MITIGATING THE IMPACT OF SYNTHETIC DRILLING MUD ON HECLA LIMITED'S LUCKY FRIDAY MINE WATER TREATMENT PLANT

Bill A. Hancock, Argo Consulting, Wilsonville, OR
Carlos Aguiar, Hecla Limited; Mullan, ID
Cindy Moore, Hecla Limited, Mullan, ID

Abstract

New permit discharge standards instituted at Hecla Limited's Lucky Friday Mine required installation of water treatment plants to manage water quality at two outfalls to the South Fork of the Coeur d'Alene River. The 002 Outfall Water Treatment Plant (WTP) is a clarification-filtration plant for treating the combined mill and underground discharge water flows. Process optimization efforts were a significant challenge until the negative impact the exploration diamond drilling products had on the clarification process was identified and resolved. The products were being wasted directly to the mine water discharge system which was pumped to the surface WTP. Anionic soluble oil and polyacrylamide based products were causing TSS particle hydrophobicity and dispersion that greatly affected coagulation and flocculation response, resulting in excessive chemical usage and treatment control issues. This paper details how problems associated with the drill products negatively impacted the 002 WTP and how system changes, alternative product usage and treatment at the source resulted in more consistent plant performance.

Background

The Hecla Lucky Friday Mine is located in the historic Coeur d'Alene mining district, or more commonly known as the Silver Valley, in northern Idaho that extends along I-90 from the Fourth of July Pass on the west to Lookout Pass on the Idaho-Montana border in the east. This is a valley through which the South Fork of the Coeur d'Alene River joins the North Fork and then flows to the west where it feeds Lake Coeur d'Alene.

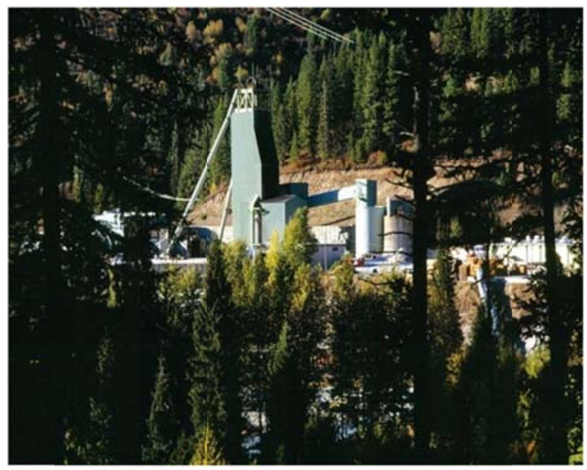

Figure 1. Photo of Silver Shaft Headframe

Silver, lead, and zinc became the primary metals produced in the Coeur d'Alene District with silver being the economic driver. For over a century to 2006, over 1.2 billion ounces of silver have been produced in the Silver Valley, more than any other US mining district. Historically worldwide, the Coeur d'Alene District ranks with Potosi in Bolivia and Pachuca-Real del Monte in Mexico districts which have also produced at least 1 billion ounces silver for comparison, but mining activities in these areas have been ongoing for several centuries.

There have been roughly 100 mining operations in the Coeur d'Alene District since 1884 with the most prolific being the venerable Bunker Hill, Sunshine, Galena, Lucky Friday, and Star-Morning Mines (1). Most operations have been and are underground mines.

Figure 2. USA Location of Lucky Friday Mine

Over the years there has been considerable consolidation and presently only US Silver's (former Coeur d'Alene Mines) Galena and Coeur Mines, New Jersey Mining's New Jersey Mine, and Hecla's Lucky Friday Mine are in operation.

Figure 3. Idaho Location of Lucky Friday Mine

The Lucky Friday Mine is located one quarter mile east of Mullan, ID on the far eastern side of the Silver Valley immediately adjacent to the I-90 interstate freeway (Fig. 2, 3). Lucky Friday has been in commercial production since 1942 and in the last 68 years has milled over 10 million tons of ore and has produced 147 million ounces of silver, 984,000 tons of lead and 159,000 tons of zinc. Hecla, which was incorporated in 1891, acquired 38% of Lucky Friday in 1958 and obtained 100% of the mine by 1964. Two concentrates are produced in the mill by flotation process, which are presently being sold to the Teck smelter in Trail, British Columbia.

