Restoring Performance of RO Membranes with Severe Scaling from Contaminated Tailing Pond Water Source using Specialty Cleaners

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Introduction

Tailings are residues left over after treatment of minerals to clean them valuable fraction of an ore. Tailings from mines are discharged as a slurry, which is a mixture of ore particles and water, to a tailings storage facility where water is subsequently recovered and recycled or disposed of [1].
The use of membranes at mining sites has exploded in the last five years. Mine waters are complex, featuring extremes of pH and high levels of calcium sulfate, metals and leaching agents. These characteristics lead to challenging scaling and fouling of RO membranes. Membrane plants for mining are used for various applications including: enhancing metal recovery, improving purification of water for reuse, reducing tailing storage and recovering leaching solution. This paper discusses a reverse osmosis (RO) water treatment process used to recover and purify tailings water contaminated with mining waste to make it safer for return to the environment. Part of this treated water is recycled for subsequent use in the mill, significantly reducing the volume of water needed to be withdrawn from the environment for mill activities.

This paper focuses on an upgraded system, that treats up 1000 m3/hr of tailings water, producing high quality water that is well below the applicable environmental quality guidelines. This RO system was experiencing several performance issues, mostly fouling and scaling related, that would result in low normalized permeate flow and cleanings every 1-2 weeks with generic cleaning solutions. The variable water quality and also the lack of antiscalant pre-treatment meant that that scale control in the third stage was especially difficult. A membrane autopsy was performed to understand the foulant composition. This paper will discuss the autopsy results in detail and will also address the selection process of an appropriate specialty cleaner based on the foulant composition, foulant location and plant design. The performance recovery after cleaning with specialty high, low and silica-specific cleaners will be discussed and compared to historic data of the system when cleaned with generic cleaners [2].

For remote locations, such as the case at this site, specialty cleaner selection is often influenced by several factors. Ergonomics, safety, ease of use, extreme storage conditions and transportation are not frequently used as a criterion for chemical selection but were considered in this specific case during the chemical selection process. Finally, savings by reducing system downtime through more effective and less frequent CIPs will be emphasized. Although fouling is often an unavoidable part of RO water treatment, the benefits and advantages of specialty cleaners for this specific case study are highlighted through this paper.

Project Description

The focus of the work covered by this paper is one of the Uranium milling operations. The tailings generated from Uranium milling activities are stored in in-pit storage facilities. The overall dewatering system that treats the tailings from the in-pits is divided into two parts: contaminated water system which is collected and transported to the mill for reuse; and clean water system which discharges to the environment. A RO plant was installed specifically to reduce contaminants in the dewatering effluent clean water that is returned to the environment.

The RO unit feed water source is tailings water from the nearby holding in-pits which are high in transition metals and silica. The feed water quality is summarized below:

Parameter	**mg/L**	**Parameter**	**mg/L**
Sr	0.3	Cl	6.8
pH	7.8	Nitrate	3.21
Ammonia	0.1	SiO2	15
Iron	0.56	F	0.17
Ca	93.19	Na	17.3
Mg	8.99	TDS	496
Al	<0.005	K	5.4
Mn	0.64	P	<0.01
Ba	0.015	Turbidity (NTU)	0.1
SO4	298.5	HCO3	15.8

The well water is pre-treated with a filter system to oxidize and remove iron and manganese.

The RO plant technical specifications are summarized below:

Type	Single Pass
Configuration	3 stage 12:5:2
Elements / Vessel	8" x 6M
Feed water	well water at ~300 mg/L TDS
Typical RO Feed	TDS at ~500 mg/L
RO Recovery	90%
Typical Salt Rejection	95-98%
Feed Capacity Per Unit	5000 GPM

Any RO plant will begin to foul the moment it is put in operation. Performance losses in RO systems from fouling will occur and the severity of fouling depends on several factors broadly based on feed water quality and plant operating parameters, as well as pretreatment system. Clean In Place (CIP) operations for cleaning membranes are necessary to remove foulants and restore membrane performance. The mechanism of the CIP consists of introducing the chemicals to the membranes, recirculation and soaking times, then flushing the chemicals from the system. In addition, maintaining proper operation of the plant helps the water treatment plant operations team meet water quality goals for successful mining operations.

