Biological Monitoring Improves Membrane Performance

A southern US water treatment facility used advanced ATP testing for biological monitoring to improve membrane filtration operations and product water quality. BY BILL TRAVIS AND DAVE TRACEY

A WATER UTILITY in the southern United States had historically struggled with groundwater treatment because of high amounts of organic material and color. Organics were oxidized and broken down by chlorination, but this practice fell out of favor once suspicions of disinfection by-product (DBP) production, including trihalomethanes and haloacetic acids, were confirmed.

The utility then moved to construct a membrane filtration plant to remove organics and microbial content rather than rely on prechlorination at the well site's storage tank. However, once prechlorination was removed, significant biological fouling of the membranes ensued. Figure 1 shows a process flow diagram of the plant. Proactive biological monitoring using advanced adenosine triphosphate (ATP) was able to guide mitigation activities and optimize several design modifications to improve plant operation and product water quality.

ATP AS A MEASURE OF TOTAL MICROBIAL CONTENT

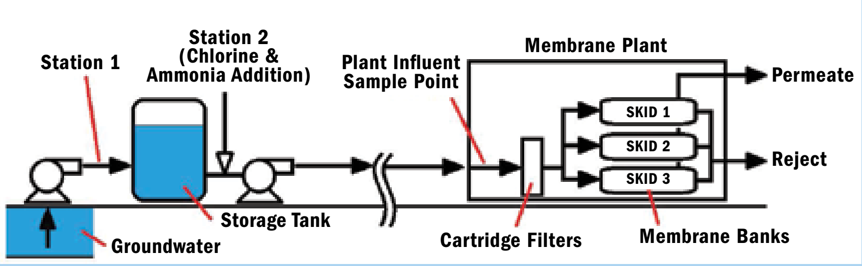
ATP is the primary energy transfer molecule for all living cells on Earth. For this reason, its measurement is directly tied to the microbial population, as most of the energy for microbial processes is stored and transmitted via ATP.

ATP production is directly related to cell growth, so higher ATP levels indicate greater cell mass and overall biological content. In addition, when cells become weak or lyse, they release their ATP into their external environment. This is termed *extracellular* or *dissolved* ATP (outside of living cells). The presence of a greater proportion of extracellular ATP indicates a less healthy population.

The most widely accepted method for quantifying microorganisms in water systems is the culture test. Of these analyses, heterotrophic plate count (HPC) is a common indicator of total microorganisms. The most widely accepted deficiency of culture tests is slow feedback. Days or even weeks can be required to obtain results because of slow growth rates of certain species. By contrast, many water managers view ATP technology as a potential rapid estimator of microorganisms, much in the same way as turbidity is used to rapidly estimate total suspended solids. Although ATP test results will strongly correlate with culture test results under most conditions, several factors affect this correlation such as population specificity, particle association, and disinfection efficacy.

Figure 1. Groundwater Treatment Process Flow Diagram

The Louisiana plant performed well initially, but prefilters and membranes soon became severely fouled, prompting the use of ATP monitoring technology to assess the problem.



GRAPHICS: LUMINULTRA TECHNOLOGIES

When membranes became severely fouled at a southern US water treatment plant, ATP monitoring technology was used to troubleshoot the problem.

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Rather than attempting to completely replace HPCs with ATP tests, ATP monitoring can serve as a screening and routine monitoring tool for detecting total quantity of active microorganisms to reveal the onset of regrowth or changes from baseline conditions. Culture-based tests can then be used to troubleshoot issues revealed through rapid screening.

PLANT SETUP AND PRECHLORINATION TEST RESULTS

The treatment plant's membrane skid arrangement was as follows:

- 28 Stage 1 modules, 10 Stage 2 modules
- 7 membranes per module
- Typical recovery: 78–85 percent

Significant problems developed once prechlorination was shut off. The prefilters and membranes became severely fouled with a thick film and had considerable odor, so the utility enlisted the services of a local water and wastewater service company to troubleshoot the problem using ATP monitoring technology to characterize the nature of the treatment problems. If the issue was found to be biological, ATP tests would be used to help monitor the efficacy of both disinfection and membrane treatment throughout the optimization study.

