IMPROVING ORGANIC REDUCTION AND OVERCOMING CHALLENGES OF A MEMBRANE BIOREACTOR (MBR) TREATING WASTEWATER FROM PLASTIC PRODUCTION

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Abstract

The Chesapeake Bay Watershed Initiative (CBWI) of 2010 required many wastewater treatment plants discharging to affected waterways to meet progressively lower effluent contaminant levels. While the initiative's impact was felt most profoundly by municipal plants that now had to meet lower nutrient limits, it also affected many of the area's industrial dischargers. One such industry – the world's leading producer of polyester films - produces polyethylene terephthalate (PET) at its Chester, VA facility. During the manufacturing process, the plant produces 0.03 – 0.055 MGD of wastewater, which is treated on-site and discharged to an internal outfall. When tighter limits were imposed on the amount of 5-day biological oxygen demand (BOD_5) in the discharge, plant management realized they would have to modify the original treatment scheme - aeration basins, clarifiers, and sand filters – in order to comply with the new requirement. They looked at four options that involved adding basins, filters, and/or membranes to their existing system and one option that entailed converting the system to a membrane bioreactor (MBR). Because the MBR option would provide a positive barrier to suspended solids (including insoluble BOD_5) and wouldn't require additional space or concrete, they chose to go with this alternative.

Two systems were piloted, and the successful system - the Aqua-Aerobic® MBR – was purchased, installed, and placed on-line in July of 2014. The system ran extremely well for about 6 months, at which time trans-membrane pressures (TMPs) started to climb and the flow through the membranes gradually stopped. Through extensive investigation and troubleshooting, it was determined that the cause was a specific extracellular polymeric substance (EPS), either created in the bioreactor by stressed microorganisms or accidentally/inadvertently placed in the wastewater stream. This paper describes the membrane pilot and full-scale systems, details the membrane fouling and troubleshooting sequences, and explains the system recovery and lessons learned.

Project Background

Existing Facilities

The city of Chester, VA is in the southeast quadrant of the state, as shown below in Figure 1, about 15 miles south of Richmond. The plant is located right on the James River, approximately 85 miles upstream of the southernmost part of the Chesapeake Bay. The plant was brought on-line in 1972 and is now handling an average daily flow (ADF) of 0.03 MGD (114 m3/day) and a maximum daily flow (MDF) of 0.055 MGD (208 m3/day).

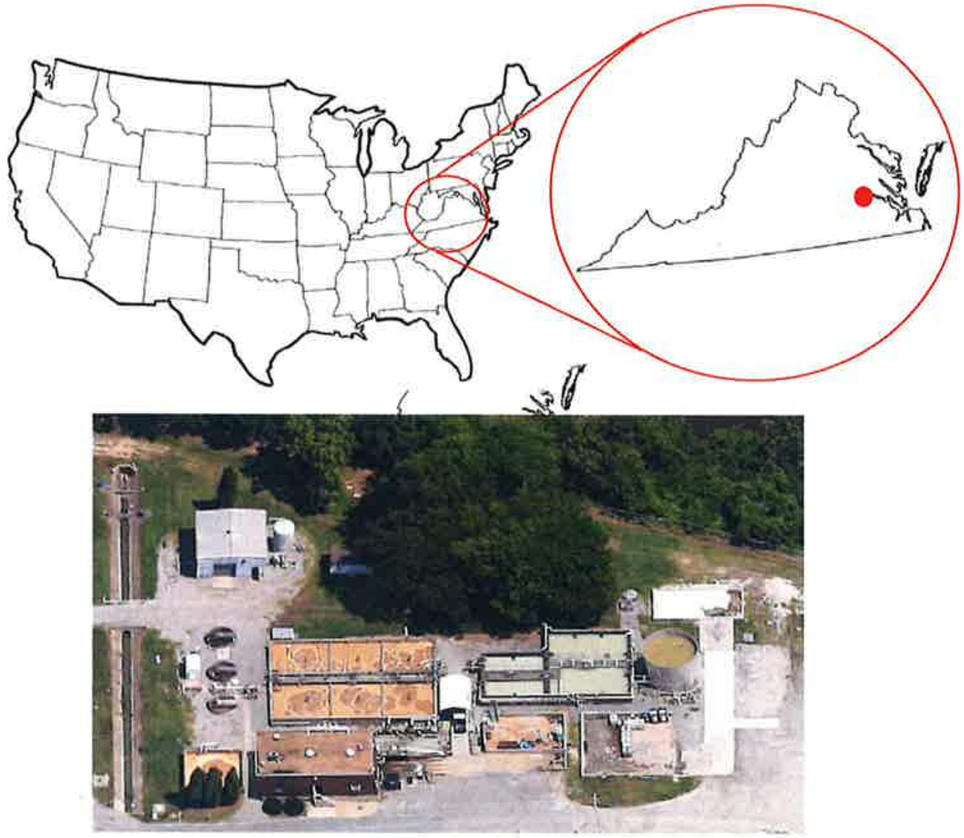


Figure 1. Plant Treating PET Production Wastewater

As shown in Figure 2, the treatment process consisted of a four-chamber equalization basin, chemical feed systems for nutrient and soda ash addition, (2) multi-compartment aeration basins, (3) clarifiers, and a sand filtration system. Waste solids were pumped from the clarifiers, treated in an aerobic digester, and dewatered. Centrate and filter backwash waste were transferred back to the equalization basins.

