

# OPTIMIZATION OF AN INDUSTRIAL WASTEWATER TREATMENT PLANT THROUGH IMPLEMENTATION OF A MEMBRANE BIOREACTOR AND REVERSE OSMOSIS SYSTEM FOR REUSE

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## Abstract

Stone Brew Co. in Escondido, California, built a brand new brewing facility with a simple wastewater treatment system adjacent to a restaurant and one acre beer garden in 2005. After some significant production growth, the City threatened to significantly increase the water rate to be able to accommodate the higher organic strength and solids content in the water. This resulted in the installation of an aeration tank to meet biochemical oxygen demand (BOD) limits and a dissolved air flotation (DAF) unit to meet total suspended solids (TSS) limits in 2008. By doing this, the City agreed to leave the water rate at the existing value. Typical influent water quality to the WWTP was 12,000 mg COD/L, 7300 mg TSS/L at a pH of 5.4. The issues with running an industrial WWTP with a rudimentary design quickly became apparent.

Due to the degree of difficulty in treating the brewery wastewater, which consists mostly of sugars, proteins, carbohydrates and yeast, the DAF was not able to achieve sufficient solids removal or facilitate consistent BOD removal required to meet the local limitations. Issues included excessive process control problems such as the need to haul away sludge that could not be separated by the DAF unit, foaming events and overflows, high chemical consumption, multiple mechanical failures and trouble with sludge dewatering. These factors caused breaches in water quality restrictions, costly repairs and time consuming labor. Since the WWTP was on-site next to a restaurant and outdoor beer garden, there were also concerns with the unpleasant odors created from poor biological performance and sludge handling becoming visible to customers. After a little over a year of operation with the problem-riddled system, the plant decided it would be advantageous to change the treatment scheme to something better suited for their particular wastewater.

The decision to replace the DAF with a membrane bioreactor (MBR) system was mainly motivated by the guarantee in TSS removal via membrane filtration. Other reasons included enhanced BOD removal and the possibility to reuse the effluent water within the plant. The MBR system was commissioned in January 2010 and was designed to process 60,000 gpd. It utilized two HYDRASub<sup>®</sup>-MBR HSM500 modules, each containing 500 m<sup>2</sup> of surface area. Upon stabilization of the system, various benefits of the MBR were soon realized. First of all, TSS in the effluent was drastically reduced and COD removal was greatly improved. Process control was enhanced so that all activated sludge could be treated and recycled back to the aeration tank, not hauled away. The simplistic and almost fully automatic operation of the system resulted in low maintenance and labor time compared to the DAF. The chemical usage and cost for separating solids and sludge dewatering decreased significantly. Finally, as soon as the MBR system was stabilized, a reverse osmosis (RO) system was commissioned to further treat the effluent for reuse purposes.

The installation of a RO system allowed the plant to reuse 30,000 gpd of reclaimed water within their facility. Prior to commissioning the MBR-RO system, 25,000 gpd was discharged to the sewer. Post-commissioning, 10,000- 15,000 gpd was discharged to the sewer and no activated sludge was hauled from the facility. The ability to reuse their wastewater combined with reduction in chemical costs and hauling fees saved the company hundreds of thousands of dollars, completely covering the capital cost of the MBR and RO systems in the first year of operation.

## **Introduction**

Stone Brew Co. located in Escondido, California, built a brand new brewing facility alongside a restaurant and one acre beer garden in 2005. As many municipalities do, the City of Escondido placed limitations on the amount and quality of the brewery's discharge to the City's municipal treatment plant. This was the primary driver for needing to install some type of on-site wastewater treatment facility. The brewery also prides itself on being socially and environmentally conscious, having installed one of the largest rooftop solar arrays in California and by being the biggest restaurant purchaser of local small-farm organic produce in San Diego County. Meeting wastewater regulations and decreasing their water usage played into this social and environmental commitment which was a secondary driver in the implementation and optimization of the wastewater treatment plant (WWTP).