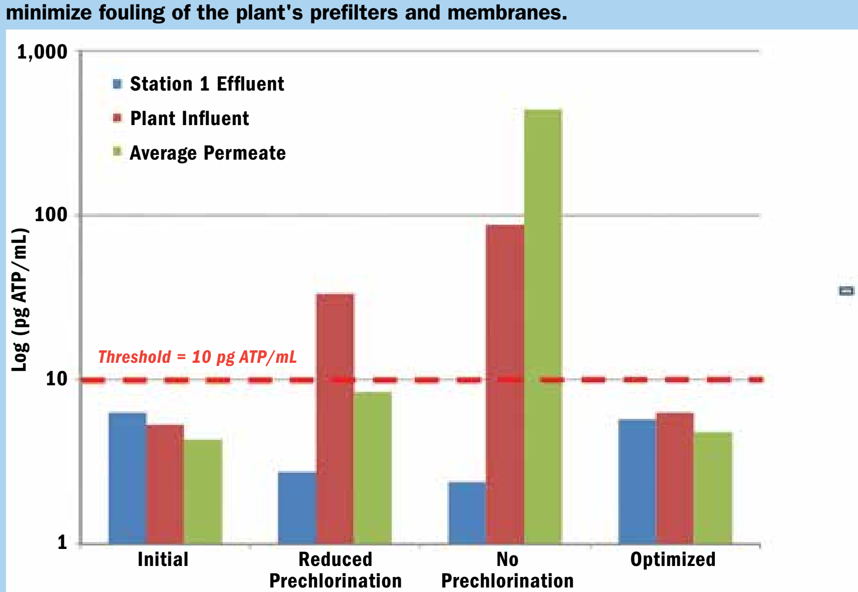
The prechlorination dosage was set to a reduced rate compared with the previous dosage during the midsummer months in the hope of establishing a middle ground in which DBP formation was reduced while still cutting down the organics loading and color in the raw water. While the reduced chlorination prior to membrane filtration resulted in less DBP formation than in the past, the microbial loading at the plant inlet became significantly higher as seen in Figure 2. Permeate quality temporarily remained acceptable, but the plant was shut down after an additional week under these conditions because of excessively high pressure differentials across the membranes.

At the time, the raw water carried no chlorine residual (neither free nor total), so there were no barriers to microbial proliferation occurring in the pipeline. This increased loading resulted in significant fouling of the prefilters and eventual microbial breakthrough and significant fouling of the membranes downstream. Membrane fouling was confirmed by using ATP testing on the surfaces of the end cap of a membrane in addition to a deposit that was removed from the membrane surface.

The surface buildup values were 10–100 times higher than what would be

Figure 2. Summary of Results With Each Control Scheme

Several changes were made in the operating procedure after the cleaning process to minimize fouling of the plant's prefilters and membranes.



Long-Term Summary

The treatment strategy and membrane configuration established after the initial investigation have been effective, resulting in improved water quality.

Location	Cellular ATP (pg/mL)
Station 1	0.47
Skid 1 Reject	1.85
Skid 1 Permeate	0.32
Skid 2 Reject	0.74
Skid 2 Permeate	0.63
Skid 3 Reject	0.36
Skid 3 Permeate	0.16
Into Tank 1	0.12
Finished	0.92

considered tolerable, although they were unsurprising considering the magnitude of the bioburden in the water feeding the membranes. Accordingly, a series of membrane cleanings were conducted to remove the fouling that had developed.

The cleaning cycle did an excellent job of cleaning the fouled membranes, so the product water quality was now in the acceptable range (<10 pg/mL) and carrying a lower risk for microbial proliferation downstream, assuming maintenance of an acceptable disinfectant residual.

With these results, it was clear that a certain degree of pretreatment was necessary to minimize fouling of the prefilters and membranes in the plant. Therefore, the following changes were instituted in the operating procedure after the cleaning process:

1. Chlorine addition before the storage tanks was discontinued.
2. Chlorine and ammonia (chloramine) were instead fed to the water as it left Station 1 to inhibit microbiological growth in the transmission line from Station 1 to the Plant Influent.
3. Dechlorination was moved from before the prefilters to behind them.

After three weeks of running under these new conditions, another set of samples were collected and analyzed, as shown in Figure 2. The cleanliness of the product water had risen slightly, but the overall picture was significantly better than when the membranes had become fouled earlier in the summer. The plant's strategy was then to perform semi-routine tests on the water downstream of the prefilters and on the combined membrane product water to detect deviations from baseline conditions and allow a more proactive stance to be taken.

