Evaluation of High-Rate Clarification for Water Treatment at a Uranium Mine – A Case Study

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Abstract The performance of a high-rate clarifier with sludge recycle capability was evaluated during a three-month pilot project at a uranium mine in northern Saskatchewan. The pilot unit tested was a 100-gpm DensaDeg® system made by Infilco Degremont, Inc. Wastewater from underground processing operations was treated in both high and low pH regimes, generating two dissimilar sludges. Removal was adequate for most targeted contaminants, but high pH sludge presented special difficulties for the mechanical equipment and for process control. Future design of solids-recycling clarifier systems used in chemical precipitation of metals should include considerations for the rheology of the generated sludge.

Keywords Clarifier, Uranium, High-rate, Sludge

Introduction

Cameco's McArthur River mine (MCA) in northern Saskatchewan, Canada is one of the world's largest producers of uranium (U) ore. The mining operation takes place underground and because of the high water table in the area, needs to be constantly dewatered. This water is contaminated with many different metals and needs to be treated before discharge to the environment. The existing treatment process at MCA is currently operating near capacity and with an expansion of the mine being planned, will need to be updated and expanded. Fig. 1 below shows a simplified process flow diagram of the proposed treatment process.

Because of the extreme winter weather at the mine site, there is a preference to contain all of the process equipment in a heated building. In order to accomplish this in as small a footprint as possible, high rate clarification was selected. A pilot study was conducted to evaluate the performance of the proposed clarifiers under the expected treatment conditions. The pilot study tested an Infilco Degremont (IDI) DensaDeg® clarifier rated for 22.7 m^3/h (100 gpm). The pilot unit tested at MCA is shown below in Fig. 2.

The chemistry used for the pilot test was based on the existing chemical treatment process at MCA. The purpose of this pilot test was primarily to evaluate the physical/me-

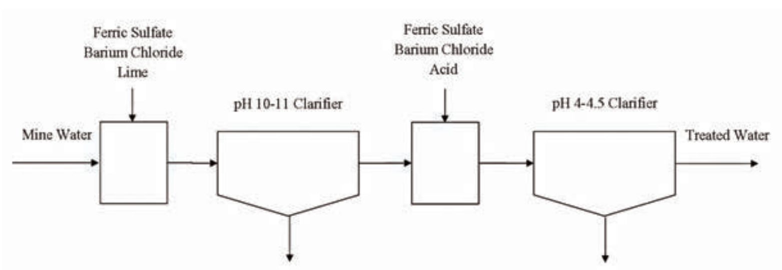

Fig. 1 *Process Flow Diagram of MCA DensaDeg® Pilot Plant*

Fig. 2 *DensaDeg® 22.7 m^3/h Pilot Unit*

chanical separation ability of the high rate clarifier for the specific sludges generated at MCA and not to determine the optimum chemical treatment process.

The pilot test consisted of operating the clarifier under two different pH conditions (low and high) and at several different flow rates (50 %-115 % of rated capacity) in order to mimic the proposed treatment process. At each test condition, the clarifier was allowed to operate for several days, at which point samples were taken from the influent and effluent of the treatment process and analyzed.

The process for the expanded mine water treatment plant (MWTP) called for a two stage pH precipitation system (Liang 2012 SME). Incoming waters would first be treated with barium chloride, ferric sulfate, and an acid or base to achieve a pH of 9-11. The first stage targeted the removal of U, but also had significant removal of many other metals, including arsenic, cadmium, lead, zinc, etc. The effluent for the first stage would then be treated with more ferric sulfate and barium chloride, as well as sulfuric acid to lower the pH to around 4.5. The low pH stage targeted the removal of molybdenum (Mo; Liang 2012 WEFTEC).

The proposed design for the MWTP calls for a blend of mine water and slurry load-out (SLO) water at an approximate ratio of 5:1. The mine water was high pH, highly alkaline, and contained high concentrations of many metals, including U. The SLO water was less alkaline and had less solids loading but had higher concentrations of Mo.

Low pH

One of the driving factors for the construction of the MWTP expansion was the site's desire to decrease Mo loading to the environment. For that reason, the low pH stage solely targeted the removal of Mo. Other constituents were monitored, but process conditions were adjusted to test Mo removal in different situations.

Because only one pilot clarifier was available, the full continuous process could not be modeled. Each pH stage would have to be tested consecutively, instead of concurrently. The flowrates during the test were too great to allow for storage of the water treated during the first stage, so the influent to the low pH stage was simulated by blending water from various sources. A mix of SLO water and effluent from the current MWTP was blended to reach an influent target of 5–10 mg/L Mo. This concentration represented the highest probable Mo concentration that the expanded MWTP could see.

The low pH process was tested at 3 different flow rates: 11.4, 18.2, and 22.7 m^3/h (50, 80, and 100 gpm). All tests were run at a pH set point of approximately 4.5. The results indicated that Mo removal was excellent and met the target effluent concentrations at all flow rates. Radium removal was not as effective as indicated in the bench scale testing, but some of the problems could be attributed to the simulated water. The radium-barium co-precipitation needs adequate sulfate to form proper floc particles, and less sulfate was available in the simulated water than would be in a full scale plant.

