Water Management and Treatment for the Copperwood Mine Project

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Abstract This paper will discuss the water treatment planning and engineering for a mining project in the Upper Peninsula of Michigan. This has included completion of a detailed probabilistic simulation of the water management system coupled with a geochemical model to predict the final water quality to be treated in the water treatment facility. One of the stated goals for the project is to minimize discharge from the site and reuse water to the extent practical. However, if discharges from the site are required, they must comply with NPDES permit requirements as outlined in the Part 57 rules in Michigan.

Keywords tailings water treatment, mercury, water reuse

Introduction

Mining in the Upper Peninsula has experienced a resurgence in interest the past five years with multiple projects in the process of being permitted and constructed. Orvana Resources signed mineral leases in the fall of 2008 and 2010 for a proposed silver-copper mine for property near the Michigan-Wisconsin boarder on the shores of Lake Superior. Positive Prefeasibility and Feasibility Studies have been completed and a Part 632 Mining Permit has been received from the State of Michigan for the Copperwood project.

The process water balance governs the management, storage, and to a minor degree the treatment of water in the tailings slurry (TS) and the tailings disposal facility (TDF), underground mine dewatering, and water in the process circuit. Three objectives of the water balance were to identify the fluctuations of water volumes in the process circuit on a daily basis over the operating life of the facility; to provide an estimate of the range of potential water deficits and water surpluses that may occur during operations so that appropriate sources of make-up water as well as provisions for storage or disposition of surplus water can be provided for; and to provide a basis for sizing the TDF, the treatment plant, and other facilities.

Of particular concern throughout the planning process has been the management and treatment of mining impacted water from the project given its location near Lake Superior and the water quality requirements as developed in the Great Lakes Initiative. If discharges from the site are required, they must also comply with NPDES permit requirements as outlined in the Part 57 rules for the State of Michigan. Application of these two sets of criteria as end-of-pipe treatment goals allowed for contaminants of potential concern and resulting contaminant removal efficiencies to be identified.

The treatment facility must be capable of treating a range of contaminants requiring a robust and flexible treatment process that is quite different from conventional mine water treatment applications. Specific contaminants of potential concern include mercury at a very low level, 1.3 ng/L. Additional contaminants of potential concern were established as constituents estimated to be at higher concentrations than the end-of-pipe treatment goals, as well as those parameters that might negatively impact the treatment units and their ability to remove other contaminants. The final contaminants of potential concern include ammonia, barium, beryllium, boron, copper, lead, mercury, selenium, silver, vanadium, and zinc.

Conceptual Water Balance

The first step in developing the process water balance was to prepare a conceptual model of the proposed water management system. The conceptual model consists of the system components and description of the interactions between the components.

Fig. 1 presents a schematic of the process water balance design basis. In summary, prior to operation of the process mill the TDF will have been constructed in parallel with the other site activities and begin to receive underground mine water, precipitation, and experience evaporation. Operation of the process mill results in a net water demand. The process mill water demand is supplied by three sources, in order of preference: Water in ore; TDF decant water; and make-up water.

The conceptual model evaluates water sources in the in ore; TDF decant water and required make-up water based on main model inputs such as the production schedule, climatic data, underground mine flow, TDF feasibility and water treatment feasibility. The boundary conditions for the model include the climatic data in the area of the site and the process mill water demand.

Climate

The climate can have a significant impact on the operation of the water management system. The tailings disposal facility has a substantial catchment area that generates significant runoff volumes during precipitation events. Therefore, a detailed record of climatic factors, precipitation, evaporation, and temperature were assembled that included data from 1977 to 2010. The record was sufficiently long to capture the long-term climatic variability in the area.

This region has a humid continental climate which is strongly influenced by the presence of Lake Superior. This indicates that the area generally experiences cool summers and weather patterns driven by the phenomenon commonly known as "lake effect". Lake effect influences a variety of factors including temperature, amount and timing of precipitation (including snowfall), and cloud cover.

The proximity of Lake Superior also results in increased cloudiness and precipitation because of the large amount of moisture available for air masses to acquire as they travel across the lake. This is a common occurrence since the predominant wind direction is from the west. This effect is exacerbated in the winter as cold air blows across the warmer lake acquiring moisture which it then releases as it comes in contacted with the colder land mass; thus resulting in frequent heavy snowfall.