Cleaning is also recommended before system shutdown and as part of a preventive maintenance program. A general rule of thumb for CIP is when one of the following occurs:

- The normalized permeate flow drops by 10%
- The normalized salt passage increases by 5 - 10%
- The pressure drop across the membrane increases by 10 -15%

The 3 parameters above are considered as key performance indicators (KPIs) for monitoring system performance and initiate CIP protocols. For the mining site in particular, two KPIs were identified and monitored daily in order to optimize the performance of the RO plant and associated operating costs: *the permeate flow and differential pressure*. Monitoring permeate water quality is important since it is discharged to the environment if it is within acceptable discharge limits.

- *Permeate flow:* Changes in permeate flow rate could be either due to the accumulation of foulants on the membrane surface or due to changes in the operating conditions (feed water temperature, feed pressure, water quality etc.). In order to differentiate between these two phenomena, permeate flow was normalized to correct for any variations.

- *Differential pressure:* Also called pressure drop or the hydraulic differential pressure and represented by ΔP, is the difference between the inlet pressure to the lead membrane element and the reject stream pressure coming off the tail elements. Changes in ΔP are commonly attributed to foulants accumulating on the membrane surface and brine spacer vexar, restricting the water passage through the membrane leaves inside the element. The ΔP is stable as long as the feed and concentrate flows and temperatures are constant.

Both KPIs indicate the fouling potential and extent of scaling, which are the main causes of longer system downtime, frequent CIPs, ineffective membrane cleans and premature membrane replacements. These KPIs will be used to compare the cleaning efficiencies, at the mining site, of specialty cleaners against generic cleaners by evaluating current and historic normalized performance data of the system.

Membrane Autopsy and Foulant Analyses

Fouling has been an issue with the main foulant being silica, barium sulphate, iron and/or filter media from the greensand filters. An independent autopsy was performed to analyze and identify the foulant types on the membrane surface.

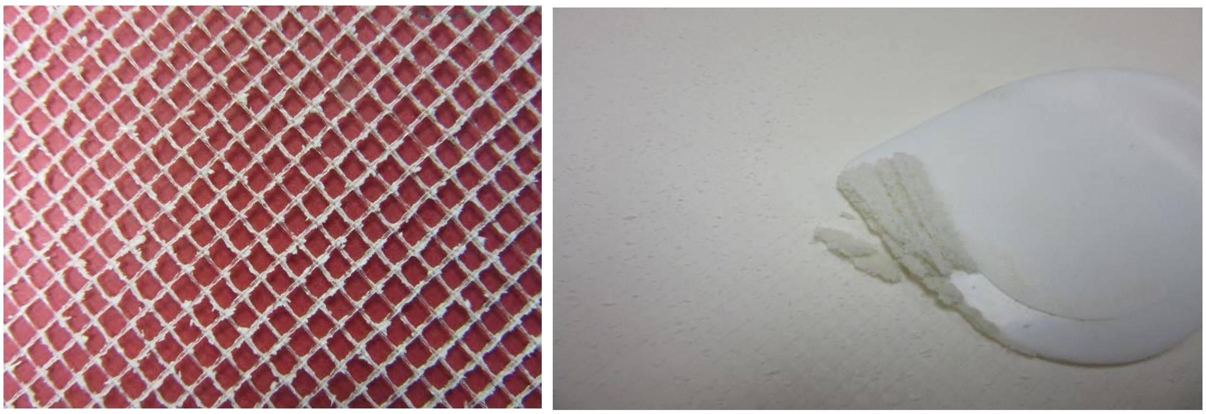

Figure 1. White foulant present on feed spacer and membrane surface.

Loss on ignition done on the sample scrapped from the surface showed that the foulant was 94% inorganic scale and about 6% organic material. SEM/EDS done on the white residue from the membrane surface showed that the foulant composition to be mostly Si (92%) and Al (3%) .

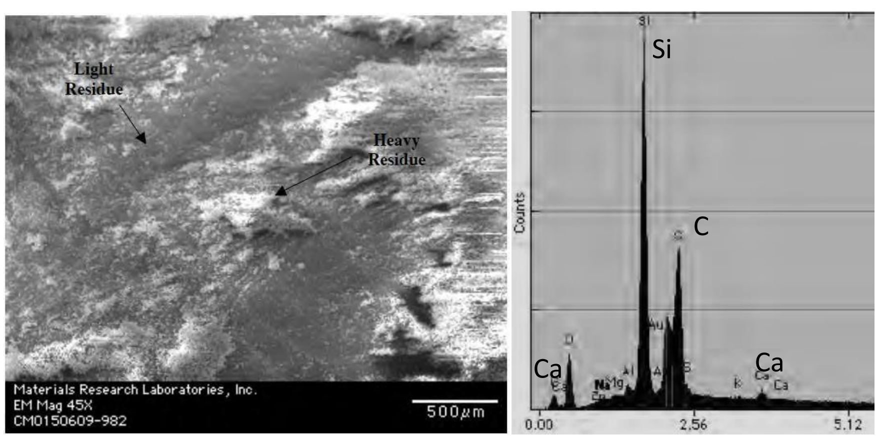

Figure 2. SEM/EDS of white foulant powder shows presence of Si.