Lucky Friday's mining targets have focused on two ore bearing structures; the Lucky Friday Vein and the Lucky Friday Extension (Gold Hunter Deposit) as shown in Figure 4. The Lucky Friday Vein is located in the Revett Formation which has hosted a number of ore bodies in the Coeur d'Alene district. Mineralogically the vein is galena, sphalerite and tetrahedrite in a quartz and siderite gangue. Vein widths measure 2 to 30 feet in width, averaging 4 feet.

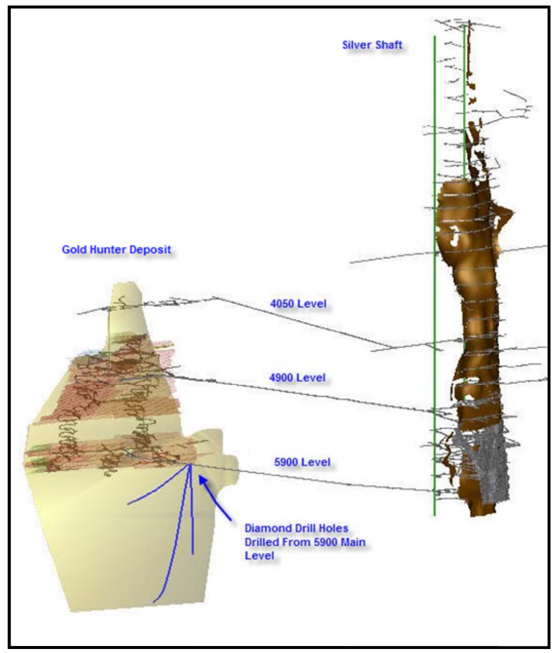

Figure 4. 3D Map of Lucky Friday Ore Body

Mining on the Lucky Friday Vein ceased in 2001. The Gold Hunter vein package is hosted in the Precambrian Wallace Formation, which accounts for only 5% of the total production from the district. The mineralogy of the main production vein, the 30 Vein, is predominantly galena, sphalerite, and tetrahedrite in a siderite, quartz, and barite gangue.

Lucky Friday is the deepest operating mine in the US where the deepest active Gold Hunter stopes are over 6100 feet below the Silver Shaft collar, which is over 2,700 feet below sea level. The primary mining method employed is underhand cut and fill with ramp access using rubber tired equipment. Access to the veins is through ramps developed outside of the ore body. After mining a cut, the stope is backfilled with cemented coarse tailings that are produced by the mill.

Water Treatment Operations

There have been numerous mine and mill process changes over the last three years; this paper refers to and describes the specific conditions during the time period during and after the water treatment plant (002 WTP) commissioning.

Lucky Friday is a relatively dry mine with water infiltration estimated as only approximately 180 gpm. Roughly 300-350 gpm service water is delivered to the underground workings to supply feed to the evaporative chillers used to cool the ventilation air and utility water to support the mining activities. Combined mine discharge flows are pumped to the surface through a series of sumps located on successively higher operating levels. Even though mine discharge water has low metal and TDS levels, the water is sent through the water treatment plant to ensure TSS control. Total combined mine water flows to the water treatment plant were on the order of 480-530 gpm.

The mill flowsheet is a neutral pH, conventional lead-zinc flotation circuit that produces separate lead and zinc concentrates. The tailings are cycloned with the overflow being pumped to tailings impoundment. Cyclone underflow coarse solids are sent to a sand thickener where the underflow is filtered and then mixed with cement before being pumped underground as stope backfill. The sand thickener overflow is combined with the mine water discharge, which becomes feed for the treatment plant. The sand thickener overflow rate is about 250 gpm. Typical total 002 WTP influent rates are 730-780 gpm.

