Reverse osmosis technology
helps optimize phosphate mine performance

by Chris Howell and Paul Hoeferlin

PotashCorp – Aurora in North Carolina is the largest vertically integrated phosphate mining and chemical plant in the world. The facility produces sulfuric acid on site, which is reacted with the phosphate rock to produce phosphoric acid for use as feedstock for phosphate products.

PotashCorp's Aurora phosphate mine, in Beaufort County, NC, operates four low pressure boilers and four high pressure boilers to meet its process steam requirements. Maintaining these boilers is critical to meeting production demands.

Processing phosphate ore into phosphoric acid requires large amounts of sulfuric acid and steam. Ore is mined from the phosphate deposit with large bucket excavators after 9 to 30 m (30 to 100 ft) of overburden is removed. The phosphate ore is mixed with water to make a slurry that is pumped to the mill. Elemental sulfur is burned in the presence of air to make sulfuric acid. This process is highly exothermic and boilers produce steam while cooling the process. The phosphate ore is reacted with sulfuric acid and the resulting products are refined into different grades of phosphoric acid for fertilizers, feed stock and food additives.

Plant operators at the mine were challenged with boiler feed water that was high in silica and other contaminants. As a result, boiler operations were experiencing difficult, labor-intensive operations and equipment deterioration. This resulted in higher operating costs and diminished processing performance. The facility was operating an aged boiler feedwater pretreatment system that included warm lime softening followed by pressure filtration and a cation/anion/mixed bed demineralizer system. The demineralizer required frequent regeneration and chemical usage was high and costs were difficult to predict.

Depressurized well water (DPW water), used for plant utility water and boiler makeup, is very high in silica, in the range of 60-70 ppm. Silica can form scale at pressures below 600 psig. Above 600 psig, silica starts to volatize, carrying over with steam to potentially form deposits on downstream equipment and processes.

Mine officials decided to upgrade the boiler feedwater pretreatment system to a state-of-the-art reverse osmosis (RO) membrane system. This new system, which started up in March 2009, has improved operating performance and reduced water consumption and overall operating expenditures.

World's largest

The Aurora phosphate operation is a subsidiary of the Potash Corporation of Saskatchewan (PotashCorp). The mine is the largest vertically integrated phosphate mining and chemical plant in the world. The facility produces sulfuric acid on site, which is reacted with the phosphate rock to produce phosphoric acid for use as feedstock for phosphate products. The operation has an annual capacity of 6 Mt/a (6.6 stpy) of phosphate rock, 1.2 Mt/a (1.3 million stpy) of phosphoric acid and 181 kt/a (200,000 stpy) of feed phosphate. Steam is generated as part of the sulfuric acid production process. It is also used in the generation of electrical power for both the plant and resale.

To ensure the new pretreatment system would meet boiler feed water requirements, mine officials teamed with Crown Solutions, a business unit of Veolia Water Solutions & Technologies, to conduct testing using a pilot trailer custom built for this specific application. The 5.7-L/min (1.5-gpm) pilot reverse osmosis system was scaled to the project, to precisely match the hydraulics of the proposed full-scale system. Operating at only 5.7 L/min (1.5 gpm), the pilot system was designed with the same hydraulic flow rates across the multimedia filters and the softeners as the proposed full-scale system.

During initial testing, the pilot unit's silt density

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index (SDI) test apparatus lost flow within five minutes of operating due to particulate fouling, and membrane performance showed poor results. It was subsequently determined that the raw process water contained very fine particulates (98 percent less than 2-micron) that flowed through the multimedia filters and softeners, fouling the RO membranes.

Once a specialized blend of coagulants was developed and used, the pilot system significantly lowered SDIs to the 0.5 range. Reverse osmosis with an SDI below 3 is considered acceptable, so an SDI of 0.5 was a significant improvement.

The final results of the eight-week pilot test showed good filtration results, good operation of the water softener and good operation of the membrane system. The RO system produced high quality water, with the operation showing no signs of fouling or scaling. Based on the pilot results, the mine gave the green light for the installation of the full-scale RO system.

System overview

The new boiler feed water pretreatment system includes multimedia filtration (MMF), ion exchange softening and reverse osmosis. DPW water for plant utility water and boiler makeup is pumped out of the mine from deep wells at roughly 145 L/sec (2,300 gpm).

Upstream of the multimedia filtration, coagulant and sodium hypochlorite are fed into the raw water at two surge tanks. These are converted, old warm lime softening vessels with about 76 L/sec (1,200-gpm) nominal capacity each. Sodium hypochlorite is used as a biocide to destroy any biological contaminants in the feed water and minimize the ability for microorganisms to grow within and contaminate the water treatment system.

Water from the surge tanks is then pumped to five 2.4-m (96-in.) multimedia filters with a flow capacity of 29 L/sec (460 gpm) per filter. The down-flow multimedia filtration system is designed to remove total suspended solids (TSS) from the DWP makeup water. All filters run simultaneously in automatic mode. When this system goes into a backwash sequence, RO reject water from a backwash water storage tank is used for backwashing. The use of RO reject for multimedia filter backwashing optimizes water usage and minimizes the virtual water footprint.