The Fourier Transform Infrared (FTIR) signatures indicate that the foulant/scalant consisted primarily of silica and water. The element also showed signs of physical damage from permeate back pressure, which was notice through blistering on the membrane surface.

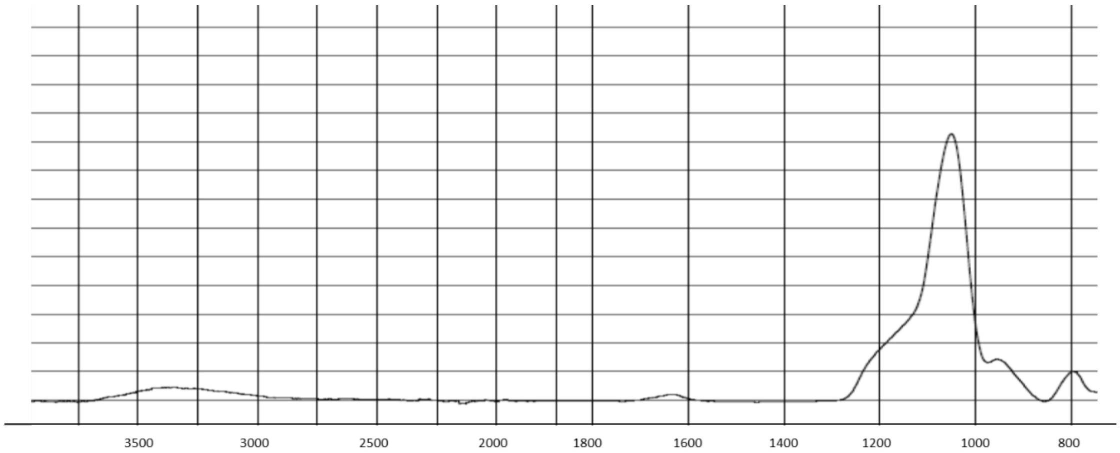

Figure 3. FTIR spectrum confirms the presence of Si.

The system was subjected to high temperature cleanings with generic high pH cleaners such as NaOH solutions, but the system struggled to run at peak performance and had to be cleaned frequently. A case of using PWT specialty cleaners is presented and the corresponding performance improvements are discussed in the results section.

Safety and Ergonomics

Chemical cleanings subject the water treatment operator performing the CIP to various risks. The risk factors are ergonomic: lifting heavy bags of chemicals, and safety related: protection against fumes and chemical dust. These considerations were also evaluated during specialty cleaner selection process. Liquid specialty cleaners were selected because they could be pumped into the CIP tank eliminating the need of heavy lifting of chemicals. Since the liquid specialty cleaners are buffered, they maintain pH throughout the cleaning cycle, reducing the chemical handling required for continued pH adjustment during the CIP. The specialty cleaners used do not release any fumes and the buffered cleaners eliminate the need for pH adjustment with acid and alkali powders, limiting exposure to respiratory danger.

A 2% CIP solution concentration is recommended for most liquid specialty cleaners to produce effective cleanings. Switching to specialty liquid cleaners provided more effective cleans and a less rigorous CIP regime, ultimately lowering cleaning frequency. This equates to less specialty cleaner storage space, which is especially important for sites, such as mining operations, that are located in remote areas with limited space and high transportation costs associated with shipping chemicals to cold weather climates where temperatures can drop to below freezing.

Results and Discussion

One of the trains was chosen to run pilot studies on to check the effectiveness of specialty cleaners. Train X was deemed the best performing train with the best performance efficiency, producing the longest run times. It was important to select a train that was not impacted by irreversible fouling, otherwise the results from the CIP would not be representative. Figure 4 below shows the normalized permeate flow of Train X with three CIPs done within a 6-month period (October to March). The first two CIPs were done using generic cleaners, and the third CIP was done using the specialty liquid cleaner products provided by PWT Chemicals. RO elements were not replaced during the 6-month pilot period.