Until September 13, 2008, Lucky Friday's discharge water quality met NPDES quality standards as the tailings water cleared sufficiently to meet requirements. Similarly the combined sand thickener overflow and mine discharge water reported to another pond system before the water was discharged to the South Fork of the Coeur d'Alene River. The new permit that went into effect September 13, 2008 provided for higher quality discharge standards which necessitated building and operating a water treatment plant at the mill treating the water before the discharge point (002 Outfall) of the South Fork.

The permit levels provided in Table 1 provides the relevant interim and new discharge permit limits. Values are not a direct comparison between pre- and post discharge limits but are more for reference to order of magnitude changes that became effective with the new permit.

Table 1. Before and After NPDES Limits

NPDES Discharge Limits - Pre September 13, 2008

001/002 Outfall	Pb (µg/L)	Zn (µg/L)	Cd (µg/L)
Daily Maximum Limit	600	880	6.0
Monthly Average Limit	300	469	2.0

NPDES Discharge Limits - Post September 13, 2008

002 Outfall	Pb (µg/L)	Zn (µg/L)	Cd (µg/L)
Daily Maximum Limit	50	190	1.8
Monthly Average Limit	30	71	0.7

Mill and mine water dissolved metal concentrations and TSS levels can be elevated and must be controlled, therefore a full clarification and multimedia filtration plant was installed. This plant configuration is fairly straightforward and standard. Metals are precipitated by lime pH adjustment, coagulant and flocculant are successively added, the treated water is conditioned in the flocculation tank to ensure good flocculation, the slurry is clarified in a lamella clarifier, and the clarifier overflow is polished in a three pressure multimedia filter train before discharge. Figure 5 provides the 002 WTP flowsheet.

The mine water discharge reported to the mill where it was combined with the sand thickener overflow in the 002 WTP feed surge tank. The combined stream was lime treated to maintain a target 9.5 pH in the WTP feed surge tank. Coagulant was added to the surge tank for conditioning, at a 4-8 minute nominal residence time, which and was then transferred to a flocculation tank. Flocculant was added in the transfer line. The mixing flocculation

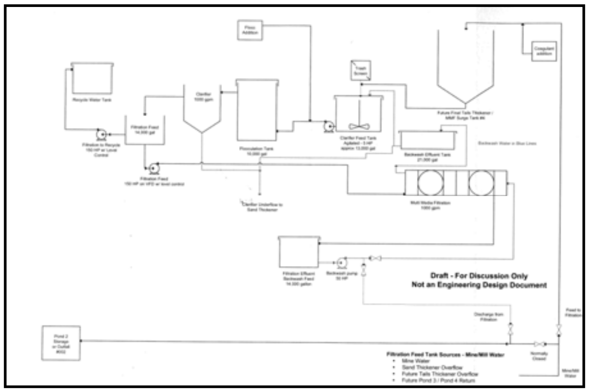

Figure 5. 002 WTP Flowsheet

tank, which has a 5-10 minute nominal residence time, promotes and ensures good flocculation and TSS capture.

Process Challenges

Many flowsheet, equipment and process operational changes were made the first 2-3 months after startup to accommodate conditions that were not anticipated prior to the plant's commissioning. Achieving consistent and favorable results was very difficult, initially, and posed significant challenges. Constantly changing mine discharge water quality and flow rates complicated matters and posed a steep operating learning curve.

Early on it was deduced that the dissolved metal ions were adequately precipitated by pH adjustment, therefore the struggle was to achieve a low discharge TSS level to control total metal concentration discharge levels. NTU was used as the plant monitoring and control measure and a <1 NTU final filter discharge level was the goal and target.