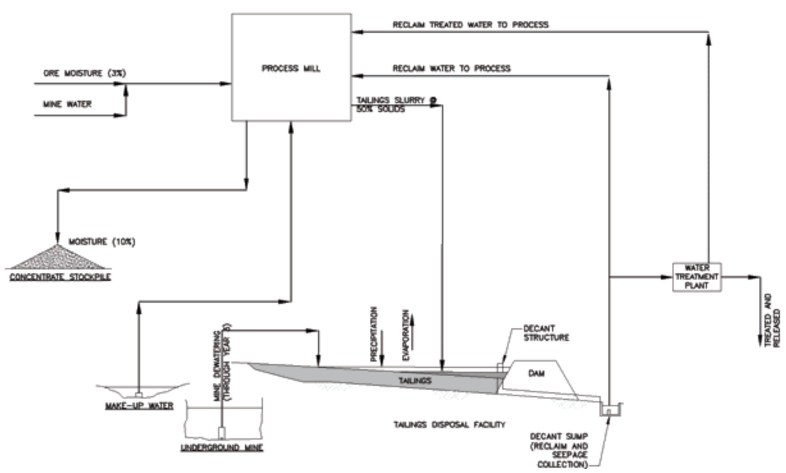

Fig. 1 *Water Management System Model*

Growth and depletion of the snowfall on the TDF occurs as a function of temperature.

Dynamic, Probabilistic Water Balance

The conceptual model was the basis for developing a mathematical model of the water management system. A dynamic, probabilistic simulation program (GoldSim) was used. Sizing of the three stages of the TDF included the operational storage required for the supernatant pond as it increases and decreases over the operating seasons and years, as well as storage of the design storm, which was selected as the 72-h/half-PMP storm event. The general operating strategy avoids the accumulation of an excessive amount of water in the TDF that will require treatment at closure. The water balance model was developed to reclaim and re-use as much water as possible from the TDF.

The water in ore is calculated as a function of the ore production and moisture content, 3 %. The TDF has been designed to store the solids and manage the liquids from the Copperwood tailings, both during the period of operations and after closure. The solids will be retained in the impoundment together with some of the liquid. Liquids not retained will be collected via underdrains or decanted from the tailings surface. The TDF decant sump water will be recycled to the process mill for re-use in the process or treated and released in compliance with applicable water quality standards. Some water from a make-up source will be required when the water in the ore and TDF water is unable to fulfill the process mill water demand.

The conceptual model included an assessment of the variability and uncertainty in the data and system operations. The interactions between the system components were represented by empirical relationships or rules derived from the planned operating practices and analysis of the projected site data. For example, the operational rules for deciding whether to send water from the TDF to the process mill or treat and release.

Chapter 40, Code of Federal Regulations (40 CFR) Part 440 Regulation, for new source copper mines specifies allowable water discharge quantities. The allowable amount of discharge is the calculated difference between annual precipitation falling on the treatment facility and annual evaporation over the same area. A provision identified in 40 CFR Part 440 states that additional discharge is allowable if the mine can demonstrate that a build-up of contaminants would interfere with the milling process, which is the case for the project. The water treatment plant starts treating and either reclaiming water to the process mill or discharging water as soon as there is excess water in the TDF. Closure of the TDF can occur when the supernatant in the TDF allows for exposed tailings to be present. The projected water treatment rate allows for all TDF water to be treated within 4 years of cessation of operations and discharged to the receiving environment.

The results of the water balance modelling effort indicate that an 80 m^3/h treatment facility will be required to achieve project goals.

Water Quality Characterization

The water quality is dependent on the quality and quantity of the Tailings Slurry (TS) and Underground Mine (UM) geochemical characterization and precipitation sampling data. Predicted contaminants in the TS water are total organic carbon (TOC), total dissolved solids (TDS), total suspended solids (TSS), ammonia, and metals including barium, beryllium, boron, cadmium, chloride, copper, lead, mercury, selenium, silver, vanadium, and zinc. Predicted contaminants in the UM water include TDS, TSS and metals including barium, boron, cadmium, chloride, copper, lead, mercury, selenium, silver, and zinc. The TDF contaminant concentration is variable throughout active mining operations. Specific contaminants of potential concern in the TDF include ammonia, barium, boron, copper, lead, mercury, selenium, silver, vanadium, and zinc. It is assumed that selenium is present in the selenate form and mercury is present in the mercurous form. Selenate and mercurous are the most common forms of selenium and mercury found in mining and other industrial wastewaters.