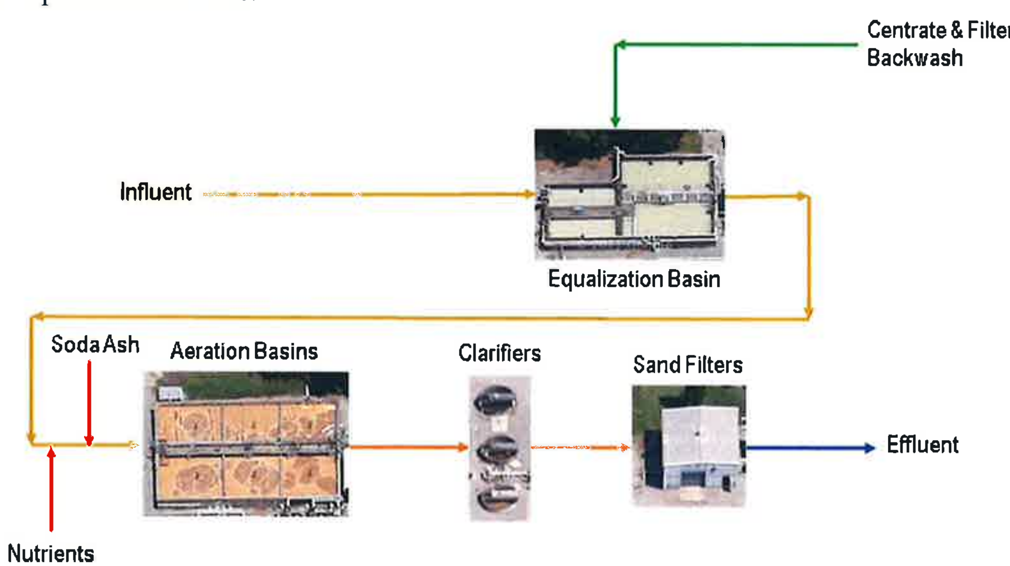


Figure 2. Existing Wastewater Treatment Diagram

New Permit Requirements

One of the main concerns that led to the passage of the CBWI was depletion of dissolved oxygen in the Bay – a process known as eutrophication - which resulted in a reduction of the bay's fish population. During eutrophication, aerobic microorganisms use dissolved oxygen and nutrients in the water (primarily nitrogen and phosphorus) to break down and consume organic material [Kahn and Mohammad (2014)]. Figure 3 shows what the process often looks like, with the affected body of water turning green with algae, which consumes oxygen in the water when it decomposes.

Figure 3. Eutrophication at a Wastewater Outlet in the Potomac River [Trubetskoy, (2012)

While the source of organic material is typically algae, it can also come from agricultural runoff and wastewater plant discharges. In addition, much of the suspended solids in treated wastewater are the aerobic microorganisms used in the treatment process, which continue consuming organic material and dissolved oxygen in the receiving waters.

In an effort to curb eutrophication, the plant's most recent National Pollutant Discharge Elimination System (NPDES) permit required that their wastewater plant effluent stay below Total Maximum Daily Loads (TMDLs) of 19 lbs (8.6 kg) BOD_5 and 40 lbs (18.0 kg) total suspended solids (TSS). In addition, the average monthly limits are now 7 lbs/day (3.2 kg/day) BOD_5 and 12 lbs (5.4 kg) TSS, equivalent to 28 mg/l BOD_5 and 48 mg/l TSS at the average flow of 0.03 MGD.

Issues with the Existing Wastewater Treatment System

There were two main issues with the existing treatment system: an inability to reach the required BOD_5 levels in the existing aeration basins, and overloading the sand filters with solids carryover from the clarifiers. To increase organics reduction in the aeration basins, the EPDM membranes on the fine bubble diffusers were replaced in 2013; however, the additional BOD_5 removal achieved was still short of the new requirement, especially given the variable nature of the production wastewater and plant cleaning regimen.

To minimize TSS excursions from the clarifiers, polymer was added to the basins in order to create a larger floc that would settle better. The plant found that it took a considerable amount of polymer to achieve the required effluent solids, which became very expensive and proved difficult to remove from the downstream filters. In addition, low-pressure air was used for both aeration and mixing of the two aeration basins, which meant the air flow could only be throttled to a certain level and still keep the basin contents sufficiently mixed. During periods of low or no flow, the biomass was over-aerated, resulting in even more solids carryover to the filters. To complicate matters, there was no anaerobic selector zone to minimize growth of filamentous bacteria, and chlorine was added periodically to eliminate filaments and improve settling.

Possible Alternatives

The plant looked at five options for improving organics and/or solids reduction:

1. Add an aeration basin, clarifier, and sand filter to the existing system. The third aeration basin would provide a 50% increase in biomass, which would then consume that much more of the incoming organics. The fourth clarifier would result in a 25% decrease in the overflow rate, allowing for better settling and less carryover. The added sand filter would reduce the flux through the filters and allow them to handle higher solids and still maintain the required capacity. The major downside to this approach was that additional basins would have to be constructed, using up what little space was still available on the site. In addition, this option didn't address the problems associated with over-aeration or filament growth in the bioreactors.
2. Convert the existing suspended growth activated sludge system to some type of fixed-growth system, which would allow the existing aeration basins to handle the increased loading. This option would require the addition of at least one more clarifier and an additional sand filter. While this would probably increase the organics reduction and improve settling, it would still require construction of extra basins and may complicate the clarification and filtration processes at times as biomass will periodically slough off the fixed-growth media. Like the first option, this option doesn't include any provisions for minimizing over-aeration or filament growth in the bioreactors.
3. Add a microfiltration (MF) or ultrafiltration (UF) membrane system after the sand filters to capture any of the solids that get past the filters. While this will be a positive barrier to prevent any TSS from getting into the final effluent, it will have a very limited affect on the organics; in fact, dissolved organics tend to foul the membrane, which will then require lower fluxes and more frequent backflushes and chemical cleanings. In addition, polymer must be used sparingly upstream of the membranes because it can cause irreversible membrane fouling; this increases the likelihood of solids carryover from the clarifiers and solids overloading of the sand filters.
4. Convert the existing flow-through system to a sequencing batch reactor (SBR) system, eliminating the need for the clarifiers since clarification will be performed in the aeration basins themselves as the final treatment process for each batch. This option also includes an anaerobic zone for filament control and provides mixers that operate independent of the aeration system to avoid over-aerating. The downside to this approach is that one or two more aeration basins would have to be constructed and additional equipment (mixers, decanters, etc.) would have to go into each basin.
5. Convert the existing system to a membrane bioreactor (MBR) system. The existing clarifiers would no longer be needed because the membranes would filter out all of the

suspended solids; this allows the mixed-liquor suspended solids (MLSS) in the aeration basins to be more than doubled, with the extra biomass consuming much more of the incoming organics. Like the third option, the membranes will provide a positive barrier to TSS getting into the final effluent. Also, this option requires no additional basins, no polymer, no extra equipment in the aeration basins (the existing aeration system was determined to be adequate), no clarifiers, and no sand filters. In addition, neither over-aeration or filaments would affect TSS removal since all of the suspended solids would be filtered out by the membrane, with no settling required. The two downsides to this approach are the need for a fine screen (perforated plate or wire mesh with 2mm or smaller openings) to protect the membranes, and the extra power required to keep the membranes clean.

Other Considerations

Besides the new effluent requirements, plant management applied some additional criteria to determine how to upgrade their plant:

- Low Chemical Usage – the effluent limits should be achieved using a minimal amount of polymer, chlorine, and other cleaning chemicals.
- Ease of Operation – the existing system was fairly simple to operate, and the operators wanted the same from the upgraded system.
- Flexibility – the system should be flexible to handle the large swings in hydraulic and organic loadings that occur during each production cycle.
- Minimal Footprint – the upgraded system should take up as little space as possible, reusing existing structures and equipment where practical.