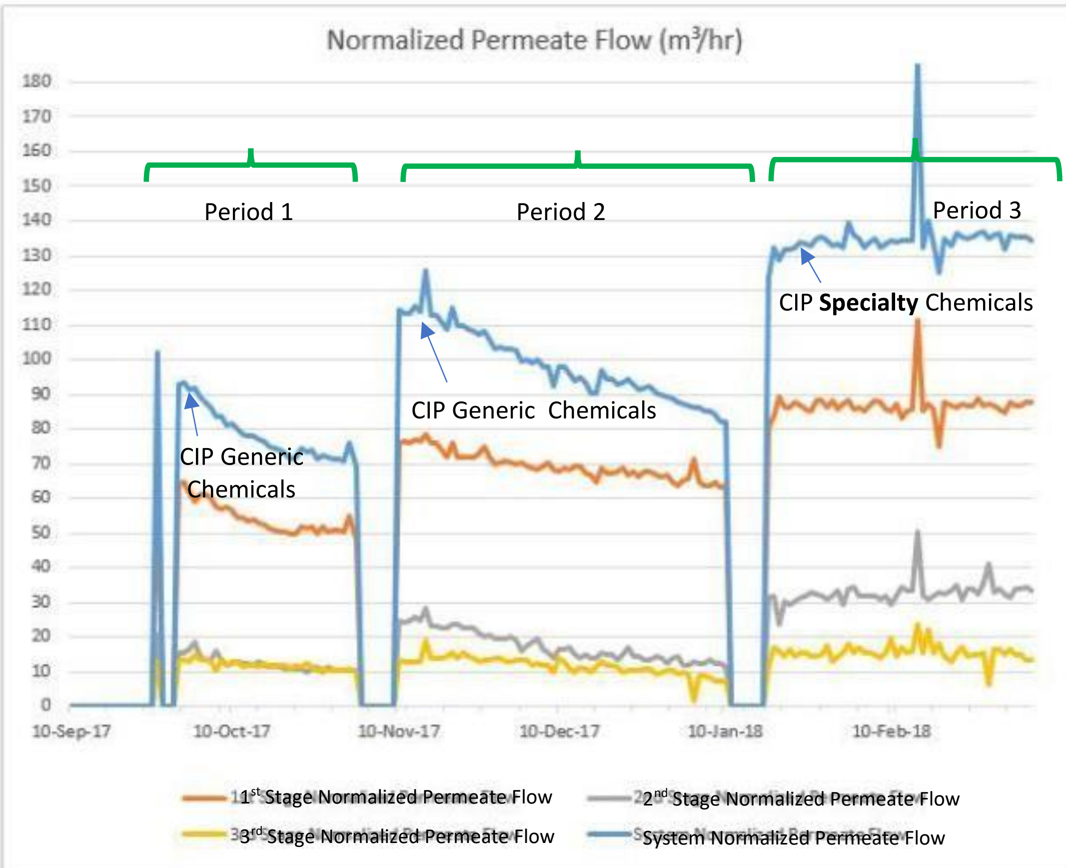

Figure 4. Normalized permeate flow split into 3 time periods: Train X.

The normalized flow trends during Periods 1 and 2 on Train X are representative of what is observed on primary skids of all Trains, after performing a CIP with generic chemicals. Normalized flow shows an exponential drop after generic cleanings in Period 1 and Period 2 cycles. This is a clear indication that the elements are fouling/ scaling rapidly and that the cleans are not fully removing the foulant/scale. With generic cleaners, the average runtime before a skid technically requires a cleaning is about 1-2 weeks, although this was seldom conducted on time.

Figures 5 and 6 below look at the Periods 1 and 2 individually. A closer inspection shows an average flow loss of 0.58 m3/hr/day during Period 1 (Figure 5). In Figure 6, we observe an average flow loss of 0.53 m3/hr/day during Period 2.

