FIRST ON-DEMAND POTABLE CERAMIC MEMBRANE SYSTEM IN U.S. MINIMIZES ENERGY AND WASTE

Dave Holland, Aqua-Aerobic Systems, Inc, 6306 N. Alpine Rd., Loves Park, IL, 61111
dholland@aqua-aerobic.com, 815-639-4470
Jim Keenan, City-County of Butte-Silver Bow, MT, 59701
Nathan Kutil, P.E., HDR Engineers, Missoula, MT, 59803

Abstract

The drinking water source for many municipalities is a lake or reservoir that is at a much higher elevation than the treatment plant, and the water must first be stored before pumping through the treatment system in order to prevent over-pressurization of the equipment. One such facility is the Basin Creek Water Treatment Plant in Butte, MT, where the overflow on the source reservoir is 175 feet above the plant. The Basin Creek Reservoir contains some of the most pristine water in all of Montana; for over 100 years, treatment consisted solely of chlorine addition for disinfection. But in 2011, a pine beetle infestation added extra organic material to the reservoir, which combined with the chlorine to form disinfection byproducts slightly above the required levels. As a result, the State mandated that the water be filtered prior to disinfection.

The City-County of Butte-Silver Bow (BSB) and its engineer, HDR Engineering, looked at the filtration alternatives and determined that a low-pressure membrane system would be the best choice, not only for lowering the organics in the water but also for removing harmful pathogens. Proposals were requested and their 20-year life cycle costs were compared. BSB decided to go with a ceramic membrane system because it was able to handle the higher inlet pressure, had a 20-year warranty, and generated much less wastewater.

The full-scale plant was constructed and placed on-line in May of 2017, designed to handle up to 7 MGD and undergo a clean-in-place (CIP) every six months. During the first year of operation, flows were as high as 7.4 MGD, yet the system was able to operate for over a year before needing its first CIP. The system is currently operating at more than 99.8% recovery, generating less than 14,000 gallons of wastewater per day. In addition, drinking water is typically provided to Butte using only the head from the reservoir with no pumping required, which results in an enormous power savings.

This paper describes the new system, how it produces excellent-quality water with minimal energy usage and waste production, and some of the lessons learned in the first nineteen months of operation.

Project Background

Existing Treatment

The County of Silver Bow is in southwestern Montana and has over 36,000 residents and 220 businesses, with an average potable water demand of about 11 MGD. To meet this demand, the county uses water from three reservoirs - South Fork, Moulton, and Basin Creek – four finished water storage tanks, and seven distribution zones, as shown in Figure 1.

