strategies, mining companies can ensure sustainable, efficient, and environmentally responsible operations, serving as models for others in the industry.

Keywords: Metal precipitation, synergy, water treatment

Introduction

In Sweden, many mines operate under outdated environmental permits or are in interim periods while awaiting new ones. When applying for new permits, mines commit to feasibility studies and water testing while adhering to provisional conditions. The regulatory framework involves multiple authorities and stakeholders who can provide input on water quality before the environmental court makes a decision. Environmental Quality Standards (EQS) are crucial in guiding efforts to ensure functionality and preservation of ecosystems, which often requires water quality improvements. The principle of non-deterioration mandates that the current status of water bodies must not worsen. Regulatory changes aim to align with these standards and address evolving environmental impact understandings, promoting sustainable mining practices.

In this case study, the mine was enhancing the treatment of existing tailings and clarification ponds in response to the provisional conditions entering in 2015. Thus, the mine began adding caustic soda to the tailings pond to precipitate metal hydroxides, which were then settled out in the clarification pond. However, in 2017, the mine effluent was experiencing non-compliances to the permit requirements, most specifically during higher flows and colder water periods.

This was the starting point to the formation of a partnership, bringing together the client, a consultant, and a technologies supplier to develop a sustainable solution also compliant with requirements from regulators and local community. The objective of the partnership was to fix and follow a comprehensive timeline of approximately five years, which included stages such as the preliminary feasibility study (PFS), trials, feasibility study (FS), definitive feasibility study (DFS), design and build phases, and commissioning, in implementing a robust and compliant water treatment strategy with limited waste management requirement and limited chemical dosing requirement to ensure flexibility of the treatment plant over time and it sustainability.

The overview of the project workflow presented in this case study is illustrated in Figure 1.

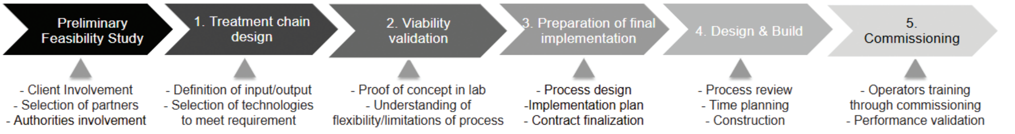

Figure 1 *Overview of the project workflow.*

Definition of the project- Preliminary Feasibility Study

In the process of selecting parties for the design of the water treatment system, a collaborative approach was adopted involving the client, the consultant, and the technologies supplier from early on. The mining company sought a partner capable of delivering a comprehensive turnkey solution, which included civil engineering, piping, machinery, electrical systems, and automation, while excluding programming and groundwork, in which the client wanted to be actively involved.

The selection of the partners was based on key criteria, including a proven track record and robust technical support capabilities. The client prioritized a consultant with extensive experience in industrial projects within Sweden and a good knowledge of local regulations. The consultant required a well-established network and partnered up with a technologies supplier familiar with the mining sector with relevant references. The work ethics of both partners was also important, to ensure alignment of the client's engagements on social and environmental performances.

The objective of collaboration early in the project timeline is to allow the client, consultant and supplier to work closely together, giving each the possibility to fully contribute to their expertise in developing the most effective solution. The stability in the design team also allows a solid understanding of the project through entire timeline, reducing risks of schedule and budget slips.

Furthermore, through the complete duration of the project, and in compliance with Swedish authorities (Geological Survey of Sweden (SGU) and Swedish Agency for Marine and Water Management (HaV)), the mining operation was required to monitor an extended list of parameters. This follow-up was integrated into the planning and execution process, ensuring that the solution met not only the current regulatory standard, but plan ahead for future needs.

Step one: Treatment chain design- Preliminary Feasibility Study

The first step of this process is the determination of what should be expected on the site and what the required output of the water treatment plant are. The information used for the design of the system, in collaboration with the consultant and the technologies supplier, are summarized in Table 1. Criteria (in brakets) are future targets and are not regulated on the actual permit.

The parameters of concern are metals. Several precipitation mechanisms are available to achieve metal removal. The main precipitation mechanisms seen in such application are the following:

- Hydroxide: metal hydroxide is the simplest precipitation mechanism. It relies on the pH of the solution to precipitate the metal to hydroxides (OH^-), mainly in alkaline conditions. Hydroxides precipitation has a fast kinetic and only requires alkali dosing and pH control. Its main limitation is its sensibility to pH as it impacts the solubility of the precipitate, thus the efficiency of the metal removal (Lewis, 2010). This could also lead to metals leaching out of sludge. The efficiency of hydroxide precipitation depends on the solubility of its precipitate, which does not allow to steadily reach µg/L levels (Kurniawan, 2006).
- Sulfide: sulfide precipitation relies on the addition of a sulfide source to bind metals and form precipitates. Sulfide chemistry does not rely as much on pH (Lewis, 2010), but pH should be monitored to prevent hydrogen sulfide gas release. The main drawbacks from sulfide precipitation is