DESIGN MODIFICATIONS AND PLANT PERFORMANCE

Following the modifications made in the spring of 2012, the plant continued to run much more effectively than under previous conditions, but other opportunities for improvement became apparent. This was determined by establishing a monitoring strategy involving a mass balance model using flow rates and ATP concentrations around each membrane. Essentially, ATP load in must be approximately equal to that which exits. If more ATP exits than what enters, it indicates a fouled membrane in which biological growth and breakthrough occurs. Figure 3 shows this concept.

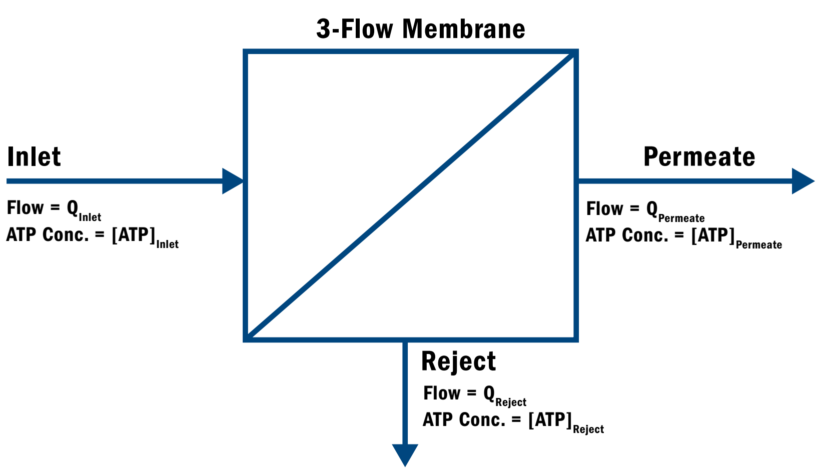
The data collected to date were analyzed using this model to assess the degree of fouling around the membranes historically compared with following the movement of disinfectant point and switch to monochloramine. Although membrane performance clearly improved and fouling was reduced because of the initial design and operational modifications, fouling wasn't completely eliminated. This initiated discussion involving the loading applied on the membranes and whether it was too much for the three primary membranes to handle.

ATP MONITORING AND MEMBRANE DESIGN

By comparing the membrane-bioburden level to the sum of permeate and reject-bioburden levels, internal biofouling can be assessed. If the bioburden out is greater

Figure 3. Membrane Fouling Concept

The plant used flow rates and ATP concentrations around each membrane.



Mass Balance: $(Q_{Inlet} \times [ATP]_{Inlet}) = (Q_{Permeate} \times [ATP]_{Permeate}) + (Q_{Reject} \times [ATP]_{Reject})$

Fouling Index: $FI = ((Q_{Permeate} \times [ATP]_{Permeate}) + (Q_{Reject} \times [ATP]_{Reject})) / (Q_{Inlet} \times [ATP]_{Inlet})$

If FI ≤ 1, membrane isn't biofouled.
If 1 < FI ≤ X, membrane is becoming biofouled.
If X ≤ FI, membrane is heavily biofouled.

ATP monitoring results proved the ability to quickly identify elevated microbial content in the raw and treated water as well as within the membranes themselves.

Figure 4. Results of Switching From 3 × 2 to 6 × 1 Arrangement

Spreading the membrane feed stream over six parallel units eases the burden on each and reduces fouling tendencies.