Treatment Design Basis

Treatment goals were established for discharge to the receiving environment (tab. 1). It was assumed that the discharges to the receiving environment are sufficient for reuse in the process mill.

Based on the projected TDF contaminant concentrations data processes including membrane microfiltration, reverse osmosis (RO), and mercury post-treatment by ion exchange have been selected as most appropriate for the project as shown in Fig. 2. The system also includes mechanical evaporation to reduce the volume of brine from the reverse osmosis system and produce a dry solid for disposal. This combination of water treatment technologies will allow for effective reuse of treated water as well as fully compliant discharge to the receiving environment.

Treatment System

The microfiltration system includes a two-stage reaction system followed by microfiltration. The first-stage reaction system allows for the softening of the water, removing a portion of the calcium and silica. The second-stage allows for polishing the pH to the target range of 10.5 to 11.1 and for additional mixing and precipitation of metals, calcium, and silica. Most metals are precipitated in the form of insoluble metal hydroxides. Other precipitates include barium sulfate, calcium carbonate and the magnesium-silica complex. The microfiltration system provides an absolute barrier to the passage of solids at a particle size cutoff of about 0.1 µm. This results in the removal of most colloids; and therefore, provides a filtrate that exhibits a very low silt density index, making the filtrate an appropriate feed for a RO unit. Sludge will be dewatered by a filter press and disposed of onsite.

Prior to the RO unit, the filtrate is adjusted to a pH of 6 and preconditioned with an antiscalant and an oxidant chemical to protect the RO membrane units. The preconditioned water is treated through adsorption using granular activated carbon (GAC) for removal of

Parameter	Units	End of Pipe Treatment Targets	% Removal Required	% Removal Projected
Total Dissolved Solids (TDS)	mg/L	500	85.8%	99.9%
Barium, Dissolved	mg/L	0.12	65.4%	100.0%
Boron, Dissolved	mg/L	5	10.3%	69.7%
Cadmium, Dissolved	mg/L	0.000918	7.4%	100.0%
Chloride	mg/L	50	89.7%	100.0%
Copper, Dissolved	mg/L	0.003	99.0%	99.9%
Lead, Dissolved	mg/L	0.003	44.2%	95.5%
Mercury, Low Level, Total	ng/L	1.3	98.6%	99.7%
Mercury, Dissolved	ng/L	1.3	98.6%	99.2%
Nitrogen, ammonia	mg/L	0.029	75.3%	97.7%
Selenium, Dissolved	mg/L	0.005	84.7%	98.9%
Silver, Dissolved	mg/L	0.00006	97.3%	13.3%
Vanadium, Dissolved	mg/L	0.012	59.2%	13.3%
Zinc, Dissolved	mg/L	0.043	43.7%	13.3%

Table 1 *Treatment Targets and Required Removal Efficiencies*

TOC. When the media is saturated (all adsorption sites exhausted) the media must be removed and disposed of. The GAC effluent will be fed to the RO unit.

RO treatment is a high-pressure membrane filtration process that utilizes a series of semi-permeable membranes. Prior to RO unit, the treatment stream is fed from through a 5 µm cartridge filter. Water and low levels of some ionic constituents pass through the membranes while the majority of the dissolved salts are retained on the brine side of the membranes. The RO System includes three RO units, two in series (primary and secondary RO units) and one to treat the brine from the first two RO units (brine recover RO unit). This configuration maximizes overall water recovery and minimizes the brine quantity.

The water is fed by a high pressure system to the primary stage RO unit. The permeate from the primary stage RO Unit and from the brine recovery RO unit is recombined and treated in the secondary stage RO unit. The permeate from the secondary stage RO unit is transferred to the permeate system. Brine from the primary and secondary stage RO units is stored to allow for an adequate reservoir prior to the brine recovery RO unit. Approximately 11.5 % of the forward feed is fed back to microfiltration system reaction tank and the remaining brine is transferred to the RO brine tank where hydrochloric acid is added to decrease the pH prior to evaporation. By recycling a portion of the brine, the overall water recovery is increased; and therefore, the volume of brine requiring further treatment is decreased by approximately 11.5 %. The brine will be fed to the evaporator/crystallizer system from the RO brine tank.

An overall water recovery rate of approximately 87 % is projected by modeling for the RO system. An increase to the overall water recovery rate above 90 % is anticipated during detailed design.