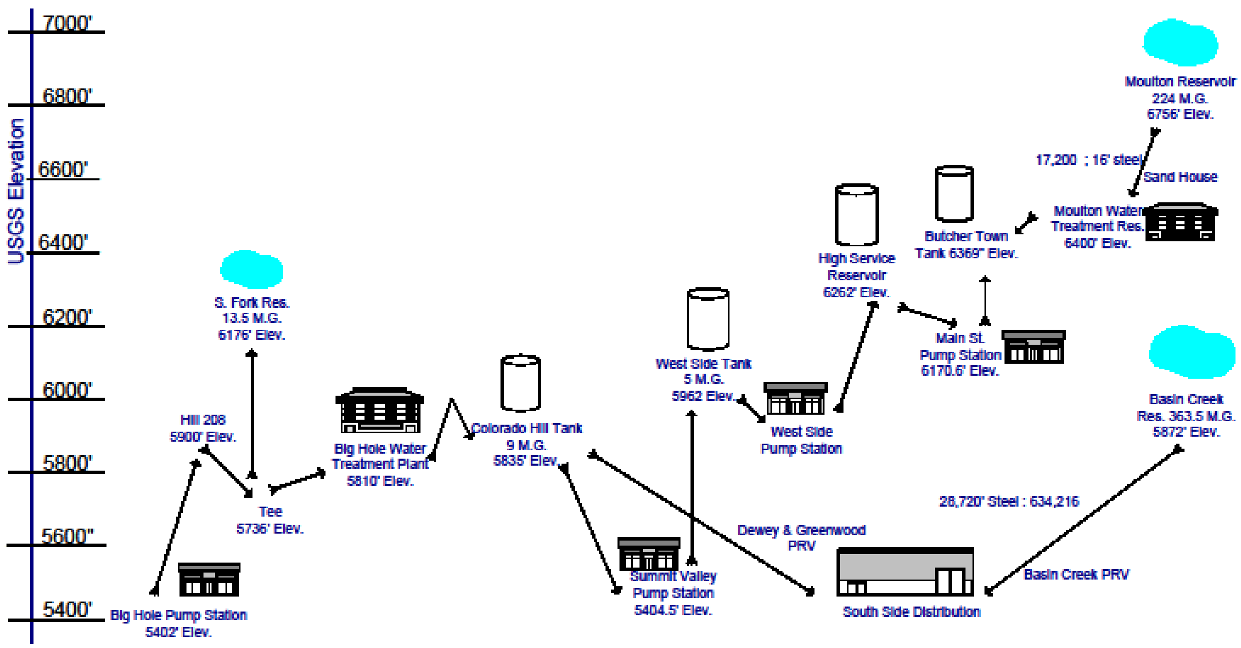

Figure 1 Butte-Silver Bow Drinking Water Sources, Pump Stations, and Plants

The Basin Creek Reservoir supplies an average of 3.25 – 5.5 MGD to the City of Butte, or about 40% of Butte's annual water demand. Table 1 gives the quality of the water in the reservoir, which, up until 2007, met all of the National Primary Drinking Water Regulations set by the United States Environmental Protection Association [USEPA (1991)], with the exception of the microorganism levels; therefore, treatment consisted solely of disinfection with chlorine. The natural organic matter (NOM) in the basin – such as humic acid, fulvic acid, algae, etc. – was low enough that, when disinfected with chlorine, the disinfection by-products (DBPs) produced were below the Maximum Contaminant Level (MCL), then at 0.1 mg/L (100 µg/L) of total trihalomethanes (TTHMs). As a result, the Montana Department of Health and Environmental Services (MDHES) – later changed to Montana Department of Environmental Quality (MDEQ) - gave the reservoir a Filtration Avoidance Status in December of 1991.

Table 1 Influent Quality

	Turbidity (NTU)	True Color (CU)	TDS (mg/L)	pH	Temp, °F	Manganese (mg/L)	Alkalinity (mg/L-$CaCO_3$)	Total Hardness (mg/L-$CaCO_3$)	TOC (mg/L)
Minimum	0.30	4.0	74	6.8	33.6	0.019	34	42	1.5
Average	0.76	10.1	101	7.3	45.8	0.124	58	65	**3.3**
Maximum	**2.25**	35.0	117	7.9	63.0	**0.545**	76	78	**8.7**

New Requirements

From 2007 – 2010, a state-wide pine beetle infestation killed large quantities of trees in Montana, including a large portion of the forest surrounding the Basin Creek Reservoir. As a result, an unusually high amount of pine needles and tree limbs fell into the reservoir, increasing the concentration of the NOM in the basin. When chlorinated, the NOM reacted with chlorine to form high levels of DBPs, and the level of one group of these - haloacetic acids (HAA5) – eventually exceeded the current MCL of 0.060 mg/L (60 µg/L), as shown in Figure 2.