Selected Technology

After comparing the above alternatives in light of the noted criteria, the plant decided to go with an MBR. This would allow them to meet the effluent limits without adding any more basins/clarifiers and without polymer or chlorine (except for membrane cleaning). The plant then interviewed several MBR system providers, receiving preliminary designs and costs from them, and evaluated each based on the stated criteria. Plant management narrowed the field to two manufacturers, and had each conduct a pilot study to determine which could achieve their main objective: over 99% reduction in BOD_5. One pilot used a pressure-driven external module with high cross-flow velocities, while the AASI pilot used a submerged vacuum-driven unit with air scour.

Pilot Study

Pilot Description

During the study, a portion of the wastewater in the equalization basin was injected with small doses of phosphorus and nitrogen – providing nutrients required for the biomass – and fed through hoses to the AASI pilot plant, shown in Figure 4. A feed pump on the pilot pumped the feed through a fine screen containing a perforated plate with 0.079 inch (2 mm) openings, designed to remove large particles that could damage the membrane fibers. Once through the screen, the feed flowed into the bioreactor basins containing activated sludge (biomass), and the bioreactor blower added low-pressure air to the biomass, providing the oxygen required for the microorganisms to consume the organic matter in the feed stream.

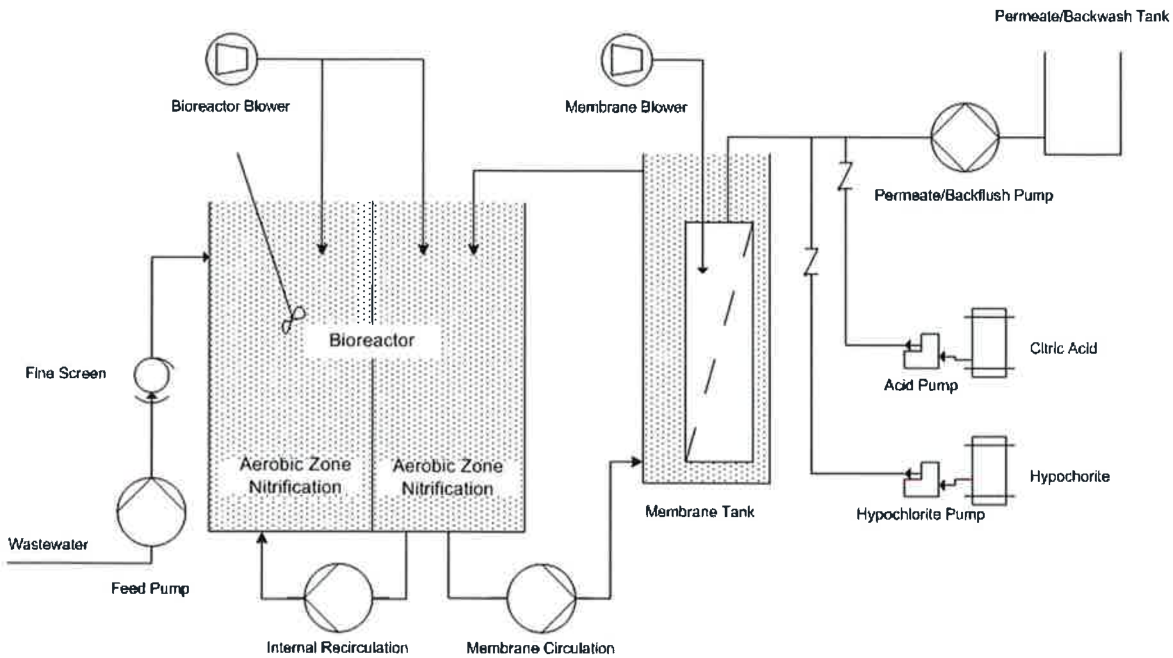


Figure 4. Flow Diagram for the AASI Pilot Plant

To simulate the full-scale system, the mixer and internal recirculation pump were not used. The membrane recirculation pump transferred the biomass to the membrane tank, which contained a single 323 ft^2 (30 m^2) membrane module. The permeate/backflush pump created a vacuum, which pulled clean filtrate (permeate) through the membrane fibers, sending it to the permeate/backwash tank. A small portion of biomass was wasted from the bioreactors to maintain the MLSS concentrations; to enable higher membrane fluxes with a relatively low influent flow, this waste activated sludge (WAS) was combined with the permeate and recycled back to the pilot influent.

A membrane blower provided intermittent air scour to the module, which minimized the solids buildup on the membrane surface. Every 10 minutes, the permeate/backflush pump reversed direction and pumped filtrate from the permeate/backwash tank back through the membrane fibers to flush out the majority of solids not being removed by the air scour. Once each day, the backflush was extended to 30 minutes at a lower flow and sodium hypochlorite was added to the permeate to produce a 125 mg/l chlorine solution, which dissolved any organic material left on the membrane. Once each week, the backflush was extended to 45 minutes at a lower flow and citric acid was added to the permeate to produce a 2,000 mg/l acid solution, which dissolved any inorganic material left on the membrane.

The pilot study was conducted for 10 consecutive weeks from February 12, 2013 to April 22, 2013. The study consisted of nine test phases, with the parameters during each phase as shown in Table 1. The bioreactors and membrane basins were each operated at three different MLSS concentrations, the membrane permeate flow was set at two separate fluxes, and the membranes were scoured at three unique air flows and two different cycling times (frequencies).

Table 1. AASI Pilot Settings

Test Phase	Test Dates	Bioreactor MLSS (g/L)	Membrane MLSS (g/L)	Membrane Net Flux (gfd / Lmh)	Air Scour Flow (scfm)	Air Scour Frequency (secs on/off)
1	2/12-2/27	6	7.5	8.9 / 15	3.5	120/20
2	2/28-3/13	***8***	***10***	8.9 / 15	3.5	120/20
3	3/14-3/18	8	10	8.9 / 15	3.5	120/20
4	3/19-3/20	8	10	8.9 / 15	***10***	***41/82***
5	3/21-3/22	8	10	11.8/20	***5.5***	***120/20***
6	3/23-4/7	8	10	8.9 / 15	***10***	***41/82***
7	4/8-4/15	8	10	8.9 / 15	***5.5***	***120/20***
8	4/16-4/17	8	***12***	8.9 / 15	5.5	120/20
9	4/18-4/22	***10***	12	8.9 / 15	5.5	120/20

Data was continuously monitored by the pilot instrumentation and recorded by the system's SCADA controls. Figure 5 shows the location of some of the pilot instrumentation. Trends for each of the major parameters are shown in Figure 6. Note that the TMP remained below 2 psi for almost the entire test and averaged less than 1 psi; this indicated that the membrane operation was fairly stable under each of the test phases. Spikes in TMP seemed to correlate with dips in pH, so soda ash was added during the final two phases to keep the pH above 6. Increasing the membrane tank MLSS for the final two phases increased the TMP to about 3 psi, but stable operation was still achieved.