The characteristics of the low pH sludge were similar to DensaDeg® applications when treating light municipal sludges. The flocculated particles were very light and had a low density. The sludge bed depth varied greatly with flow rate, as the bed expanded and contracted. While the low density of the sludge might seem to decrease its settleability, in practice it still settled very well. Very little solids carryover was observed during the low pH testing, and the effluent was almost always clear and free of flocculated solids. At higher flow rates, some particles were carried through the clarification section, but were caught in the plate settler section. The plate settlers required periodic cleaning.

The flocculant for the low pH stage was not optimized during the pilot testing. The light floc was easy to pump and work with, but a slightly more dense sludge would dampen fluctuations in bed depth and reactor solids concentration. In terms of removal efficiency, there is not much improvement available in flocculant selection. The site polymer was effective at promoting proper flocculation with the low pH sludge. High rate clarification technology is a good application for this type of sludge.

High pH

A total of five different high pH tests were conducted to assess the performance of the DensaDeg® system under varying pH and flow. Three different process flow rates of 18.2, 22.7, and 26.1 m^3/h (80, 100, and 115 gpm) were tested under the pH 10 control set point while pH 11 and pH 9 tests were both conducted at 18.2 m^3/h. The primary constituent of concern was U but other metals and radionuclide contaminants were also removed at high pH.

Ferric sulfate (12 % Fe) and barium chloride (30.5 g Ba/L) were dosed at 0.09 mL/L and 0.4 mL/L, respectively. Sulfuric acid was also dosed to maintain pH set points. An anionic polymer, Magnafloc-351 was the sole flocculant utilized in all tests. Although the manufacturer recommended the use of a different polymer for high pH experiments, Magnafloc-351 was the only flocculant available on site during the course of this project. The polymer dose was varied between 0.25 and 0.5 mL/L from a neat concentration of approximately 0.2 %.

The DensaDeg® system facilitated better than expected removal of U at all tested pH values. However, removal of most other contaminants of concern was equal or lower compared to effluent of the current WTP during

Constituent	Units	Pilot Scale Testing Results		Test for Best Effluent Quality (High or Low pH)	Treatment Target
		Value	% Removal		
Non-Radionuclides					
Arsenic	mg/L	0.0023	47%	High pH	0.03
Copper	mg/L	0.0024	47%	High pH	0.02
Lead	mg/L	0.00055	91%	High pH	0.004
Molybdenum	mg/L	0.073	99%	Low pH	0.1
Nickel	mg/L	0.00063	21%	High pH	0.12
Zinc	mg/L	0.0020	89%	High pH	0.14
Radionuclides					
Lead-210	Bq/L	0.06	95%	High pH	0.21
Polonium-210	Bq/L	0.21	83%	High pH	0.54
Radium-226	Bq/L	0.23	98%	Low pH	0.067
Thorium-230	Bq/L	0.058	95%	High pH	0.09
Uranium	µg/L	1.4	96%	High pH	2

***Table 1** DensaDeg® Pilot Test Results*

this time. Table 1 lists the average final effluent concentrations for pilot plant target criteria.

One of the main purported advantages of the DensaDeg® system is that by externally recirculating the sludge, the precipitated flocs can be reintroduced to the influent stream and thus have a second chance to adsorb or bind contaminants. Since the pilot unit consistently demonstrated better U removal than bench scale studies suggested, it may be possible that the sludge recirculation process and the internal recirculation occurring in the Reactor section of the DensaDeg® may be responsible for enhanced U treatment. Additionally, on average, better U removal was observed at higher pH conditions (around pH 11) than at lower ones.

During the course of the first high pH test, it became apparent that any previously-established operating guidelines had to be significantly amended to ensure successful performance. The most significant operational challenge encountered throughout the high pH tests was proper sludge handling and flocculation. Ferric hydroxide floc, when laden with U, became significantly denser and heavier than what was seen with the low pH sludge. Therefore, a different strategy for sludge handling was necessary.

For the initial low pH experiments, operators were instructed to build up a sufficiently high solids inventory in the clarifier tank, indicated by sludge bed of approximately 1.8 meters. However, the solids created through this treatment under high pH conditions not only had a fast settling velocity, but also exhibited significant compaction. The progressive cavity-type sludge recycle pump was rated for approximately 4 % solids but the clarifier underflow solids concentration had already exceeded this value and began to plug up the pump before the sludge bed had reached 0.9 meters. At one point, the sludge became so viscous that it could not be pumped out of the clarifier without repeated backflushing through the wasting line.