The filtered water flows to the softener system, which includes seven softeners, each with a flow rate of 21 L/sec (328 gpm). The system is designed to automatically manage the number of softening units online, based on the number of reverse osmosis units online in standard automatic operation. During regeneration, brine is injected into the system to reverse the ion exchange process. The system includes the ability to use brine reclaim where a significant portion of the brine waste is recaptured and sent to a brine reclaim tank to be used in future regenerations.

Table 1

Specific water contaminants that are present at the beginning of each process, and what remains after processing.

Multi-media filters		
	Influent	**Effluent**
Turbidity (NTU)	8	<1
SDI_{15}	>6	<1
Conductivity (uS/cm)	650	650
Hardness (ppm, as $CaCO_3$)	450	450
1) Primarily for TSS removal 2) Addition of coagulant to aid in particulate removal 3) Addition of sodium hypochlorite to kill biological		
Ion exchange softeners		
	Influenet	**Effluent**
Turbidity (NTU)	<1	<1
SDI_{15}	<1	<1
Conductivity (uS/cm)	650	670
Hardness (ppm, as $CaCO_3$)	450	<1
1) Units regenerated with a 12% brine solution 2) Serves as a form of ion exchange; NOT removal		
First pass RO machine		
	Influenet	**Effluent**
Turbidity (NTU)	<1	<1
SDI_{15}	<1	<1
Conductivity (uS/cm)	650	10
Hardness (ppm, as $CaCO_3$)	<1	0
1) Antiscalant is injected upstream of this system 2) Bisulfite is injected as a means of biological control and to bind any remaining free chlorine		
Second pass RO machine		
	Influent	**Effluent**
Turbidity (NTU)	<1	<1
SDI_{15}	<1	<1
Conductivity (uS/cm)	10	<1*
Hardness (ppm, as $CaCO_3$)	0	0
* Heavily dependent on amount of CO_2 in feedwater		

The softener system includes seven softeners, each with a flow rate of 21 L/sec (328 gpm). The system is designed to automatically manage the number of softening units online. During regeneration, brine is injected into the system to reverse the ion exchange process.

This lessens the amount of virgin brine required for the process and further reduce the water needed to operate the process.

The softening resin is also a specialized resin — a shallow shell technology (SST) resin — by Purolite resin company. The polystyrene resin keeps ion exchange sites to the outer 60 percent of the resin beads, which allows for more efficient regenerations and lower salt usage compared with other more conventional resin types.

The RO system is designed to operate as a single and double pass system. All four RO units have a 16:8 array and 144 membranes. Units A, B and C are single pass units. They are always fed with soft water from the upstream softeners. Unit D can operate in both first pass mode (fed water from the softeners) or second pass mode. If Unit D acts as a second pass unit, permeate off the first pass feeds the second pass and produces high quality water.

The concentrate/reject of the units operating in the first pass mode, which is highly concentrated in TDS, is sent to waste. This reject is also captured in the backwash tank for the MMF/softener backwash. The concentrate of Unit D, if operating in second pass mode, is recovered and sent to the first pass RO feed.

RO units A, B and C, acting as first pass, have a designed recovery rate of 70 percent. RO Unit D, when acting in second pass mode, has a designed recovery rate of 90 percent. A major portion of the first pass water is process water used in Potash Corp-Aurora's low-pressure boilers. Second pass RO water is used for high purity processes and in the plant's high-pressure boiler. In addition to filter and softener backwash, RO reject water can be used for softener regeneration and cooling tower makeup.

In effect, Potash Corp-Aurora operates a two-stage RO in which two RO systems are running in series with the permeate of the first acting as the feed to the second. Staged or series RO operation is typically done when a single-stage RO system does not produce the required quality of product water. For Potash Corp-Aurora, two-stage RO is justified because the additional expenses of operating the second RO system is lower than alternative forms of polishing the first-stage RO permeate to reach a higher quality of final product water.

The first pass RO machine produces a permeate stream and a concentrate stream. The magnitude of these flows depends on the recovery of the RO system. Running at 70 percent recovery, the first pass RO reject stream is 3.33 times concentrated versus the feed water. Since the silica in the feed water is 60 to 70 ppm, this means that the silica in the first pass RO reject stream is 200 to 234 ppm. Based on the solubility of silica, this could cause a scaling issue in the concentrate stream of the RO machine.

A key issue regarding the success of the project was based on developing an anti-scalant blend that could handle the high silica levels. A silica anti-scalant program using this blend was implemented to keep the membranes at optimal performance. Based on the chemistry of the water, it was expected that the membranes would require cleaning every three months. In the initial operation of the system, four months passed before the first cleaning was required. The initial cleaning of the RO membranes restored full flow to the system, thereby indicating the anti-scalant program has been successfully implemented and is working well.

Improved performance

The new boiler water pretreatment system provides the PotashCorp-Aurora's facility several advantages over its previous system. Although the initial investment in the new technology was significant, there are substantial savings in maintenance, labor costs and chemicals. There are also the additional benefits of increased reliability and availability of the water plant, as well as the savings due to their extended project life.

The new RO system at the Aurora mining complex has consistently provided high quality feed water, ensuring greater reliability of its systems. It has also proven its sustainability and worth in several other ways versus the performance of the old system.

The RO technology now offers Aurora's water treatment operators an easier system to operate. It has significantly reduced maintenance demands at the plant and lowered the overall cost of boiler feed water operations. High quality boiler feed water is helping to ensure the maximum life of the boilers as well as optimal thermal performance to help the plant operate more efficiently. ■