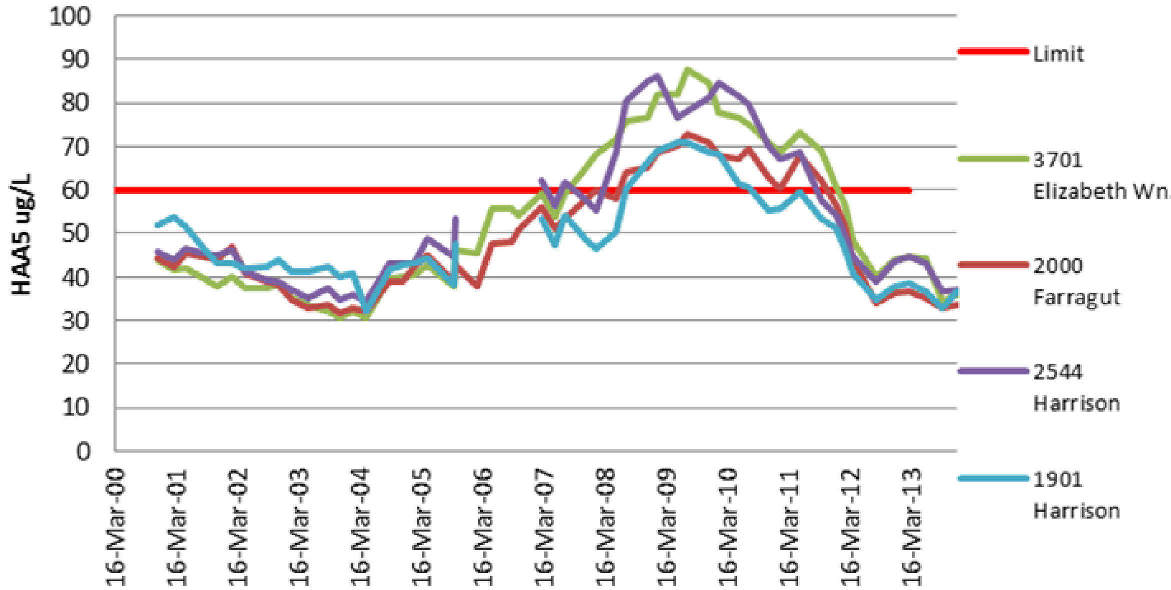

Figure 2 Haloacetic Acid (HAA5) Levels in Basin Creek 2000-2013

In August of 2010, MDEQ rescinded the Filtration Avoidance Status for the Basin Creek Reservoir; BSB stopped using water from the reservoir that December and began investigating a filtration system that would remove the particulate portion of the NOM and reduce the HAA5 levels.

Plant Design

Technology Selection

In addition to removing enough NOM to stay below the HAA5 requirement, BSB and HDR came up with several other goals for the new filtration system:

1. Minimize the size of the waste line going to Butte's wastewater treatment plant
2. Use gravity, in lieu of pumps, to push the flow through the plant and distribution system
3. Minimize staff / automate system
4. Displace water from the South Fork Reservoir during high-solids events
5. Design, construct, and start up the new plant for under $30M

They narrowed the technology choices down to two options - contact adsorption clarifier (CAC) with mixed media filter, or a low-pressure membrane system – and piloted each option. While the CAC was a familiar technology and worked well on the Basin Creek water, the low-pressure membranes were chosen because they were an absolute barrier to pathogens (even without chemical addition), generated less backwash waste, and provided some pressure for the downstream distribution system.

Membrane Selection and Testing

In early 2014, a Request for Proposal (RFP) was advertised, and three companies responded: GE Zenon (now Suez), Pall Corporation, and Metawater USA (now Aqua-Aerobic Systems, Inc., AASI). The respondents were interviewed, and their bids were evaluated based on twenty-year present worth, warranty, and experience. The Metawater (AASI) ceramic membrane system was selected due to its membrane warranty, higher pressure threshold (75 psi), and higher recovery (>99% with recovery skid). Some of Metawater's ceramic membrane plants had been operating over 16 years (at the time) with the same membranes, and Metawater was willing to give a twenty-year 100%-replacement membrane warranty.

Unlike the other two membrane modules that were evaluated – each containing thousands of hollow fibers made of polyvinylidene fluoride (PVDF) – the AASI ceramic membrane module contains a single piece of aluminum oxide, modified for extra chemical/temperature resistance and higher flux. The ceramic element, shown in Figure 3, doesn't require the pinning that the other membranes will require once their fibers start to break, a repair that was found in one study to be needed an average of nine times per year per million gallons of water treated [Freeman (2012)].