The unexpectedly high density of the sludge also resulted in over-torque damage to the gear train of the scraper drive. Multiple power outages occurred during this phase of testing, and it is likely that critical mechanical failure occurred when the scraper mechanism tried to restart against a deep, thick sludge bed. The broken scraper drive led to a few additional problems, most notably an inoperable sludge recirculation system. The sludge bed had a sharp horizontal incline, depressed towards the side of the clarifier that held the sludge waste line and all of the sludge bed sample taps. This caused inaccurate sludge bed readings, and allowed the bed to build above the sludge recirculation intake cone. When the cone plugged, sludge could no longer be pumped and the lack of flow caused the stator of the sludge recirculation pump to fail. Operators developed temporary stopgap measures to continue the testing, but as soon as the scraper mechanism was repaired, similar sludge issues we no longer experienced.

All of the challenges pertinent to dense U sludge were further compounded by inconsistencies in polymer concentration. The mechanical problems with the polymer make-up system would occasionally lead to very dilute batches of flocculant. This resulted either in under-dosing of polymer before the problem was discovered, or over-dosing when operators had already adjusted for the previous, dilute concentration. Insufficient polymer dose resulted in light, disperse flocs of varying size (including pinfloc) but this effect was partially reduced when good quality sludge was being recirculated concurrently. Overdosing of polymer, however, led to the formation of large, spherical flocs, some over 1 cm in diameter. This type of floc created sludge that was nonhomogenous, amorphous, globular in appearance and would expel water readily upon physical compression. This phenomenon was observed repeatedly when over-polymerized sludge was being pumped for recirculation or wasting. Initial pumping would only produce water, followed by a dilute sludge stream, until the frictional headloss became too great and all flow stopped. Bed depth samples taps were thus found to be unrepresentative of the clarifier conditions when this type of sludge was present because water would be separated from sludge solids in the small-diameter sample tap piping. Once issues with the flocculant make-up system were identified and repaired, flocculant dosing for subsequent tests was considerably more consistent.

Several changes to system operation were made to address issues with sludge and polymer dosing. The previous operational metric of sludge bed height was eschewed in favor of reactor tank solids, which were measured every 3–4 hours with a 1-L graduated cylinder and were maintained between 5-15 % (by volume) after a 10 min settling time. Sludge compaction was best accomplished through direct visual observation of the sludge recirculation stream, which led to a brief but consistent wasting and a resulting sludge bed depth of about 0.3–0.6 m. Consistent qualitative checks of the reactor tank flocs also helped to safeguard the process against any unexpected mechanical malfunctions with the polymer delivery system.

Inconsistencies in the main influent stream presented the remainder of the operational challenges associated with running the DensaDeg® system. The original pilot plant configuration called for influent water to be provided via a series of underground dewatering pumps but the resulting flow rate soon proved to be too unreliable for steady state conditions so influent water was rerouted from a large equalization pond. Grit, cement, and other debris were present in the influent water and could be found in the settled sludge as well. While this may have contributed to increased sludge density, some amount of each is likely to occur in all mine water treatment operations.

Recommendations

A flocculant study should be performed in order to determine the proper polymer dose and type best applicable to the process water and its coagulant(s). Brief on-site bench scale testing performed during the course of the experiment concluded that at least some polymer was necessary to settle ferric hydroxide flocs. Pure recycle of settled, flocculated solids was not sufficient enough to completely eliminate the need for polymer addition. However, decreasing polymer dose gradually while maintaining sludge recirculation is a viable method of slowly reducing the amount of over-polymerized solids when they are already present in the system, without significantly impacting effluent quality. Operators found that a dense and fast-settling sludge like the one generated in the high pH tests requires only a very small bed depth to attain good compaction in the clarifier underflow. This information should have been communicated by IDI to the pilot team so that proper operational changes could have been implemented.

High pH, U-laden sludge presents special challenges to the operation and design of the DensaDeg® system. In the interest of redundancy and good safety factors, it is recommended that special operating procedures be developed for handling sludge that is thicker than typically encountered or anticipated in the initial design. Accidental overdose of flocculant or coagulant can lead to sludge that exhibits a rheology different from the one typically encountered during normal plant operation, so sludge handling equipment needs to capable of addressing these occasional upsets. It was the operators' observation that the overall performance of the DensaDeg® process for high pH U treatment was good, but some modifications in sludge handling procedures and equipment, with special consideration of U sludge properties, could make the system perform even better. Increased diameter piping, long radius fittings, emergency or even routine operation flush water connections, and pumps rated for high-viscosity, high-solids sludge transfer with run-dry capability, and higher torque rake mechanisms are just some of the ways the sludge handling capability of the DensaDeg® system should be specified in a full-scale installation.

Conclusion

The DensaDeg® high rate clarification technology tested at MCA was demonstrated to be effective and feasible for the type of sludge produced by the expected low pH treatment condition. Though the pilot unit worked adequately and produced acceptable effluent under high pH treatment conditions, there are some areas for optimization in future designs specific to this type of application. Specific detailed operating procedures and specification of more robust sludge handling equipment will allow this technology to be utilized for dense metal sludges.

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