The WWTP originally built for the brewing facility included a 0.01" rotary strainer and pH control mixing tank, as pH and TSS were the only concerns at that time. After some significant production growth, the City threatened to increase the water rate from \$2.70/kgal to \$46.00/kgal to be able to accommodate the higher strength and solids content in the wastewater. The urgent need for an on-site WWTP resulted in the installation of an aeration tank to meet biochemical oxygen demand (BOD) limits and a dissolved air flotation (DAF) unit to meet total suspended solids (TSS) limits in 2008. By doing this, the City agreed to leave the water rate at the existing value.

The DAF ran for a little over one year and was riddled with problems the entire time. The main issues being that the system could not process the needed amount of water at the TSS concentration coming in from the aeration tank. The high TSS created a sludge that would not completely rise in the DAF. An excessive amount of polymer and coagulant had to be used to create flocs that would float to the surface, and even then, it did not always work. During upsets, the unit would have to be completely emptied and contents hauled away, incurring costly fees and excessive downtime. Dewatering the sludge after the DAF was also a major issue as it was saturated with polymer and coagulants and a screw press was being used, which was not able to handle the high solids content present in the system. After dealing with these issues for a year, the plant decided to change out the DAF and replace it with a membrane bioreactor (MBR) system. There were also design changes made on the aerobic treatment and waste sludge dewatering systems in order to improve the overall efficiency of the plant. Finally, a reverse osmosis (RO) system was installed to treat the MBR permeate so that the overall water usage of the plant was reduced. Optimization of the WWTP was achieved by installing a MBR-RO system, which solved issues regarding BOD and TSS effluent requirements, water usage, sludge handling, chemical consumption and creating water re-use opportunities.

## Process Description

### DAF System

The original WWTP was installed in August 2008 to handle the waste coming from several processes in the brewery. Rinse water from cleaning mash tuns, boilers, fermentation tanks, centrifuges and other process and storage tanks were sent to the WWTP, along with the leftover sugars, yeasts, proteins, cleaning agents and other compounds used in the brewing and cleaning processes. Additionally, wash downs from cleaning the brewery floors and the outside of finished products (bottles and kegs) were also sent directly to the WWTP.

The raw feed water first went into a 40,000 gal equalization tank which then fed an 80,000 gal aeration tank at a constant flow rate. Additional nutrients (nitrogen and phosphorous) were fed to the system in the form of urea and phosphoric acid.

Figure 1 shows the overall process flow diagram of the DAF system.

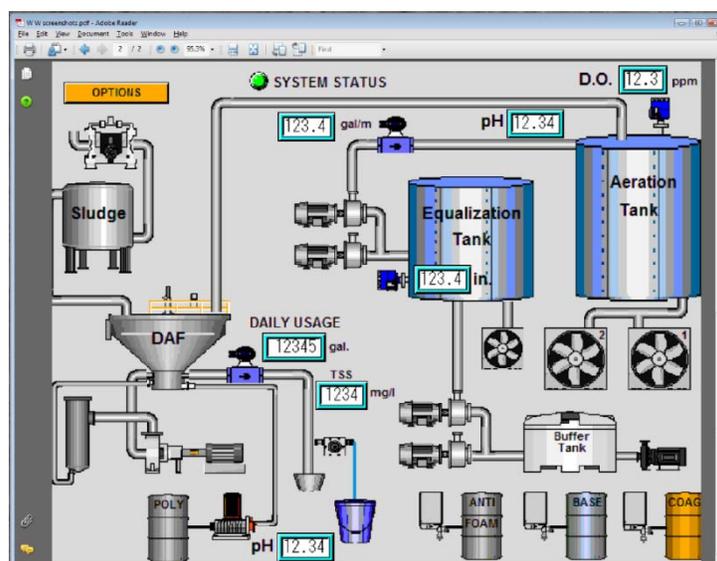


Figure 1. DAF System Process Flow Diagram

Raw feed and aeration tank water qualities are given in Table 1 and Table 2, respectively.