Figure 5. Photo Showing Some of the AASI Pilot Instrumentation

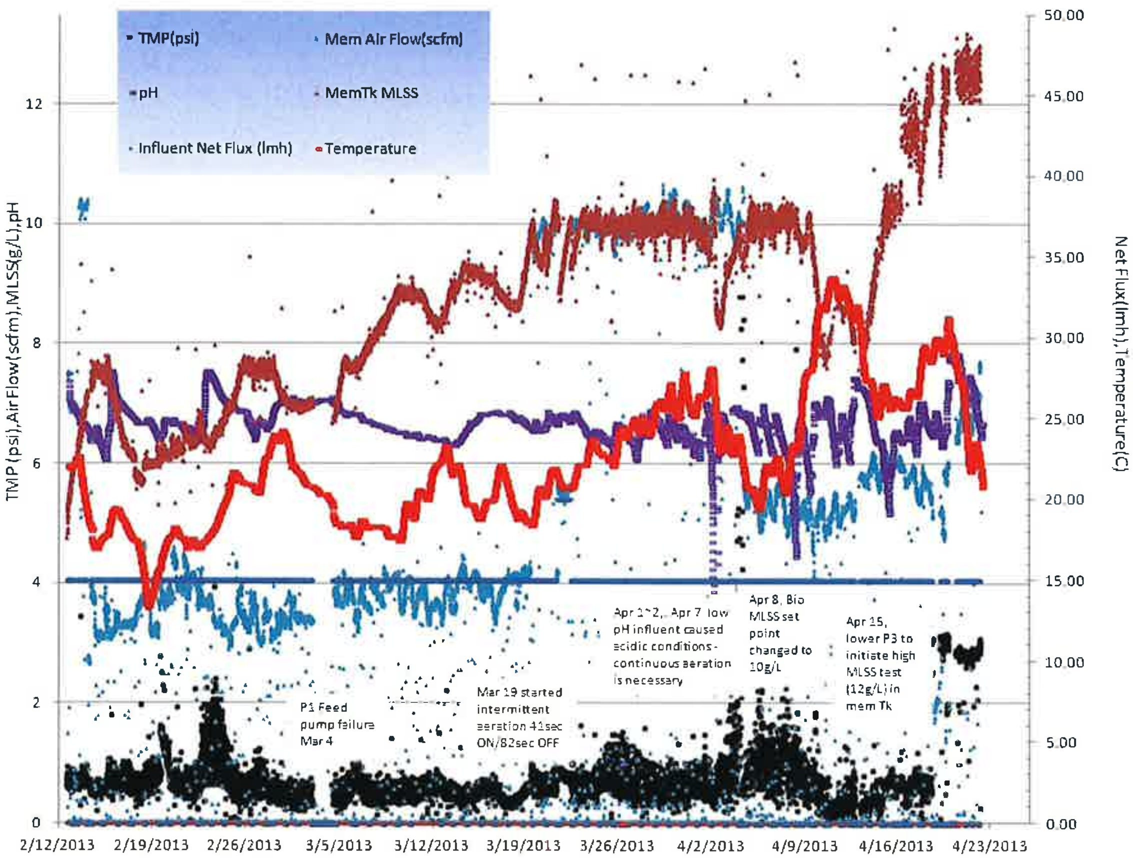


Figure 6. AASI Pilot Trends

Figure 7 shows how the pilot performed with regards to BOD_5 and TSS removal. During the first test phase, BOD_5 removal was sporadic. During phases 2 - 8, BOD_5 removal averaged above 99%, reducing influent values from as high as 5,048 mg/l to less than the required 28 mg/l. During the final phase, there was a slight drop in BOD_5 removal, probably due to the lower food-to-microorganism (F/M) ratio that results from a higher bioreactor MLSS.

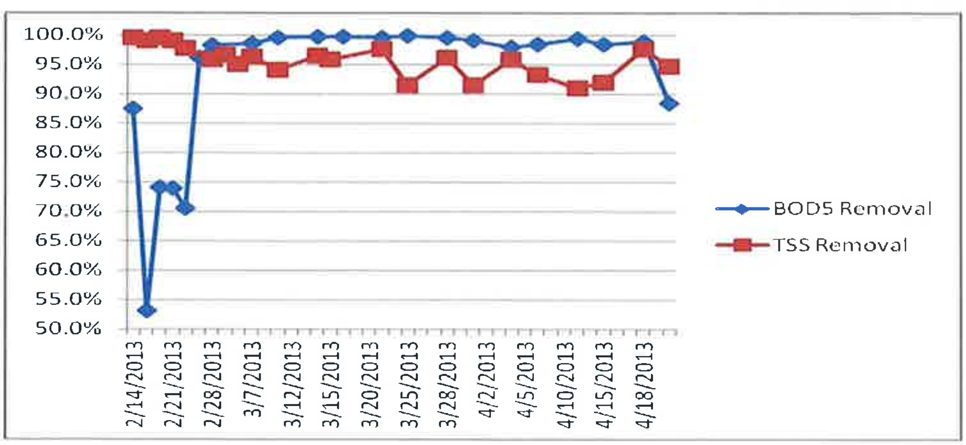


Figure 7. AASI Pilot Performance

The TSS removal varied between 90 and 99%; this fluctuation was due to influent values ranging from 25 – 320 mg/l, while effluent values were fairly constant around 3 mg/l, as would be expected with a positive solids barrier.

The other pilot system was a pressure-driven system - in lieu of vacuum-driven - that consisted of hollow tubes enclosed in horizontal fiberglass housings. The system employed a high recirculation flow through the membranes to create excessive velocities for removing the solids from the membrane surfaces. This allowed the system to operate at higher fluxes, but used significantly more energy to do so. In comparison with the AASI pilot, this system produced appreciably more foam and was unable to reach the target effluent BOD_5 concentration (28 mg/l) on a consistent basis.

Plant Upgrade

Selected System

In July of 2013, the plant issued a Request for Quotation, and received proposals from both of the vendors that had piloted their systems earlier that year. Plant management reviewed the proposals and selected the Aqua-Aerobic® MBR, primarily because its pilot had out-performed that of the other vendor. A purchase order was issued in August with delivery requested by the end of the year. The full-scale system was manufactured, delivered, and installed by the Spring of 2014, and commissioned in July of that year.

Figure 8 gives the flow diagram for the upgraded system. The MLSS concentration in the aeration basins was increased to 8 g/l, the value that proved to be most effective and stable during the pilot test. The clarifiers are now bypassed, with the biomass being recirculated through the membranes and back to the aeration basin inlet. The sand filters were removed from the tertiary building, and the 2-basin membrane tank was installed in the building instead.