Process monitoring and response assessment was based on plant influent, clarifier effluent, and filter discharge NTU levels as well as required chemical addition rates, primarily coagulant and flocculant. The main 002 WTP enhancements during this period included:

- Optimized lime feeding and pH target
- Changed the coagulant (to Z Clear™ 254) and flocculant (to Z Flocc™ 912) program
- Installed a flocculation tank
- Optimized the lamella clarifier operation
- Adjusted procedures and learned how to operate the mixed bed filter system
- Diverted part of the clarifier overflow to the mill process water tank to reduce filter feed flows
- Modified the existing equipment to accommodate conditions and reduce downtime
- Changed water flow balances to enhance operational flexibility and ability to manage the plant

By November operations was gaining control, albeit without sufficient operating safety margin, and with that a significant underlying trend was being noted. An important, fairly consistent weekly trend was identified where the clarifier and filter discharge clarity levels markedly deteriorated starting Monday afternoons with clarities improving Friday afternoons. During that Monday-Friday period, achievement of target clarities was very difficult. To illustrate this trend, the following graph (Fig. 6) shows the average clarifier and filter NTU discharge levels by day over a 5 week period from November 30, 2008 to January 3, 2009.

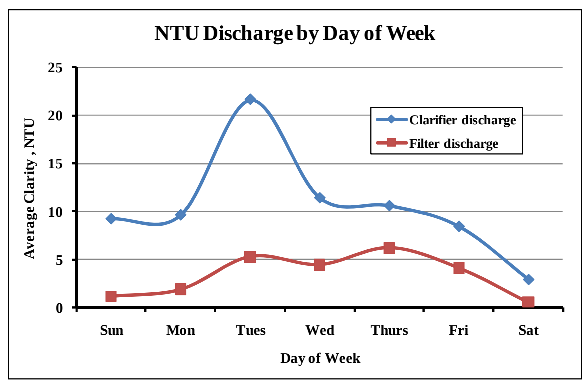

Figure 6. Process Operation Clarity by Day of Week

The cyclical influence was observed during the normal work week while improving through the weekend. Clarifier NTU discharge increases were more pronounced on Tuesdays with decreasing values thereafter; however the importance of this trend shows the significance as related to filter discharge values. Targeted filter effluent values of <1 NTU could not be achieved until Saturday afternoons, with decreasing clarity at each start of the work week.

As shown in the graph below (Fig. 7), no correlation between plant response trends and plant feed clarity levels were indicated. There apparently was a ‘bad actor(s)’ in the feed water itself that was causing the 002 WTP responses.

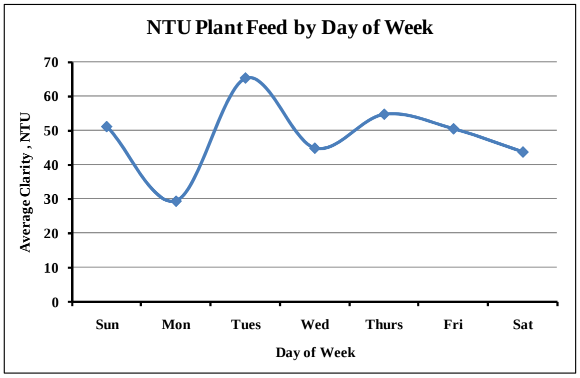

Figure 7. 002 WTP Feed NTU Levels by Day

Investigations and Studies

Throughout this period a significant number of bench-scale flocculation-clarification tests were conducted to understand the process issues and define operational resolutions. A curious ongoing observation was that ‘rafts’ of coagulated-flocculated TSS particles would form and float on the surface of the beakers.

These particle rafts indicated some introduced condition where very fine TSS particles were being rendered hydrophobic; causing these particles to aggregate and separate from the water phase and float on the surface. This is similarly observed in a mineral flotation system where very fine values that have been rendered hydrophobic by specific collector chemistries will come together and float on the slurry surface. Surfactant induced particle surface hydrophobicity causes particle aggregation which minimizes their surface exposure to water. If the particles are sufficiently fine and hydrophobic, particle rafts will float on the surface similar to that being observed in these 002 water laboratory tests.

Investigation of the Monday-Friday upset condition source quickly focused on the underground mining operation because there was nothing identified in the mill operation that could account for the cyclical 002 WTP operational response. Initial efforts focused on identifying and analyzing all possible underground water sources, even the most minor, which accounted for 29 individual streams. Fairly quickly though, attention was focused on the underground diamond drilling operation.