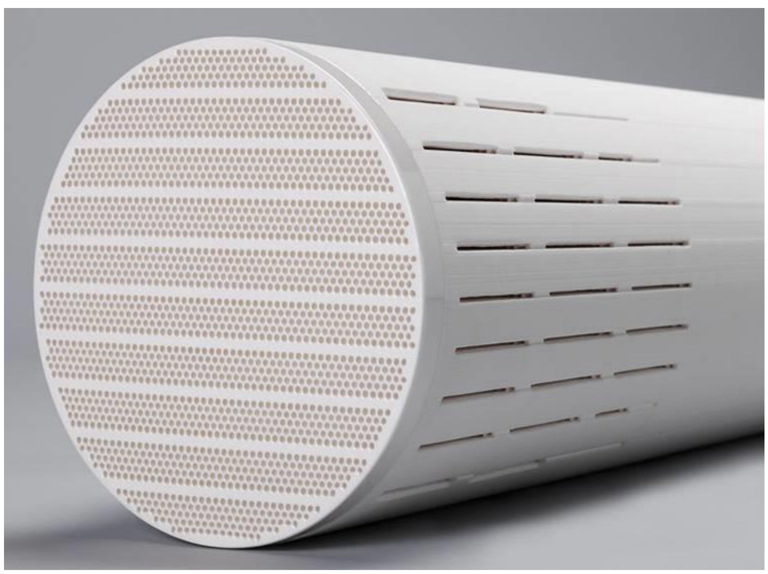

Figure 3 Metawater (AASI) Single-Piece Ceramic Element

In addition, data presented showed that the ceramic membrane exhibited better chemical/thermal resistance, lower fouling potential, and higher flux than the other two (polymeric) options. For instance, testing done by Montgomery Watson Harza (MWH) showed stable membrane operation on a surface water source at a flux of 175 gfd [Adham (2005)].

From May through October, 2014, a pilot was performed with (3) parallel trains of Metawater ceramic membranes in order to set the primary system operating parameters at the design flux (69 gallons per day per square foot of membrane area, GFD). Figure 4 shows the results of a test where a different amount of coagulant was injected into the feed to each train in order to determine the optimum dosage and corresponding rise in trans-membrane pressure (TMP).