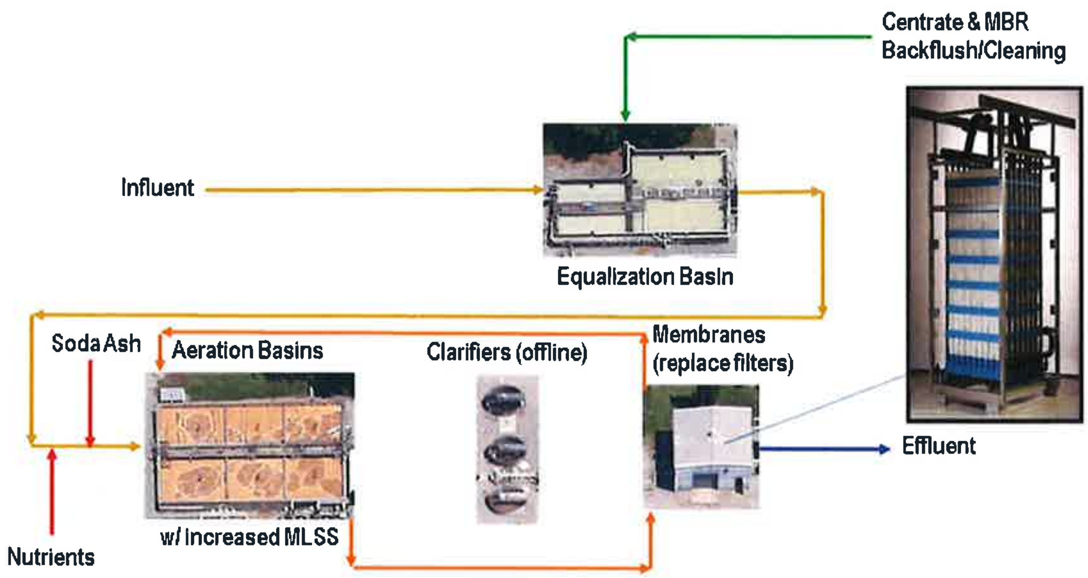


Figure 8. Flow Diagram of Plant Upgrade

The following equipment was added to the existing system:

- (2) 3,229 ft^2 (300 m^2) modules in a 316L stainless steel tank
- (3) feed pumps
- (3) skid-mounted permeate pumps
- (2) RAS pumps
- (2) air scour blowers
- Duplex chemical cleaning assembly
- Compressed air system for valve operation
- Control panel with PLC and HMI

In addition to the membrane's ability to meet the new effluent requirements in a consistent and stable fashion – as demonstrated in the pilot – the new membranes also have several other advantages. Unlike other submerged hollow-fiber membranes, the fibers are only potted at one end such that there is no top header for sludge and other debris to collect; refer to the membrane bundle shown in Figure 9. The fibers are also potted in exact, evenly-spaced locations to allow for uniform biomass flow past each fiber. In addition, the air scour is introduced in the middle of each of the nine fiber bundles that make up a module row; the air contacts the full length of each fiber, which minimizes solids buildup, and creates an air lift that draws the biomass up through the bundle. The eight rows that make up the membrane module slide into the stainless steel frame, locking in place such that there is only one air and one permeate connection to supply all of the fibers in the module.

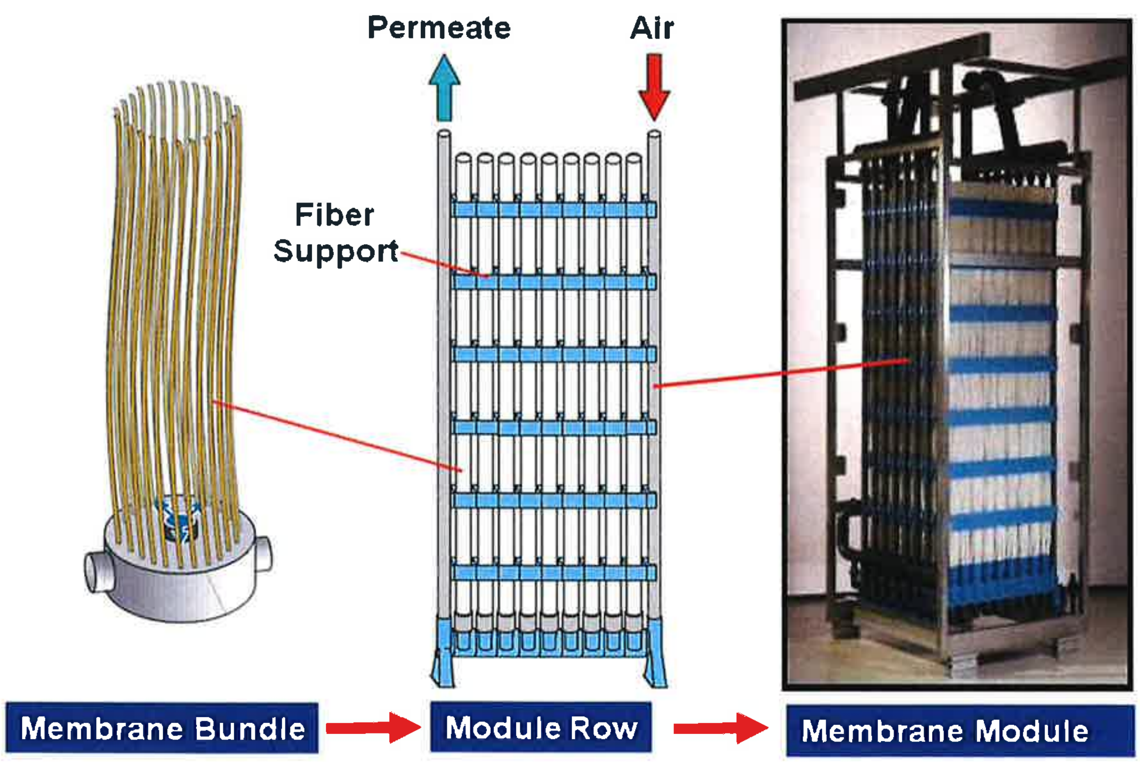


Figure 9. Unique Module Construction [Lawrence (2008)]

System Performance

After being placed on-line in July of 2014, the system ran extremely well for about 6 months. Table 2 gives the design basis for the system as well as the typical average monthly concentrations of the three main contaminants in the system effluent: chemical oxygen demand (COD), BOD_5, and TSS. As you can see, the BOD_5 and TSS levels averaged nearly half of the required values. Both membranes were operating consistently at TMPs between 2 and 3 psi.