Two drills were being operated on the 5900 level from 6:00 AM Monday to midnight Thursday evening. Accounting for the pumping lag time, the drill water would report to the 002 WTP at approximately the time the treatment plant upset conditions were being experienced.

Once focus was narrowed to the exploration drilling program, the impact of the fine cuttings generated in drilling contributing TSS and the chemical additives used in the drill water were studied. Small sumps are excavated at all drill stations for the roughly 20 gpm fluid flow required during drilling. The coarse solids settle out but the fines not settling out reported as TSS. Also, the drill fluid additives used are water soluble and are present in concentration in the water pumped to surface and reporting to the 002 WTP along with the other discharge streams previously addressed.

The overall plant feed 50-60 NTU clarities being experienced were not obviously considered unreasonable and a negative plant performance factor which eliminated drill generated fines as an issue of concern. Moreover, water visual indicators focused efforts on drill fluid additives as the culprit to the filter effluent turbidity control difficulties. Monday-Friday clarities were often described as milky versus weekend brownish colorations. This condition was duplicated under laboratory conditions when evaluating varying concentrations of drilling fluids against turbidity readings.

A Hagby Onram-1500 core rig was using these fluids to help with lubricity issues when drilling deep from the 5900 Level. Hole lengths approaching 2500 feet are difficult to achieve without assistance from drilling fluids. Previous attempts to stop using these products resulted in significant drilling rate decreases, therefore additives were necessary as long as a viable solution to 002 WTP feed clarities could be addressed.

Generally two drill additives were utilized; a light end highly dispersible ‘soluble oil’ and an anionic emulsion polyacrylamide flocculant product. The soluble oil is a refined light end oil that is commonly used to help reduce drill string torque and keep the drill bit lubricated. This product easily disperses and stabilizes in water and causes higher NTU levels due to the degradation of clarity. The attached photo (Fig. 8) shows the increasing turbidity as the concentration increases to 15 ppm concentration along with a graph showing the actual turbidity measurements (Fig. 9).

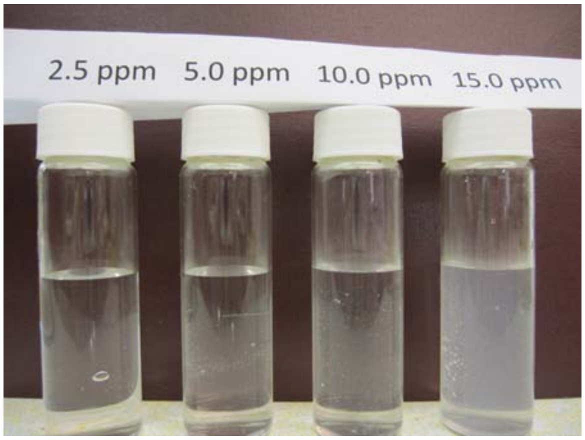

Figure 8. Photo of Increasing Soluble Oil Concentration

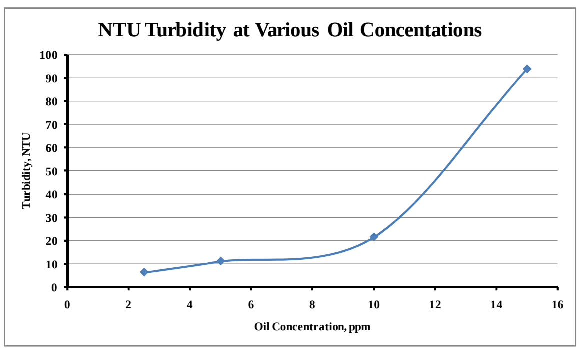

Figure 9. NTU Measurements of Increasing Soluble Oil Concentration

Polymer provides drill mud viscosity for carrying cuttings as well as aiding lubricity. Importantly, emulsion polymers are generally 1/3 each: polymer, water and a low order paraffin solvent, which is typically a light end oil. Emulsions also have roughly 2-5% surfactants to emulsify the polymer in manufacturing and to break or invert the product to release the polymer into the water. While dosing the emulsion polymer product in water did not have a pronounced visual turbidity impact, the oils in the emulsion product were of concern as well as the implications that the actual polymer could be dispersing very fine TSS.