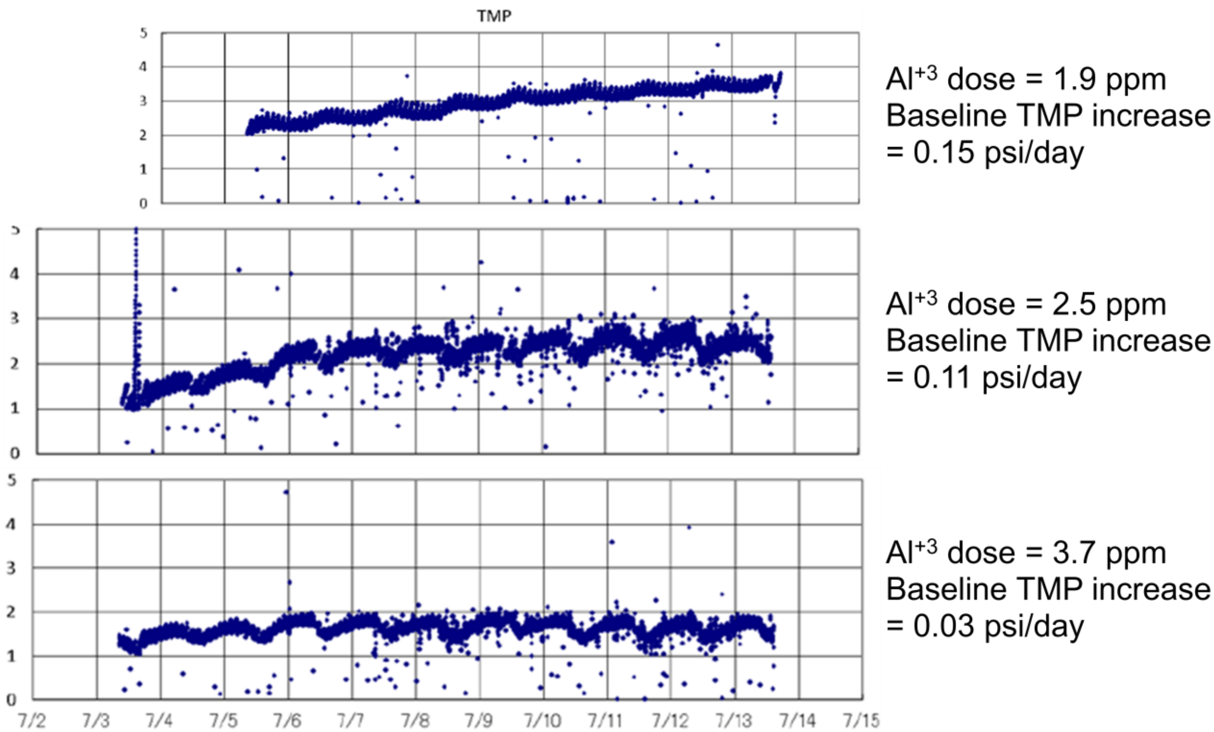

Figure 4 Results of Pilot Test to Determine Coagulant Dosage

Based on the pilot, the parameters for the full-scale primary system were set to 4-hour filtration times, 1.9 mg/L coagulant dosage (as Al), weekly chemically-enhanced backwashes (CEBs) using 5 mg/L of sodium hypochlorite, and clean-in-place (CIP) cleanings every 6 months. In April 2015, DEQ approved the membrane for 4-log removal of Giardia lamblia and Cryptosporidium and 1-log removal of viruses [Fraser (2015)].

Full-Scale System Design

BSB and HDR then determined that the best location for the required filtration system was about half-way between the Basin Creek Reservoir and the Butte city limits; in this location, the plant would be about 160 feet below the reservoir weir, limiting the feed pressure to the membranes to less than 75 psig. This would require, however, that a three-mile long wastewater pipe be installed to connect to the City's nearest lift station; therefore, it was important to design the system for the highest recovery (lowest wastewater volume).

The full-scale facility was then designed with a firm capacity of 7 MGD and includes fine straining, chlorine injection for iron and manganese oxidation, primary ceramic membrane filtration, chemical injection for corrosion control, and finished water disinfection. To allow sufficient contact time for the oxidation process, a large section of pipe is buried underneath the plant between the chlorine injection point and the membrane influent connection. The backwash water from the primary membrane system is passed through an inclined plate settler, backwash recovery ceramic membrane filtration, and into a sludge holding tank, where it is pumped into the sanitary wastewater line. The facility also contains a large control room, a laboratory, storage area, garage, office space for employees, and a large conference room.

Because the plant is being fed directly with water from the Basin Creek Reservoir at a much higher elevation, the water typically flows through the plant and directly into the distribution system without any pumping. In case finished water pumping is required – i.e., the membrane system is experiencing higher TMPs - effluent stored in a standpipe is drawn out with effluent pumps, which are sized to meet system demand using variable frequency drives (VFDs) and pump control valves; these pumps discharge to a second standpipe to provide the exact pressure and flow rate required in the distribution system.

The primary ceramic membrane system consists of four 100-module skids (400 modules total), each with ten rows of ten Aqua MultiBore® C-Series ceramic modules. Figure 5 shows one of the skids.

Figure 5 Primary Ceramic Membrane System Skid (One of Four)

The backwash recovery ceramic membrane system consists of one 12-module skid with two rows of six C-Series ceramic modules, as shown in Figure 6. Each of the five membrane skids includes an air receiver and backwash tank sized for backwashing one row at a time. Also provided was a three-tank CIP system designed to clean up to five rows (fifty modules) at a time. The entire system was manufactured, delivered, installed, and started up by May 2017.

Figure 6 Backwash Recovery Ceramic Membrane System Skid

Results

From May 2017 through November 2018, flow through the plant varied from 2.5 to 3.5 MGD during the winter months and 5 to 6 MGD during the summer months. During this same period, TMPs through the four primary trains ranged from 2 to 6 psi, with the highest TMP occurring about 13 months after startup, signaling the need for the first CIP. Figure 7 shows trends of the finished water flow and train TMPs for the first 19 months of operation; the data gap in November 2017 was due to a system shutdown for a scheduled pipe replacement.