Table 2. Typical Monthly Performance – July through December 2014

Parameter	Design Influent (mg/l)	Design Effluent (mg/l)	Actual Effluent (mg/l)
COD	11,870	---	275
BOD	3,257	28	<15
TSS	603	5	<3

In late-January 2015, trans-membrane pressures (TMPs) started to climb for no apparent reason. It was suspected that the membranes were plugging with solids, so the permeate and air hoses for one of the modules were disconnected, and the module was lifted out of the MLSS and inspected (see Figure 10). Sludging wasn't excessive but certainly more than expected after only 6 months of operation. The module was flushed with a hose to remove the sludge, and returned to service.

Figure 10. Module Showing Early Signs of Sludging

Shortly thereafter, both trains began to shut down routinely on high TMP (> 9 psid), and capacity dropped from 30,000 gpd (114 m^3/day) to 0 gpd in just 2 weeks, even with repeated intensive (recovery) cleanings. Initial thoughts were that a substance incompatible with the membranes had been accidentally spilled into the plant wastewater, though this couldn't be confirmed. The immediate objective, however, was to do whatever was necessary to keep the wastewater flowing through the membranes and avoid paying to truck it offsite for treatment, which was very expensive. At the request of AASI, one of the trains was soaked overnight in 1,000 mg/l of sodium hypochlorite (NaOCl), then flushed and placed back in service. The TMP dropped to 2 psi but climbed to 9 psi within 24 hours.

The membrane manufacturer, Koch Membrane Systems (KMS), was consulted, and they informed the plant that the most likely contaminant that could cause such abrupt and persistent fouling was silicone, such as that found in silicone-based degreasers and defoamers. The operators checked with the plastic production facility, and were informed that no silicone-based chemicals are used in the production or cleaning processes.

Another possible cause could be EPS in the biomass, excreted by microorganisms under some type of stress, typically nutrient deficiency. Though there was no indication that the plant's nutrient addition systems had malfunctioned, the sludge on the fibers was slimy, a characteristic of EPS fouling, as shown in Figure 11.

Figure 11. Magnification of Typical EPS Slime Layer

At the recommendation of the KMS, the following corrective actions were taken:

- The raw wastewater was analyzed to make sure it no longer contained any silicone or other substance incompatible with the membrane, as listed in the system's operation and maintenance (O&M) manual.
- Wasting was increased to hasten the removal of any contaminated biomass.
- Maintenance clean frequencies were increased to twice daily.
- Maintenance clean chlorine concentrations were doubled to 250 mg/L.
- Chlorine recovery cleanings (soaks) were performed more frequently, as needed.
- The permeate tank was drained, flushed, and filled with clean water to avoid backflushing with contaminated wastewater.
- Spare membrane modules were ordered to replace the plugged modules, which would be sent to KMS for evaluation and cleaning.

While the extra and concentrated chlorine cleanings lowered the TMPs considerably, the affect was very temporary, with TMPs climbing to alarm levels within only a few short hours after each cleaning. In case the cause was indeed EPS fouling, jar tests were performed with a proprietary flocculant to see if the EPS could be coagulated to minimize its fouling potential and make it easier to clean off the membrane. In addition, solids in the membrane tanks were periodically settled and drained in an attempt to remove coagulated EPS before it passed through the membrane or recirculated back to the bioreactors. Acid cleanings were performed to remove the inorganic flocculant from the membranes.

In addition to the flocculant, it was decided to test a polymer to see if it could accomplish the same thing. The problem is that most polymers are themselves incompatible with polymeric membranes; therefore, the plan was to add it to the membrane feed tank with the feed pumps off, let the polymer react and settle the EPS, and manually remove the settled sludge. However, jar tests showed only limited reduction, so the plan was abandoned.

Another corrective action was to adjust the feed tank level settings to fool the system into thinking it was in a high-flow condition, which runs the permeate pumps at their highest flux setting and operates the air scour blowers continuously. This remedy slowed the TMP rise to allow the membranes to produce more permeate.

Just as the system showed its first signs of improvement, an unexpected side effect occurred: the weight of the sludge within each fiber bundle in combination with the slimy nature of the sludge caused some of the fiber bundles to fall down and out of the frame. As the fibers flopped over the lower part of the frame, some of the fibers were sliced open, as shown in Figure 12. This required lifting the module out of the biomass and plugging the affected fibers so that the biomass wouldn't bypass the membrane and contaminate the permeate.

Figure 12. Fibers Sliced by the Lower Module Frame

Since chlorine was having limited success removing the foulant, other chemicals were tested to see if they could do a better job. Samples of the gel-like foulant were placed in several different beakers, a different chemical was added to each beaker, starting with low concentrations and gradually increasing the dose until the foulant dissolved. The chemicals used were:

- CLR
- Borax

- TSP
- OxyClean
- dishwasher detergent
- caustic
- bleach
- citric acid
- hydrogen peroxide
- hydrochloric acid

The only cleaner that dissolved all of the foulant was hydrochloric acid (HCl) at 1 pH. Unfortunately, this pH might also dissolve the membrane! Instead, the modules were repeatedly soaked in a 5,000 mg/l chlorine solution with intermittent aeration. This intensive cleaning regimen worked fairly well, resulting in a moderate increase in capacity. The relative success of this procedure prompted AASI to make a drastic change to the maintenance cleaning method: the twice-daily 30-minute chlorine cleanings were changed to frequent but short cleanings in an attempt to keep the TMPs down. The cleanings were set to occur every 4 backflushes (20 minutes) but for only 30 seconds per cleaning. This proved to have the desired effect, keeping the TMPs from getting too high and increasing system capacity.

To determine the best way to remove the foulant from the membrane, several of the fouled fibers were cut away from the modules, the cut portions on the modules were plugged, and the fiber samples were sent to KMS for cleaning. Unfortunately, KMS personnel came to the same conclusion as the plant operators has previously: the most effective cleaner by far was HCl at 1 pH, which allowed the membrane permeability to recover to 70% of that of a new fiber with only a single 18-hour soak, as shown in Table 3. However, the long-term effect of this cleaning on the membrane couldn't be determined and, therefore, it wasn't recommended.