Drilling mud additive consumption was variable due to duty requirements; however roughly 10 – 13 ppm residual soluble oil or emulsion polymer was present in the mine discharge water. Periodically high use periods presented as much as 50 ppm, which occurred during difficult drilling conditions. An immediate concern was that, based on the particle rafts observed in the lab work pointing to hydrophobicity as an operative factor, it was reasonable to conclude the soluble oil and/or the emulsion products were causing particle hydrophobicity.

How these negatively impacted the process was theorized; however as a physical mechanism where the oils coated the fine TSS particles rendering them very difficult to coagulate and flocculate. Additionally, a mechanistic case could also be made that the actual anionic polymers were coating the fine particles because while the plant was only using up to a 1.2 ppm flocculant dose, the mud additive dose was in excess of 10 ppm. Fine particles are too small to effectively flocculate without prior coagulation, therefore it was theorized that similarly the surfaces were rendered unavailable for coagulation and flocculation. This was suggested in a test series with 002 WTP feed water where additional emulsion polymer was dosed in the test. The water sample inevitably had soluble oil and emulsion polymer residual oil from drilling activities which probably accounts for that anomalous result at 10 ppm.

Lab testing strongly supported the suggestion that these were significant levels which are provided in the graph provided in Figure 10.

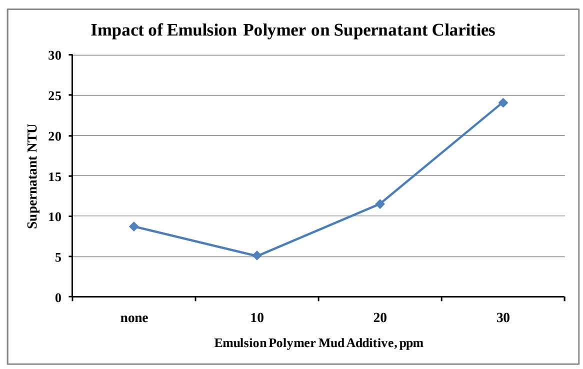

Figure 10. Lab Tests Showing Negative Impact of Emulsion Polymer on Supernatant Clarity

Once the source of poor water clarity and poor plant performance was identified, operational restrictions on mud additive use were immediately instituted. At the same time an immediate effort was begun to identify an alternative mud additive product program that would minimize any impacts on the 002 WTP.

Product Evaluations

Once it was resolved that the soluble oil and oil-based drill additives were having a significant negative impact on the plant, drill mud suppliers provided alternative additive products not composed of any oils and yet could provide the drilling productivity required. Lab clarification response testing was conducted on several products/programs that were supplied and the strongest candidates were tested underground.

Lab Testing Results

All products supplied were dry products which eliminated the oils. Mainly, the replacement program suggested by three suppliers replaced the soluble oil product with dry CMC (carboxymethyl cellulose) and a dry polymer product for the emulsion polymer. Because both the CMC and polymer are soluble, it was apparent that residual levels of both products, if left untreated, would still remain as residuals in the water reporting to the 002 WTP feed, leading to continued significant polymer overdose situation and 002 WTP problems.

The plan developed was to precipitate the CMC and dry polymer product residuals using a cationic epi-dma product, which is commonly referred to as organic polyamine coagulant. Polyamines are rarely used for mineral coagulation because the molecular structure is not particularly conducive to neutralizing mineral surface anionic charges. For organic substrates, however, polyamines are often particularly effective when a coagulant is required.