While the finished water flow peaked at about 6 MGD, flow through the ceramic membrane system itself was often higher than this whenever the effluent standpipes were being refilled. Even though influent flows got as high as 7.4 MGD, the total wastewater volume discharged from the plant never exceeded 14,000 gpd, indicating that the total system recovery was around 99.8%, even higher than expected.

Figure 8 shows the influent and effluent turbidities for the primary ceramic membrane system during the first 19 months. The influent turbidity ranged from 0.1 to 2.7 NTU, while the effluent turbidity was consistently around 10 mNTU (0.01 NTU). The permeability of each membrane train during this same period is given in Figure 9; as shown, permeabilities varied from 9 to 23 gfd/psi, typically increasing as the flow through the system decreased and following the CIP in June of 2018.

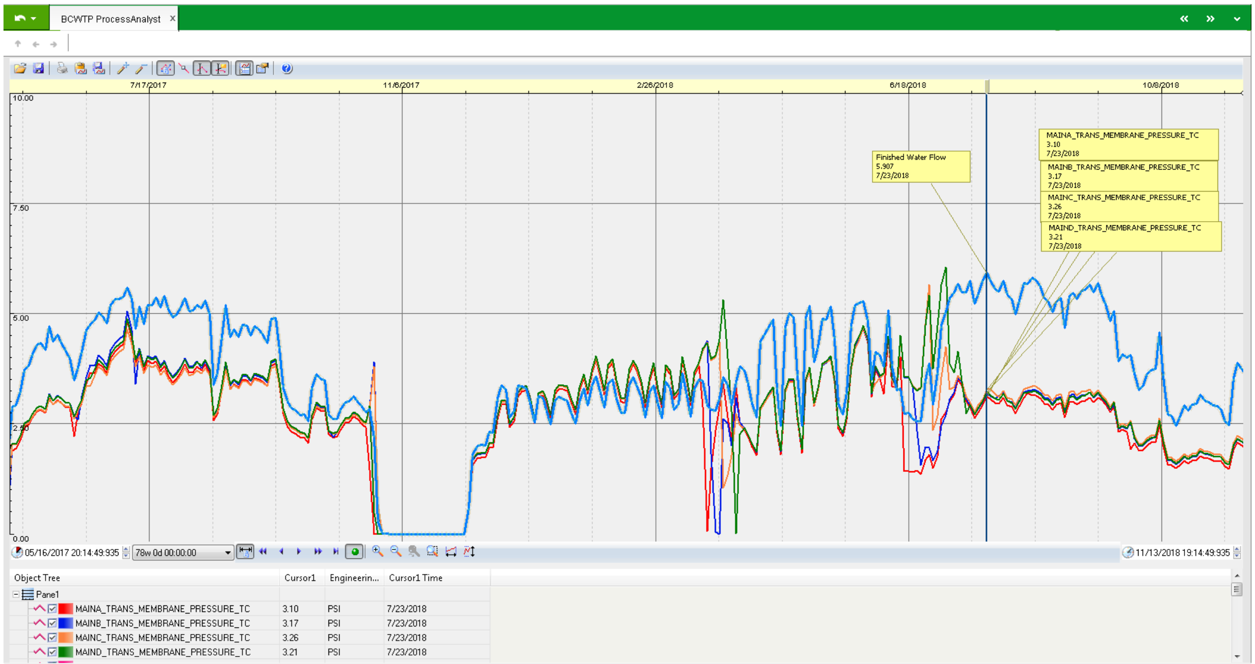

Figure 7 Primary System TMPs and Flow during the First 19 Months of Operation

Figure 8 Primary System Turbidities during the First 19 Months of Operation

Figure 9 Primary System Membrane Permeabilities During the First 19 Months of Operation

Issues Encountered

Several problems were encountered during the first nineteen months of operation. For instance, the filtrate during startup was being diverted to a drain discharging to a nearby creek, and it was noticed that the creek contained an excessive amount of entrained air, as shown in Figure 10, but the effluent turbidities were below the 0.1 NTU alarm setting.