Table 3. Result of Prolonged Soak at 1 pH

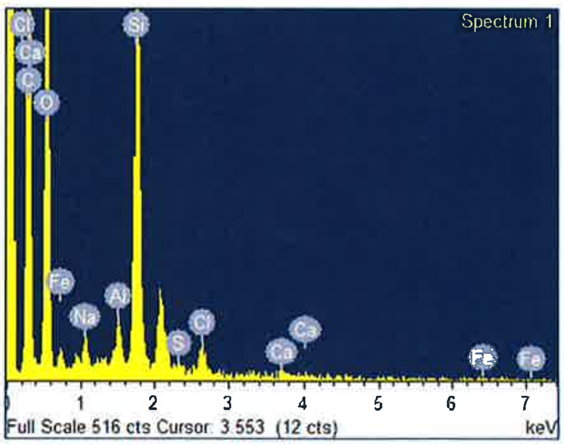
		HCl Soak	(4pm to 10am,18hrs, pH 1)					
			TMP 15 PSI, RO water feed					
		Collection time, sec for 10 mL permeate						
						Water flux	**Water flux**	
Sample	Temp, oC	Rep 1	Rep 2	Rep 3	Average	***mL/min/cm2***	***LMH***	sec/2mL
2psi		164.10	168.10	165.85	166.0	0.2	104	
15psi		17.88	17.86	17.96	17.9	1.6	961	

Armed with the information gathered thus far, chlorine cleanings were increased to 125 mg/l NaOCl for 1 minute every 30 minutes, and acid cleanings were increased to 1,000 mg/l citric acid for 45 minutes daily. Using this cleaning procedure, the membranes were able to recover about 80% of their original capacity by the time the new membranes arrived on site and were installed. The original membranes were then placed in stock as backup units.

Advanced Troubleshooting

Fiber Analysis Using a Scanning Electron Microscope (SEM) Coupled with Energy Dispersive X-Ray (EDX) Spectroscopy

To avoid plugging the new membranes in the same way as the original membranes, it was very important to determine exactly what caused the fouling. The next step in the troubleshooting process was for KMS to analyze the fiber samples for the contaminant(s) causing the issue. The first analysis was with an SEM/EDX technique [Rabiller-Baudry (2012)]. Figure 13 shows a high silicon (Si) level in the foulant gel but a much lower Si concentration on the fiber surface itself. The analyses show only the elemental Si and not what form it's in, so further analyses would be needed to discover the type of Si present. What was revealed was that, if Si is the problem, it's almost exclusively in the foulant; once the foulant is removed, the situation will be much improved. This may explain how most of the original membrane capacity was recoverable.



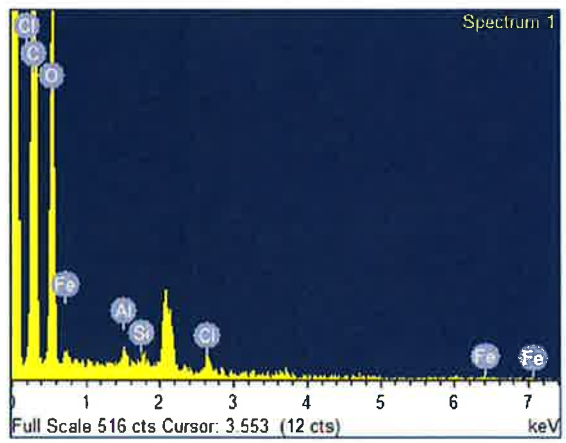


Figure 13. Results from SEM/EDX Analyses of Foulant (left) and Fiber (right)

Fiber Analysis Using a Fourier Transformed Infrared (FTIR) Technique

KMS then analyzed the composition of the fiber itself using the FTIR technique [Rabiller-Baudry (2012)]. Figure 14 indicates that a fiber sample analyzed before and after cleaning has a composition that is nearly identical to that of a new fiber. This confirms that the culprit contaminant is not found in any significant concentration within the membrane itself but resides almost exclusively in the foulant gel on the fiber exterior.

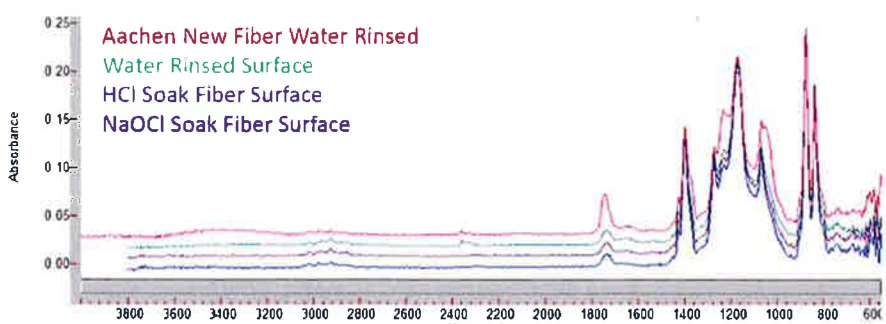


Figure 14. Results from FTIR Analyses of New and Fouled Fibers, Rinsed and Cleaned

Foulant Analysis Using the FTIR Technique

KMS then analyzed the composition of the foulant gel using the FTIR technique to try to determine the exact form of the Si. Figure 15 shows that the foulant sample has a similar – though not exact - composition to that of silicone.

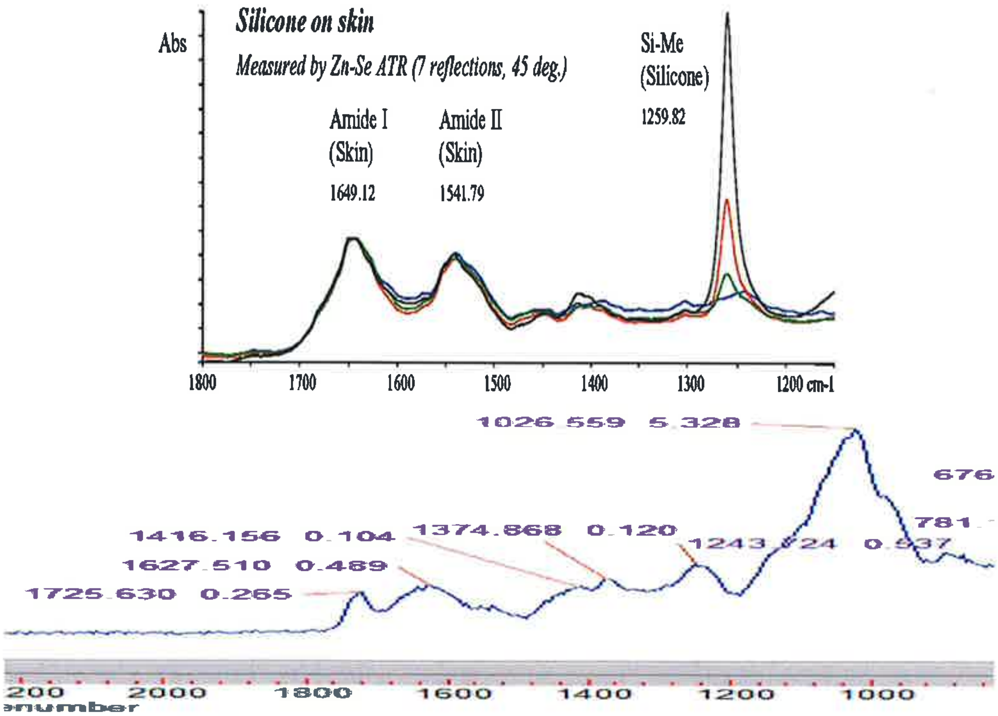


Figure 15. Results from FTIR Analyses of the Foulant (bottom) and of Silicone (top)

Not satisfied that the foulant composition matched that of silicone, the plant engineers consulted their own in-house experts and discovered a far better match with silicon dioxide (SiO_2) – refer to Figure 16. Unlike silicone, SiO_2 is prevalent is many wastewaters and is completely compatible with polymeric membranes; therefore, it's not what caused the membrane fouling.