Lab testing identified that the Mi Swaco company drill additive combination of Platinum Pac Mi Swaco brand UL, which is a dry CMC product, and Poly Plus LV, which is a low molecular weight dry anionic polyacrylamide, used at a 50:50 ratio could provide very good results. But precipitating the additives with a polyamine product supplied by Zeroday Enterprises, LLC (Z Clear™ 129) was definitely required to achieve low supernatant turbidities. In these lab tests, 1-2 NTU clarities were consistently achieved with this mud additive suite and precipitation treatment program (Fig. 11).

Field Evaluations

In the field evaluations, the Mi Swaco synthetic drill products completely replaced the existing oil based products.

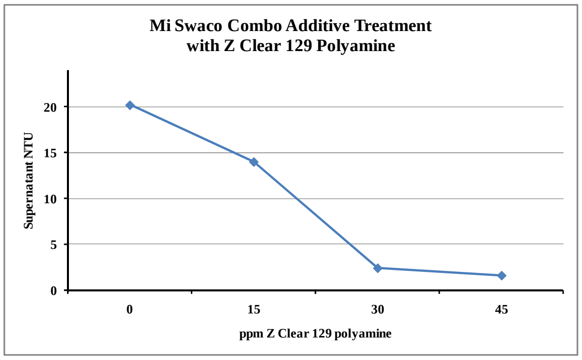

Figure 11. Mi Swaco Synthetic Mud Lab Test Results

These products were used at the supplier prescribed combination use ratio and it was found that actual drilling efficiencies with these programs were comparable to those of the former program.

Water treatment plant performance superseded the importance of drill productivities, ultimately resulting in a stoppage of drill fluid usage until the proper mitigation methods could be instituted. Rather than wait a couple of weeks for the initial polyamine delivery, available organic DADMAC (diallyldimethylammonium chloride) coagulant was initially used without good results. Response of the program on the 002 WTP was not significantly improved over the former program. From a chemical precipitation standpoint this was not unexpected. While both products are organic cationic coagulants, their chemical structures are different which impacts their efficacy in this type of application.

When the Z Clear 129 arrived and was used in precipitating the spent drilling mud at the drill sump, the results were immediate. The 002 WTP process control measurably improved and the plant rapidly, with optimization, consistently achieved < 1 NTU filter discharge clarity levels. Furthermore, the water treatment plant coagulant and flocculant dosages decreased by at least 75% and improved flocculation was observed in the flocculation tank.

Optimizing Mud Additive Use

Removing the oils from the mud additive suite was felt to be an important improvement that minimized potential surface interference in 002 WTP coagulation-flocculation. Key, though, was precipitating the synthetic mud additives in the drill sump and allowing separation before pumping the water to the surface for treatment. This is actually a fairly simple process of pumping the polyamine, via a Masterflex peristaltic pump, directly into the sump at the point where the spent mud is injected (Fig. 12). The polyamine mixes and rapidly precipitates the drill mud.

Figure 12. Z Clear 129 Injection Through Pump Tube

The synthetic mud formulation mixing procedure uses 2 cups each of the CMC and dry polymer products in 300 gallons of water. Drilling typically requires 20 gpm of the mix. Following much trial and error, optimum polyamine feeding rate was determined to be roughly 60 cc/minute. There is visual precipitation and the organics settle out in the sump as can be seen in Figures 13 and 14.

When the sump begins to fill with insoluble precipitated chemical and drill cuttings, it is mucked out and the precipitate is disposed of underground. The chemicals pose negligible environmental or health hazards. Photos in Figures 15 and 16 show the synthetic mud additive mixing system and polyamine feeding systems, respectively.

Due to underground logistical issues and surface water treatment operational constraints, only one drill rig is allowed to use synthetic drilling fluids at any given time.

Figure 13. Mud Sump Showing Precipitated Mud

Figure 14. Another Photo Showing Precipitated Mud in the Sump

Figure 15. Dry Synthetic Mud Mixing System

Figure 16. Polyamine Feed Pump from Tote

Summary

Since the mud additive suite was changed to dry, synthetic non-oil based products and the in-sump precipitation treatment program implemented, Lucky Friday's 002 WTP operation has been providing excellent results. Fairly consistent <1 NTU filter effluent discharge target levels are achieved. While these particular changes were only a part of the overall 002 WTP optimization and modification efforts, achieving the target discharge clarity levels absolutely would not have been possible without resolving the issues posed by the mud additive program.