Table 1 *Influent composition of the mine effluent water and regulatory limitation.*

Parameters	Units	Mine Effluent Average	Water Quality Design	Regulation – Criteria Monthly Average
pH	–	7.8	6.0 – 8.0	6.5 – 8.5
Temperature		7	2 - 22	–
Total Suspended Solids (TSS)	mg/L	12	1000	5
Chloride	mg/L	34.7	–	–
Total Calcium (Ca)	mg/L	248	450	–
Sulfate (SO_4)	mg/L	1.3	–	–
Total Arsenic (As)	mg/L	0.015	0.090	(0.010)
Total Cadmium (Cd)	mg/L	0.0014	0.0047	0.0005
Total Copper (Cu)	mg/L	0.0064	0.028	0.010
Total Lead (Pb)	mg/L	0.154	1.30	0.060
Total Nickel (Ni)	mg/L	0.028	0.090	(0.020)
Total Zinc (Zn)	mg/L	0.800	1.70	0.400

the toxicity of its residual in water, as well as its colloidal precipitates. A performant clarification step must be implemented to capture these fine precipitates. The main advantage of sulfide precipitation is its very low solubility, making it attractive in low metal concentration effluent (Lewis, 2010).

- Surface complexation: surface complexation is an adsorption mechanism. It relies on the adsorption of the metal of concern on a charged metallic surface. The metallic surface is formed using a metallic coagulant, mostly ferric iron, and is called ferric oxyhydroxide. It is a transitional crystal formed during iron precipitation of the form Fe_2O_3 x H_2O (Randall, 1999). Once oxyhydroxide is formed, according to the pH of the solution, it is either charged positive for oxyanions removal, or negative for metal removal. The main advantage of surface complexation is the absence of a solubility limitation. As long as there is binding surfaces available, metals will be adsorbed and captured. However, it is highly pH dependant; sludge management must prevent pH drifts to prevent metals leach.
- Phosphate precipitation: phosphate precipitation is effective for metal removal. However, it is useless for arsenic removal. It is also susceptible to delayed onset of precipitation, and increase the phosphorus discharge to the environment, which when not regulated is a source of eutrophication in the environment. Given that other precipitation mechanisms are unaffected by these problems, phosphate precipitation was not considered.

In the case of the Swedish mine, the metals of concern are zinc, cadmium, copper and lead. Arsenic and nickel are also expected to be added to the regulation to a further date. The main elements of concern for the metal precipitation step were the following:

- Very low criteria: most of the hydroxide solubilities are over the criteria. Therefore, this mechanism is not enough; it must be combined to other mechanisms.
- Several metals to be removed: metal hydroxides and surface complexation both relies on the pH to precipitate/adsorb the right metals. For surface complexation, fair removal can be achieved for all the main contaminants of concern at a slightly alkaline pH. However, adding arsenic removal, it cannot cover oxyanions and metals in a single stage.

The metal precipitation mechanisms selection is based on several considerations; the central point of focus is the limitation on the number of stages required to address all the metals of concern and providing flexibility for future requirements. Stability of the sludge as well as limitation of the sludge production is also considered in the selection of the precipitation mechanisms, to a lesser extent as it was not designated as a priority concern. The selected design was a combination of hydroxide precipitation and surface complexation until permit modification. Contingencies to add sulfide precipitation was included in the design to cover its addition to support metals and arsenic removal at a later date.

Once the metals out of solution, care must be taken for the solids separation step. Regulations are mainly based on total metal concentrations, thus adequate removal of the particulate metals is essential. The level of solids separation efficiency required must be evaluated to reach the balance between performance and cost. Therefore, the design must consider the following:

- Expected flow variations: fluctuating water composition as well as fluctuating flows require operation adjustment to the solid separation system. Conventional clarifiers, with long retention times, operate best in steady conditions and could be negatively impacted by sudden variations. Short retention time reacts faster and thus are favourable in applications with important turndowns.
- Efficiency to capture metal precipitate: sulfide precipitates require a cohesive chemical conditioning to efficiently capture these through the solid separation step.
- Particulate metals versus inert suspended solids: the higher the inert solids are, the lower is the metallic fraction in total solid load. The solids separation system let solids out to effluent no matter which. The higher the metallic precipitate fraction is, the higher will be the particulate metal concentration, and thus total metal concentration, at final effluent.
- Solids load: mine effluent solid load and precipitates generated in the metal precipitation step must be handled by the solids separation step. Systems such as ballasted flocculation requires customization to operate at higher extraction rate for very high solids loads, while clarifiers such as clarifier/thickener thrive in higher solids load conditions.
- Footprint availability.