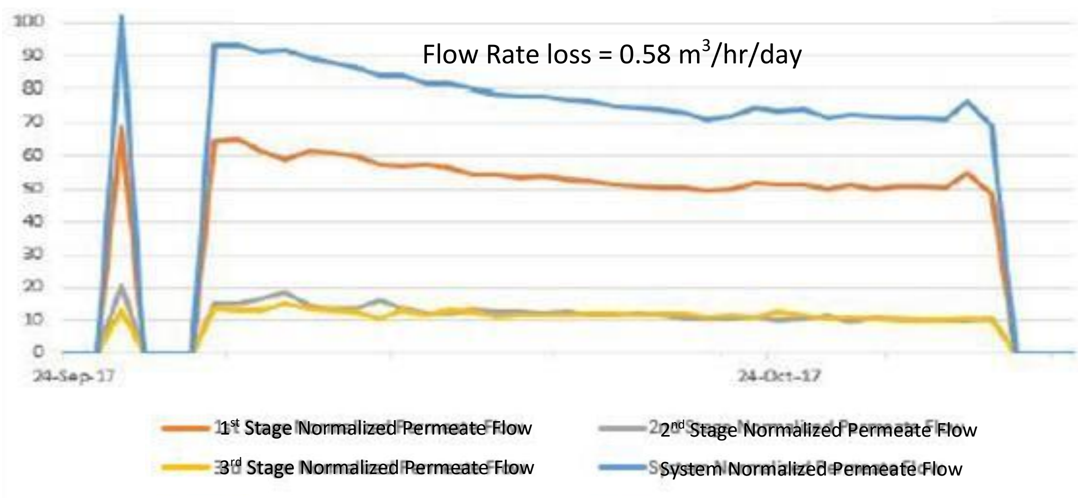

Figure 5. Train X Period 1- Normalized Permeate Flow (m^3/hr)

The system normalized flow dropped from 93.1 m^3/hr to about 81.3 m^3/hr, which is greater than 10% drop in flow in 10 days. This triggers the need to clean to maintain system performance. Period 2 represents the system performance after initial clean.

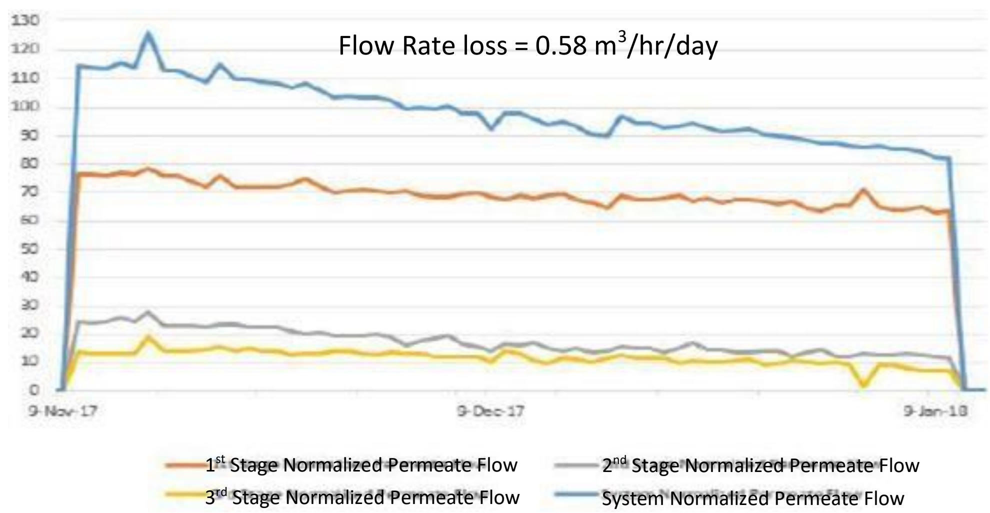

Figure 6. Train X Period 2- Normalized Permeate Flow (m^3/hr)

During Period 2, the system normalized flow dropped from 115 m^3/hr to about 92.4 m^3/hr, which is ~20% drop in flow in 25 days. This again triggers the need to clean to maintain system performance.

Due to the nature of foulant (silica) and its location, the drop in permeate flow was more apparent for stage 2 (grey curve) and stage 3 (yellow curve) compared to stage 1 (see Figure 6). From the autopsy done on the RO element taken from stage 3 described above, Energy Dispersive X-Ray Spectroscopy (EDS) elemental analyses identified the white residue as silicon based and as the primary foulant/scalant. Furthermore, the FTIR analysis indicates that the foulant/scalant consisted primarily of silica and water.

Generally speaking, when silica scaling occurs, it can be rapid and is commonly detected by a loss of flow in the second or third stages. Silica can exist in a wide variety of structures, ranging from a simple colloidal silicate to a more complex polymeric material. Cleaning strategies differ based on the form of silica. Normally, high pH NaOH-based cleaners are recommended for cleaning polymerized silica. PWT's silica specific cleaner, was used in conjunction with other Specialty cleaners for cleaning silica scale from the membrane surface.