Figure 10 Entrained Air in Basin Creek

The only steps of the process that use air are the backwash and CEB steps –to pressurize and discharge water from the backwash tank – and the drain steps at the end of the backwash and chemical cleaning modes – to displace to drain all of the solids/solution in the modules. The backwash mode consists of two primary steps, as shown in Figure 11: a backwash with filtrate to loosen the solids collected on the membrane surface, and a discharge of the solids to drain using a blowdown with air. During the first step, water in the backwash tank is pressurized to 70 psi with air and then pushed through the membrane. An investigation uncovered that this step on the primary system was lasting too long, allowing air to fill the filtrate side of the row in backwash; when the row returned to its filtration mode, this air became entrained in the filtrate water.

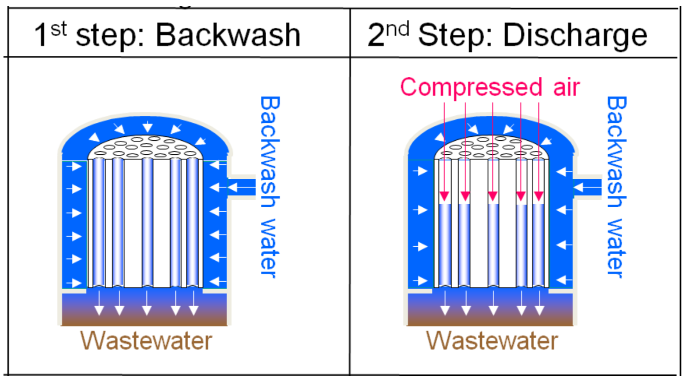

Figure 11 Steps in Backwash Mode

Another issue encountered was that the TMP on the backwash recovery train was rising much more quickly than expected, requiring more frequent backwashes and CEBs and creating a high volume of wastewater. It was discovered that all of the flow was being pushed through a single six-module row each time the other row went into backwash or CEB, which overloaded the modules with solids, compacting the solids into the membrane pores. A programming change was implemented that set a maximum flow through each row, and the TMPs dropped dramatically, as shown in Figure 12.

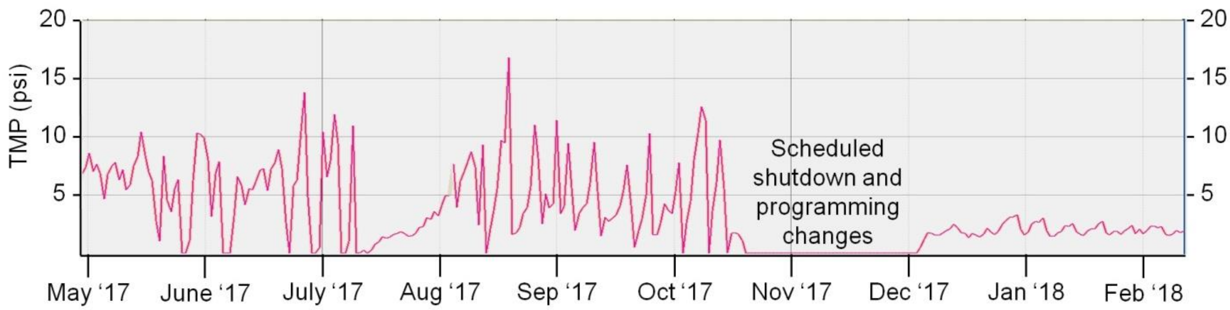

Figure 12 Recovery Train TMP

During the first attempt at a CIP, the CIP caustic pump failed so that only the acid portion of the CIP was performed initially – this can be seen in Figure 9 on the previous page, where the permeabilities increased in March 2018, following the acid CIP, and then later in June following the caustic CIP.

The MDEQ requires the membrane system perform a daily air integrity test to verify that there are no cracks in the ceramic elements or leaks in the module seals. This test is performed on each membrane row as part of the automatic sequence; if a test fails, the row will not return to filtration and an alarm will alert the operator of a problem.