For the Swedish mine, the metal criteria are stringent but not prohibitive to physico-chemical approaches. The treatment chain is been installed between a tailing pond and a clarifier pond, resulting in a low inert solids load and a limited footprint availability. The site location also lead to seasonal and fluctuating flows. The selected technologies in this application were ballasted flocculation, for its efficiency in tight space and its quick response in varying conditions, combined with a discfiltration polishing which provides over 50% removal of remaining solids out of the clarified water. In order to optimize the ballasted flocculation step and efficiently implement surface complexation, part of the sludge extracted is recirculated back to the metal precipitation step, allowing sufficient retention time for oxyhydroxide formation in a limited footprint.

To increase the robustness of the proposed treatment chain, sludge management is also key. Due to the selection of combined hydroxide precipitation and surface complexation, the sludge must be managed against leaching. Sludge out of the ballasted flocculation is sent directly to a centrifuge for dehydration. The dry cake falls into a container to be moved to the tailings for final disposal and centrate is sent back to the metal precipitation reactor, for zero liquid discharge.

The flow diagram of the water treatment plant for the Swedish mine is illustrated in Figure 2.

Step 2: Viability validation- Trials and Feasibility Study

Bench-scale tests has been carried out by the technologies supplier, using water from the site, to understand the capabilities of proposed treatment chain. The tests have been carried out at different pHs and using different coagulant dosages, as well as testing additional flexibility of the treatment by addition of a sulfide source. Results of interest from these tests are presented in Table 2. All metal concentration results are from an external accredited laboratory. The selected sulfide source is Hydrex 6909, a carbamate-based metal chelatant. Criteria (in brackets) are future targets and are not regulated on the actual permit. All criteria are as monthly averages.

Early involvement of the technologies supplier in the design team increases the understanding of the process capability at full-scale application. For this particular

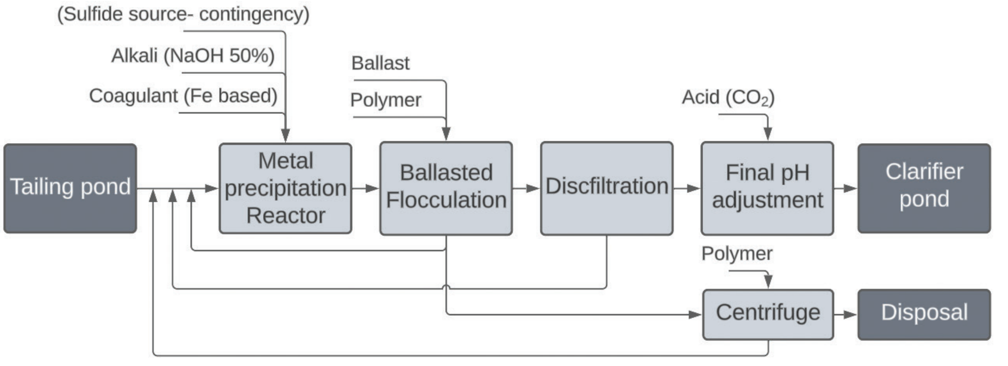

Figure 2 *Treatment chain flow diagram.*

application, results from the laboratory tests has shown compliancy to all criteria operating at pH 9.0, with a low chloride ferric concentration. The addition of carbamate has shown good performances at a lower pH (pH= 8), increasing the efficiency of the overall treatment efficiency, thus allowing for additional flexibility of treatment plant if needed. The laboratory testing can also be used for an operation cost (OPEX) estimation of ±30%, providing understanding of the chemistry of the mine effluent.

Step 3: Preparation of final implementation- Definitive Feasibility

Once the process chain has been validated and its flexibility capabilities better defined by the technologies supplier, detailed engineering could carry-on. At this stage, lists (equipment, instruments, valves), P&ID, layouts and process design are worked in collaboration of all parties.

End result of this step is a precise process treatment with an implementation plan. At this stage, estimation of the capital costs (CAPEX) and operating costs (OPEX) within ±10% is available. The client signs a contract of delivery with the consultant, acting as a contractor. Once the contract is finalised between the parties for execution of the project, the design and build step is initiated.

Step 4: Design and build

The first part of the design and build step is the process reviews and construction preparation. During this phase, effective communication between the client, consultant, and technologies supplier is essential; in-person and virtual meetings were conducted to finalize the design of the process train and the architectural aspects of the building, to align details prior to construction.