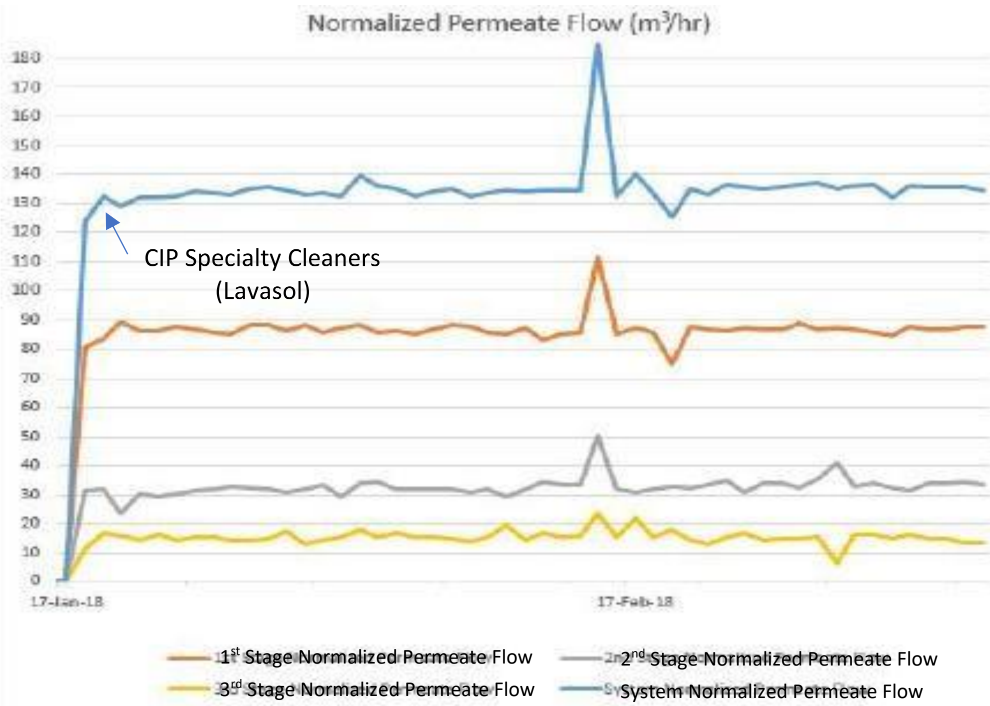

Figure 7. Train C Period 3: Normalized Permeate Flow

Figure 7 above shows performance of Train X after the onsite trial with the cleaners. The normalized permeate flow remains stable with minimal drop in flow. The average flow loss during this period is 0.037 m3/hr/day. This flow loss is minimal (94% lower) as compared to average loss in flow rates of Periods 1 and 2.

There is also a considerable gain in the normalized permeate flow after using the specialty cleaners during the CIP in Period 3. The permeate flow in Period 3 (134m³/hr) increased by 16% compared to the flow at the beginning of Period 2 (115 m³/hr) and is 45% higher than the permeate flow at the beginning of Period 1 (92 m³/hr). Even after 50 days, Train X showed stable performance with no loss in normalized flow rates. This is significant as the system is able to produce permeate water consistently without having to stop for a cleaning cycle.

In addition to monitoring the normalized permeate flows, differential pressure trends also indicate the health of a skid. Train X particularly excelled in having lower differential pressure and overall lower inlet pressures, which indicates better overall performance.