In September 2018, one of the primary ceramic membrane rows failed its air integrity test. Since the backwash pressure (70 psig) is fairly high for a low-pressure membrane system, there is not a clear section of pipe on each module's filtrate line as there is on most of other MF/UF systems; therefore, the module with the air leak had to be determined by listening for the air bubbles using a sonic detection device (a common stethoscope works well). Once the faulty module was identified, the piping was disconnected from the module (in order to remove the module), and a bolt was discovered in the filtrate line, as shown in Figure 13.

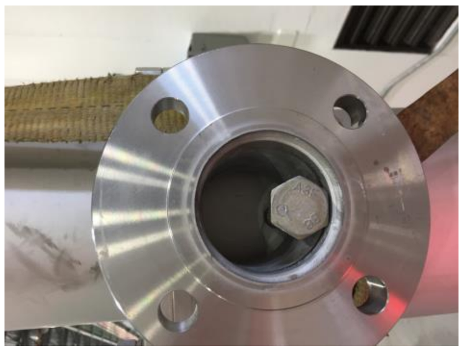

Figure 13 Bolt Discovered in Filtrate Line

During each backwash, the bolt was propelled into the side of the element until it eventually chipped a hole big enough for air to pass through the membrane during an integrity test. Figure 14 shows where the bolt chipped the element at the spot where the filtrate first enters the module during a backwash.

Figure 14 Damage to Ceramic Element

Because all of the modules and piping had been installed at the factory, and the plant had not disconnected the piping since that time, the bolt must have been left in the line during pipe fabrication. Though each line was flushed with clean water prior to loading of the ceramic elements, the flush water flow was not enough to push the bolt out; however, the backwash flow during operation was of sufficient velocity to project the bolt into the side of the ceramic element with a force that eventually chipped away at the material on the outside of the element.

Conclusion

There are several conclusions that can be drawn from the first nineteen months of operation:

1. Since the primary ceramic membrane system uses only head pressure during its filtration modes, no energy is expended to produce filtrate that meets all of the current drinking water standards.
2. With the flows treated during that period – as high as 7.4 MGD – the effluent pumps were used only a small fraction of that time; therefore, minimal energy was expended to distribute the drinking water to the users in the City of Butte.
3. Recovery of the entire system exceeded 99.8%, which resulted in a daily wastewater discharge of less than 14,000 gallons.
4. It's important to consider present-worth, warranty, and experience when selecting a technology. While the ceramic system was not the lowest capital cost, its 20-year life cycle cost was low because no feed or filtrate pumps are required (typically), very little wastewater is discharged, and membrane replacement will not be needed.
5. Piloting more than one parallel train of the same membrane enables different parameters to be tested on the exact same water.
6. Turbidity measurements won't always detect entrained air, so it's important to visually inspect the filtrate.
7. Limiting the flow that can be passed through the membranes avoids compacting solids into the membrane pores.
8. A thorough inspection/flushing of the piping and housings should be made prior to installing the membrane elements, with each pipe being flushed with the same flow/velocity that will be used during operation.

References

Adham, Samer, Kuang-ping Chiu, Geno Lehman. (2005) *Final Report: California Department of Health Services Conditional Acceptance Testing for NGK Ceramic Membrane*, p. 5-2.

Fraser, Denver. (2015) *EQ# 15-1037: Basin Creek Water Treatment Plant Metawater USA, Inc., Ceramic Membrane Certification—Butte-Silver Bow Water Department (MT0000170)*, DEQ, Public Water and Subdivisions Bureau, pp. 1-2.

Freeman, Scott, Paul Delphos, Ron Henderson, and Vasu Veerapaneni (2012), *"Real World Fiber Breakage Rates and Costs"*, Proceedings of the AWWA/AMTA Membrane Technology Conference & Exposition 2012, pp. 627-630.

USEPA. (1991) *Fact Sheet / National Primary Drinking Water Standards,* USEPA Office of Water Publication EPA-570-9-91-012FS, pp. 1-8.