After finalizing process reviews and construction preparation, the client initiated the groundwork. To avoid concrete work during the winter months and prevent any kind of downtime on the construction site, the project schedule was carefully managed. Detailed design work was largely completed during the definitive feasibility study phase, ensuring that construction proceeded

Table 2 *Main results from the laboratory testing for risk mitigation of the water treatment plant.*

	Coagulant dose mg Fe/L	Sulfide dose mL/L	pH	Total As µg/L	Total Cd µg/L	Total Cu µg/L	Total Pb µg/L	Total Ni µg/L	Total Zn µg/L
Criteria				**(10)**	**0.5**	**10**	**60**	**(20)**	**400**
RW	–	–	7.5	4.42	0.21	0.744	13	11.1	1 160
Test 3	5	–	9.08	1.93	< 0.01	0.418	1.91	6.67	87.4
Test 4	5	–	8.02	2.2	0.0281	0.377	3.11	10.5	528
Test 7	10	–	9.03	1.45	< 0.01	0.402	1.52	5.78	60.8
Test 20	5	0.1	8.04	1.76	< 0.008	< 0.1	0.424	0.59	39.9

smoothly. The main focus at this stage is on time completion. This efficient planning allowed for the timely installation of all necessary equipment, ensuring the project schedule stayed on track.

Step 5: Commissioning

Commissioning of the plant was successfully completed by the staff from the mine, the consultant and the technologies supplier. Operators of the plant were hired by the client prior to construction and they were trained all through construction of the plant. They were also an active part of the commissioning alongside the consultant and technologies supplier. Commissioning is not yet completed, but preliminary results are showing complete compliance of the treatment chain, as shown in Table 3. Results are presented as dissolved metals, to give better appreciation of the process variation with fluctuating pH of operation. Total metal concentrations criteria (monthly average) are also presented for reference. pH compliance is not considered as the water quality is measured prior to final pH adjustment. Criteria (in brackets) are targets and are not regulated yet.

Results from commissioning shows great performances of the water treatment chain even if the process is not tuned in yet. It is interesting to note that operation at pH < 8.5, without sulfide addition, results in higher metal concentration for zinc, lead and cadmium. These metals were showing great removal with sulfide precipitation during bench test at pH 8.0 (refer to Table 2).

Key Insights

The main conclusions and implications from the collaboration are as follows:

- Effective Collaboration: Strong cooperation across all stages and disciplines, such as project managers and process specialists, among the three parties facilitated problem-solving and maintained project momentum over the five-year period. Collaboration of all parties had also strengthened validation of the process, understanding of it and identification of its limitations.
- Achievements: The project delivered a high-quality plant with an excellent working environment and robust process solutions, due to the practical experience of all parties in consulting, design, construction, supply, commissioning, and operation.
- Success Factors: The project's success was driven by a collaborative approach from the outset, supported by a fixed-price agreement. Regular meetings ensured alignment and prompt issue resolution.
- Areas for Improvement: Allocating more time for the design phase would have benefited the integration of internal components like ventilation, piping, and electrical systems. Extending the design phase by two months due to initial delays proved advantageous, underscoring the need for adequate planning time.

***Table 3** Preliminary performance of the treatment chain through commissioning.*

	TSS mg/L	pH	Diss. As µg/L	Diss. Cd µg/L	Diss. Cu µg/L	Diss. Pb µg/L	Diss. Ni µg/L	Diss. Zn µg/L
Criteria	**5**	**–**	**(10)**	**0.5**	**10**	**60**	**(20)**	**400**
2024-12-09	1.2	7.2	0.97	0.032	0.42	0.21	2	4.2
2024-12-16	1.1	8.6	0.88	0.02	0.44	0.038	1.8	3
2024-12-20	5.3	7.6	1.4	0.068	0.32	0.33	2.7	76
2024-12-27	5.2	7.6	1.3	0.11	0.47	0.83	2.3	79
2025-01-02	1.3	8.4	0.69	0.04	0.51	0.13	1.5	3.2

Conclusion

The case study highlights the advantages of a collaborative and structured approach in developing a robust and flexible water treatment plant. The project adeptly addressed regulatory and technical challenges through effective communication and cooperation among the client, consultant, and technologies supplier. The project delivered a high-quality plant, benefiting from the practical experience and expertise of all parties involved. This collaborative approach ensured alignment and facilitated problem-solving, highly contributing to the project's success.

Nonetheless, the experience revealed areas for improvement, particularly in allocating adequate time for the design phase. Lessons learned offer valuable insights for future projects, highlighting the importance of comprehensive planning and strong partnerships to achieve sustainable mining practices that protect aquatic ecosystems.

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