The combined permeate from the RO units will be fed to the ion exchange system. The ion exchange system consists of two pressure vessels in a lead/lag configuration containing proprietary mercury-specific media. The ion exchange system is used to reduce the mercury concentration remaining in the permeate from the RO system in order to meet the stringent Great Lakes Initiative mercury limit of 1.3 ng/L. The treated water is gravity fed to the receiving environment. When the active sites on the resin are exhausted, the media is replaced and the spent media is disposed of. The two-column system is operated in to allow complete exhaustion of the first column before the media is replaced.

The evaporator/crystallizer system is a vapor recompression evaporator system sized to handle up to 11.3 m^3/h of brine. It is an energy efficient system that can provide up to

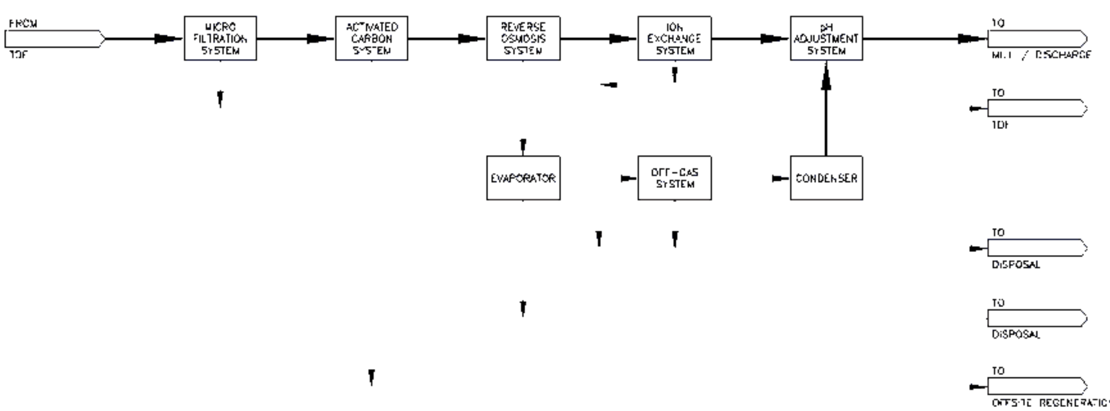

Fig. 2 *Water Treatment Plant Selected Unit Processes*

99 % volume reduction for waste streams. Steam is required for this system at start-up; therefore, a boiler will be rented or steam will be taken from another process on the site. The pH of the brine stream is adjusted by the addition of hydrochloric acid prior to entering the heat exchanger to prevent scaling. The heat exchanger serves to preheat the feed and recover heat from the evaporator distillate. After the heat exchanger the feed then passes through the deaerator where carbon dioxide and other strippable (volatile organics not expected to be present) constituents are removed prior to the evaporation step. It should be noted that if mercury is present and volatilizes it will be condensed with the distillate and require further treatment possibly by an additional ion exchange unit.

From the deaerator the feed is transferred to the evaporator where caustic may be required to adjust pH to an optimal value. The brine slurry from the evaporator sump is continuously recirculated to the top of the vertical heat-transfer tubes where it falls as a thin film and a portion of it is vaporized. The vapor is then compressed and introduced into the shell side of the vertical tube bundle to provide the energy for evaporation of incoming brine. The heat of compression from the compressor significantly increases the temperature of the compressed vapor and provides that energy. The temperature difference between the vapor and the brine film causes the vapor to release its heat of condensation to the falling brine and to condense on the outside of the tubes as distilled water. This distillate is collected at the bottom of the condenser and flows to the distillate tank. A small vent stream from the distillate tank maintains the evaporator vessel at a slightly positive pressure. The hot distillate is the heat exchange fluid described above that preheats incoming feed to the evaporator system.

The concentrated brine is removed as a slip stream from the evaporator sump and then further processed in a crystallizer. Antifoam is fed to the crystallizer to preventing foaming in the process. The brine becomes supersaturated in the crystallizer and salts form and precipitate out of solution. The waste stream from the crystallizer is a solid. Solids will be further dewatered by a filter press prior to disposal. The average estimated generation rate for waste solids is three tons per day.

Water Management and Treatment

The simulation duration was set equal to the mine life for the specified production schedule and a one-day time-step was evaluated. The simulation projections indicate that the selected design configuration of the water infrastructure will support the project objectives.

The selected water treatment technology is expected to meet or exceed all applicable regulatory requirements, including meeting water quality standards and concentration thresholds of measured constituents in any water released to the environment from the facility. Natural resource conservation protection and mitigation measures remain key components in the project design and ongoing environmental analysis.

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