Figure 17 provides the process clarity trend lines from late November 2008 through August 2010 showing the significant progress made and process stability achieved.

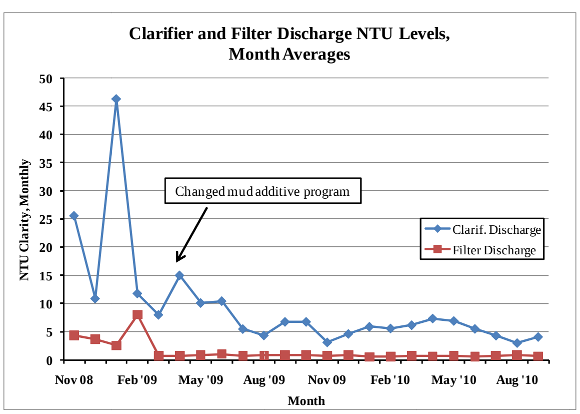

Figure 17. 002 WTP Clarifier and Filter Discharge performance

Further, there were dramatic decreases in the chemicals used. The graphs in Figures 18 and 19 show the significant decreased coagulant and flocculant dosages required as process optimization progressed and the mine water NTU clarity levels fed to the 002 WTP plant were reduced. Note the mine water NTU levels were not separately measured until after the synthetic mud drilling additive program was implemented. Further, the 002 WTP coagulant program from November 2008 to February 2009 utilized an organic coagulant that did not provide acceptable results. Therefore, the coagulant program was changed to an inorganic aluminum chlorohydrate coagulant (Z Clear 252/254 products) which provided much better coagulation performance.

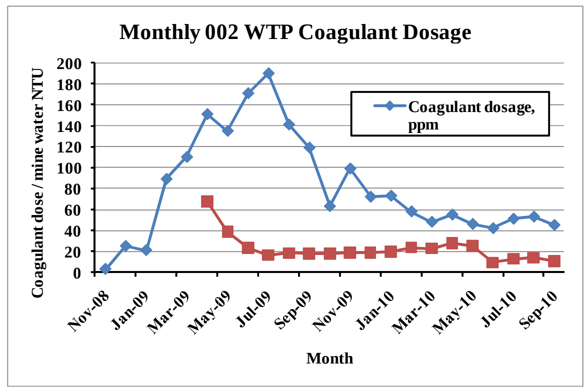

Figure 18. Coagulant Dosage Trend

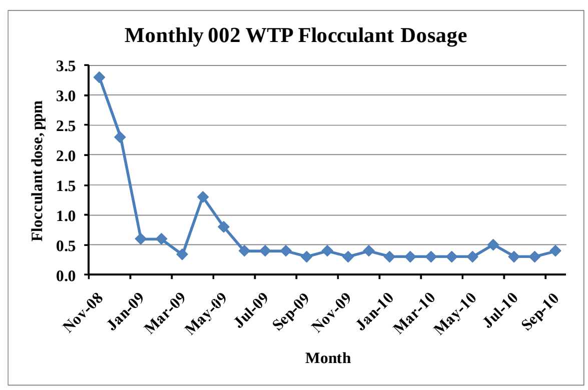

Figure 19. Flocculant Consumption Trend

The authors feel that based on these findings and experiences, Lucky Friday is likely not the only mine that had/has, at least in part, water treatment plant upsets due to the impact of diamond drilling mud chemical additives used. From a surface chemistry standpoint, mechanistically this must pose at least a background water treatment plant issue at other mines where mine water contains synthetic drill mud additive residuals. We found that this issue can be effectively controlled taking appropriate treatment measures.

Reference

1. Chapman, R. (2000). *History of Idaho's Silver Valley, 1878-2000.* Chapman.