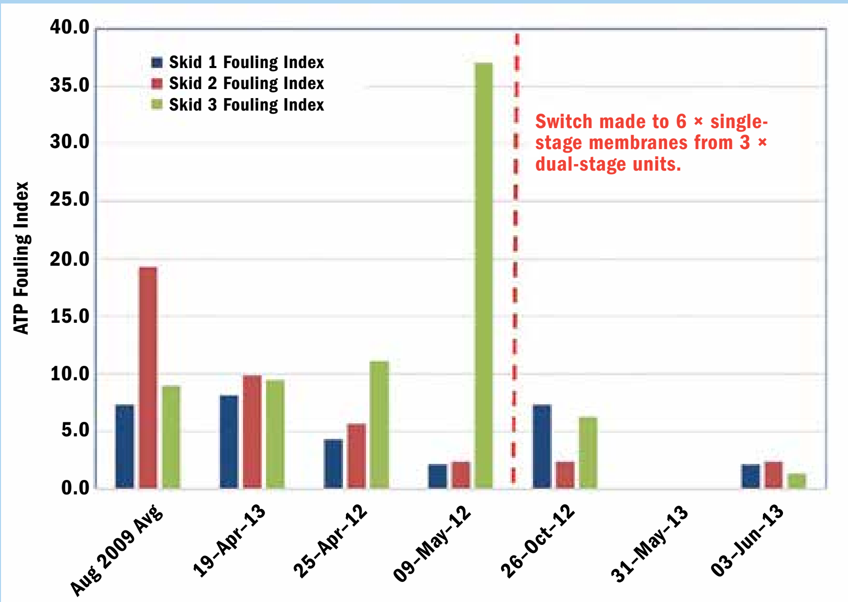
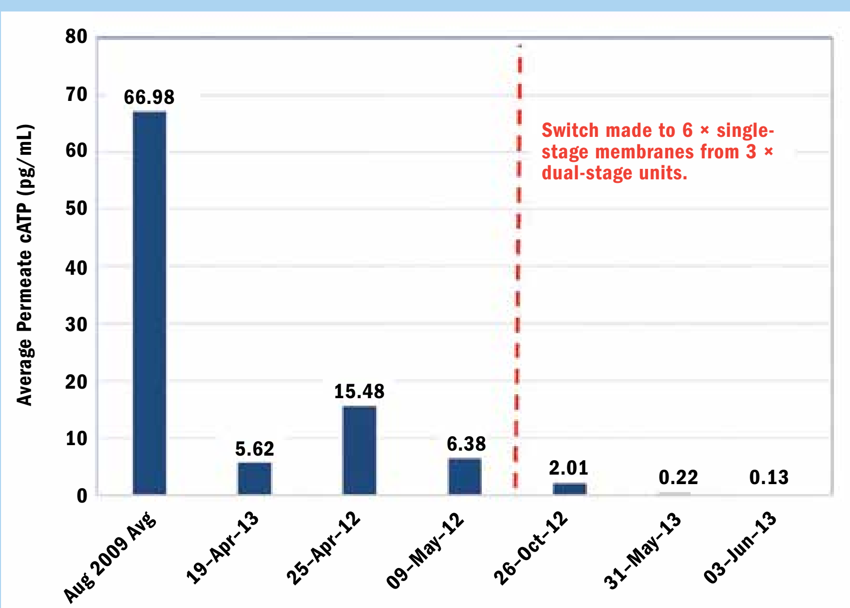


Figure 5. Final Product Water Quality

Reduced fouling in the membranes, achieved by switching to six single-stage membranes, significantly improved water quality.



than that which enters, the result immediately indicates that growth is occurring within the membrane, thereby initiating preventive maintenance. This operational strategy maximizes membrane life while optimizing produced water quality and overall process efficiency.

As data were analyzed relating to microbiological loading and the resulting biofouling, design and operational changes were considered. It was decided that rather than having three skids of two membranes in parallel, the six should be operated as parallel membranes, all operating as single-stage units. This change was implemented in fall 2012. After a routine cleaning, the membranes were operated in this arrangement as a long-term solution.

The results in Figure 4 show that spreading the membrane feed stream over six parallel units eases the burden on each one and results in reduced fouling tendencies and improved filtered water purity, as shown in Figure 5, which quickly became apparent after the switch and has gotten better over time. Also, plant electricity usage dropped significantly as a result of reduced pumping back pressure, exceeding $1,000 a month since the switch.

ATP TESTING SUPPORTS OPERATIONAL SUCCESS

Because of its speed, ease of use, and specificity to total living organisms, ATP monitoring serves as a valuable method for rapid water quality assessment. In working with potable water systems, use of ATP testing facilitates routine maintenance and troubleshooting and helps maintain water quality by detecting microbial contamination at the earliest signs.

ATP monitoring results proved the ability to quickly identify elevated microbial content in the raw and treated water as well as within the membranes themselves, which enabled plant personnel to assess effects of decreased prechlorination, diagnose a fouling issue as a biological problem, and assess the efficacy of the membrane cleaning process within minutes of sample collection.