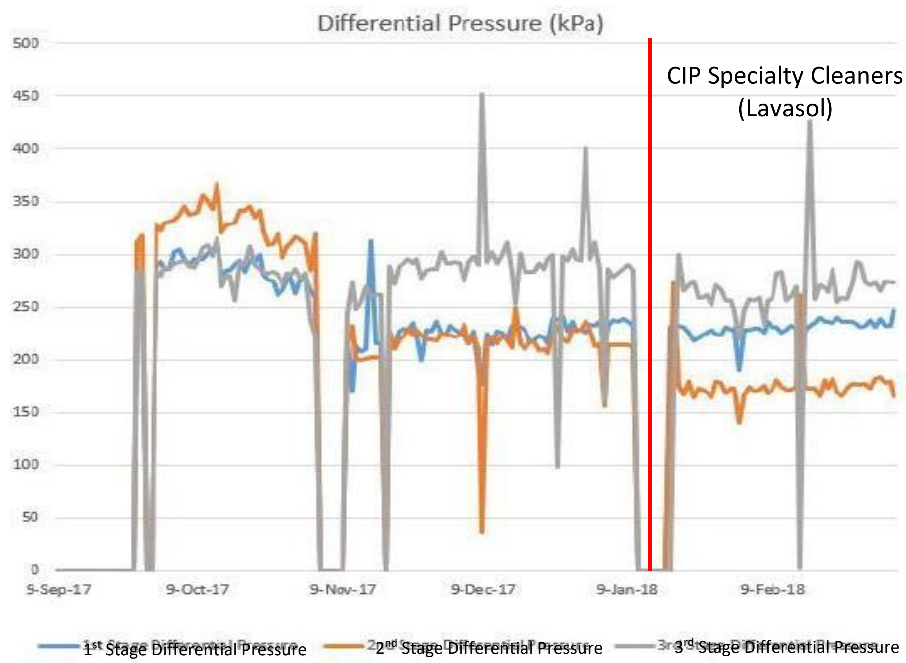

Figure 8. Train X: Normalized Differential Pressure variations of the system.

There is a noticeable drop in differential pressure across the 2nd (orange line) and 3rd (grey line) stages. This is a clear indication that the specialty cleaner was effective.

The average runtime before a train would require a clean (normalized permeate flow drops 10%) was about 1-2 weeks with generic cleaners. Unfortunately, trains were operated past this early indicator and were cleaned on rotation or when badly needed, when normalized permeate flow dropped close to ~25% as seen in Figure 9 below. In Period 1, the normalized permeate flow dropped by 25% before a cleaning was performed. In Period 2, the normalized permeate flow dropped by 26% before a cleaning was performed. This is not recommended as any delay in performing a clean can result in the foulant becoming more compressed on the surface of the membrane and becoming much more difficult to clean and remove.

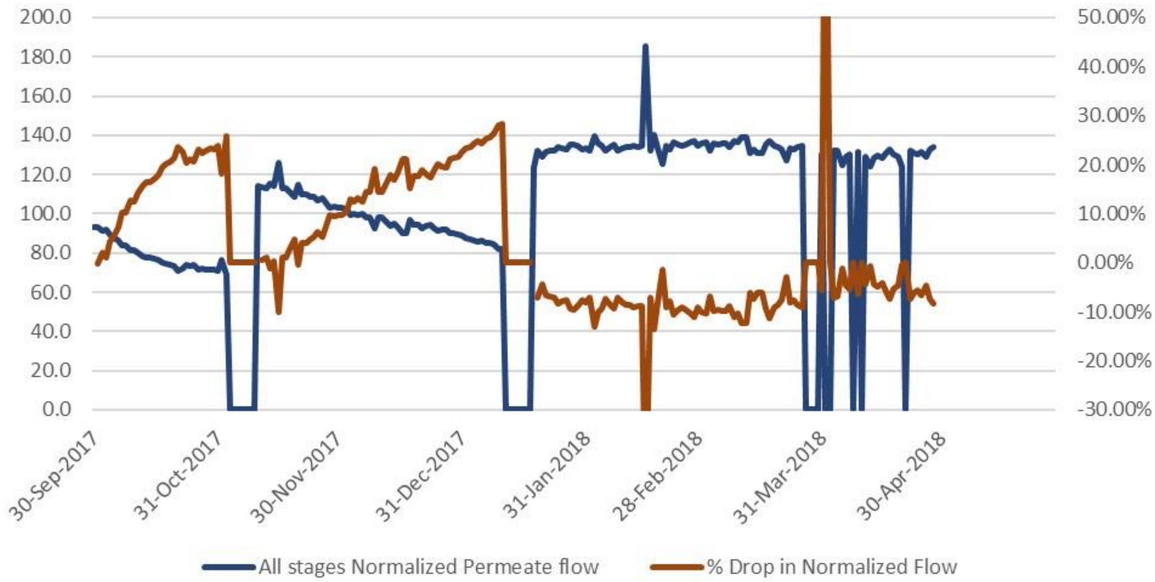

Figure 9. Percent drop in Normalized Permeate Flow

A Pareto chart was created to track all the instances for system downtime. Figure 10 below shows the percent split between factors for system shutdowns. To date, an accumulated 10,000 hours (417 days) of downtime have been contributed to cleans and membrane changes. That is roughly 1.25 million m^3 of brackish water that was untreated in the 20-month period due to downtime from system cleanings.