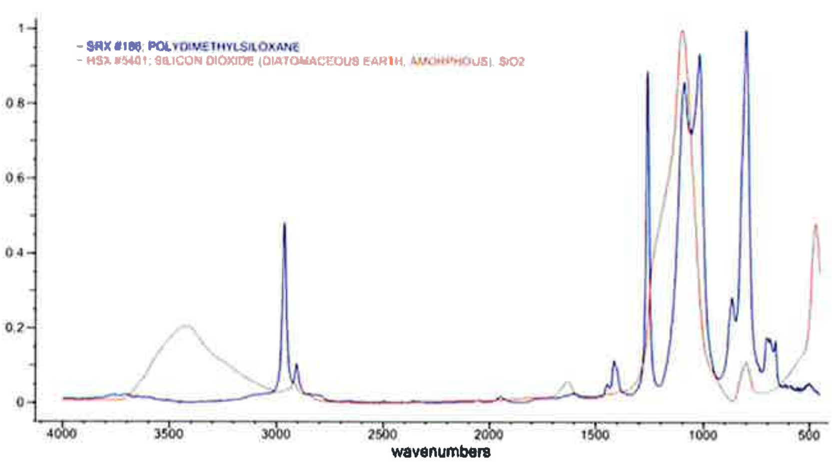


Figure 16. Comparison of the FTIR Analyses of SiO_2 (orange) and of Silicone (blue)

Because of the discrepancy, a foulant sample was sent to an independent lab, Atrona Labs, for FTIR analysis. Atrona concluded that the foulant most closely matches that of cellophane, as shown in Figure 17.

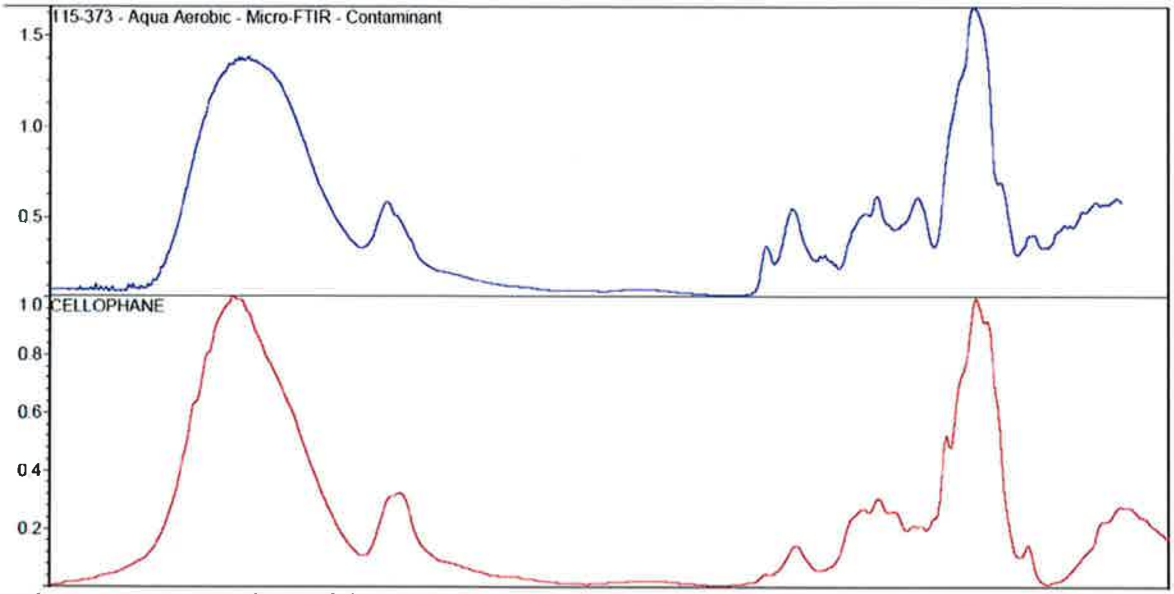


Figure 17. Comparison of the FTIR Analyses of Cellophane (orange) and of the Foulant (blue)

Cellophane is produced from cellulose using an acidification process. Cellulose occurs naturally in trees and plants, but can also be synthesized through the breakdown of glucose by the *Acetobacter xylinum* bacteria [Cheng (2002)]; therefore, it's technically an EPS. The creation of a significant amount of cellophane in a plastic production facility or its wastewater treatment plant would have to be the "perfect storm", maybe even a literal storm: perhaps a very large tree limb or bunch of branches falls or blows into an equalization or aeration basin, and an equally-significant amount of acid is present in the basin to create the cellophane. One of the sources of wastewater in the plant contains 500-1,000 mg/l of acetic acid, but it's questionable that this would be enough to produce a damaging amount of cellophane. And to make the scenario even more unlikely, cellophane is very biodegradable, so most – if not all – would be degraded before it reached the membranes. A far more possible reason for the presence of cellophane in the wastewater is that cellophane wrapping material was improperly discarded/placed in the wastewater.

Lessons Learned

The plant has been running smoothly with the new membranes for over a year now without any significant upsets. To keep it that way, there are several key lessons that the plant management and operators have had to learn:

1. Don't add anything to the biomass that will not fully degrade within the operating sludge age. While this may have not been the root cause of the fouling, it's still a good rule to follow.

2. Any spills or process upsets should be reported to treatment plant personnel. To avoid a major catastrophe, a little communication goes a long way.
3. The membrane manufacturer must approve all chemicals added to the bioreactors. This plant has been very good about this, but it only takes one time of not doing it to cause a major issue.
4. Cleaning frequencies, concentrations, durations, and flows must be fully adjustable. AASI has since modified its standard MBR control strategy to incorporate the additional flexibility that was added for this project.
5. Fiber/foulant analyses must be done on representative samples and by multiple labs. It's always good to confirm results/conclusions by having another set of eyes look at it.

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