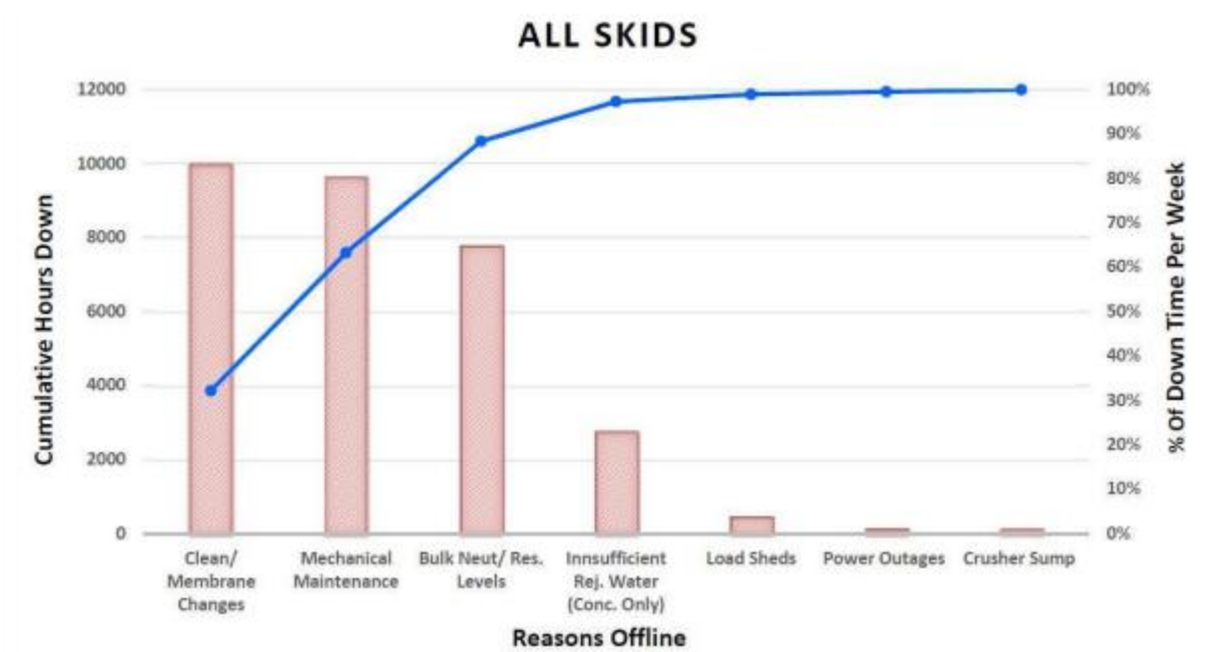

Figure 10. Chart to track downtime factors for the RO system at the mining facility.

The use of specialty chemical cleaners to selectively clean foulants from the RO system at this mining site showed obvious benefits over generic cleaners. In a short time of 8 weeks, the trial with specialty cleaners more than doubled the run time for Train X, effectively increasing clean water production and also lowering the chemical consumption of cleaners which in turn lowers operations cost. After the success of cleanings on Train X, the same cleaning procedure was adopted for the other trains at this site.

The operations team spent nearly 30% of their time per week doing ineffective CIPs. Highly skilled human capital resources are very scarce and inimitable in mining operations. This meant that a huge portion of the human capital resource was needed for a secondary activity, to perform a CIP, considering the fact that this is not a complicated task but rather a time consuming one.

Using more effective specialty cleaning chemicals equates to lower frequency of clean, decreasing the system downtime and associated time spent on secondary tasks. Which means that the operations team can free up and allocate its human capital resource for more important and strategic activities. These are important considerations which are often ignored during chemical cleaner selection process.

Summary

Preliminary results from a trial clean using specialty cleaners from PWT Chemicals on one Train X showed a very positive response. The Specialty products PWT recommended effectively removed foulants and restored system production capacity and efficiency. The specialty cleaners were selected based on the autopsy analyses and were chemically designed to specifically treat and maintain RO membrane elements fouled with Si and $BaSO_4$ scale and organic materials. Along with improving Key Performance Indicator’s (KPI’s), the specialty cleaners offered a safer, more ergonomically appropriate chemicals to handle.

References

1. Bascetin A., Tuylu S., Adıguzel D., and Ozdemir O., New Technologies on Mine Process Tailing Disposal, 2016, 63.
2. White M. J., Masbate J. L., and Gare S. G., Reverse Osmosis Pretreatment of high Silica Waters: Water Technologies and Solutions Technical Paper.