Table 1. Raw Feed Water Quality from Brewery Processes

Raw Feed Water Quality <sup>1</sup>		
Parameter	Unit	Value

<sup>1</sup> Average over one year of operation (including start-up)

COD	mg/L	11716
sCOD	mg/L	5113
TSS	mg/L	7246
pH	s.u.	5.4
Temperature	°F	86.5

**Table 2. Aeration Tank Water Quality in DAF System**

<b>Aeration Tank Water Quality<sup>2</sup></b>		
<b>Parameter</b>	<b>Unit</b>	<b>Value</b>
MLSS	mg/L	6709
Temperature	°F	98.9
pH	s.u.	7.2
DO	mg/L	2.8
sCOD	mg/L	268
soluble NH <sub>3</sub> -N	mg/L	4.4
soluble NO <sub>3</sub> -N	mg/L	3.7

The aeration tank was maintained at an average dissolved oxygen (DO) of 2.8 ppm O<sub>2</sub>, average temperature of 99°F (37.2°C) and 6700 mg/L MLSS. Other key system parameters are listed in Table 3. Antifoam was dosed into the aeration tank via a spray nozzle manually as needed and pH adjustment was also done manually using sulfuric acid.

**Table 3. DAF System Aeration Tank Operating Parameters**

<b>Parameter</b>	<b>Unit</b>	<b>Value</b>
F/M Ratio	mg COD/mg TSS/day	0.74
SRT	days	54.0
HRT	hrs	67.7

The activated sludge was mixed with polymer and/or coagulant as needed and sent to the DAF, which was designed to handle 150 gpm (818 m<sup>3</sup>/day) at 5000 mg TSS/L. The DAF was a 5000 gal unit that stood 12 ft (3.66 m) high. It utilized an air receiver that saturated DAF effluent with air which was sparged into the bottom of the unit to promote solids to rise to the top. The solids that floated to the top were scraped off by a skimmer and a baffle separated the skimmed portion from effluent that exited at the bottom of the unit.

The DAF operated at an average of 20.2 gpm and 7250 mg TSS/L when it was running at full capacity. DAF solid waste was sent to a screw press where the sludge was mixed with polymer and coagulant. Thickened sludge from the screw press was typically 1-5% solids, and 2.8% solids on average. A total of 25,000 gpd effluent (the maximum allowable by the City) was discharged to the sewer.

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<sup>2</sup> Average over one year of operation (including start-up)

### ***MBR System***

The MBR system was commissioned to replace the DAF in January 2010. The system was designed for 60 gpm (327 m<sup>3</sup>/day) using two Hydranautics' HYDRAsub®-MBR HSM500 modules, giving a total surface area of 1000 m<sup>2</sup>. Two membrane tanks were put in place of the DAF unit, one to contain each module. The existing equalization and aeration tanks were used in the MBR system and remained in operation while the switch from the DAF to MBR system was made to keep the biomass viable. This shortened start-up time and allowed the membranes to immediately go into operation at a high TSS concentration. The membranes were reinforced PVDF, 0.4 µm, hollow fiber elements that utilize an outside-in filtration with no regular backwash. The filtration sequence consisted of a seven minute on, one minute off interval with constant aeration. The modules required a nominal air flow of 90 scfm (152 Nm<sup>3</sup>/hr) each. In situ weekly maintenance cleanings were done by backwashing 300-500 ppm sodium hypochlorite and in situ quarterly recovery cleanings were done by backwashing 3000-5000 ppm sodium hypochlorite. Acid cleanings were done using 1-2% citric acid once or more per year and depend on the scaling propensity of the feed water.



**Figure 2. HYDRAsub®-MBR HSM500 Module**

The raw feed water characteristics listed in

Table 1 were also valid for the MBR system, but changed over time depending on the processes being operated or cleaned at the time. Nutrients were added to the aeration tank in the form of urea and sulfuric acid is used for pH control, as needed. Phosphoric acid was added as a phosphorous supplement until it was determined that enough ortho-P was present in the feed water to supply nutrients to the system. DO was maintained at 2.0 ppm O<sub>2</sub> by manually changing the speed on the blower daily. Average concentration in the aerobic tank was 8000 mg TSS/L and temperature ranged from 96-104°F (35.6-40°C). The aeration tank overflowed by gravity to the membrane tanks and return activated sludge (RAS)

was pumped back into to the bottom of the aeration tank at a rate of three to four times the filtrate flow. The two membrane tanks were linked hydraulically to maintain the same MLSS concentration and liquid level. The membranes operated at an average of 100°F (37.8°C) and could tolerate up to 104°F (40°C). The membranes operated at an average of 10,000 mg TSS/L and could handle up to 12,000 mg TSS/L. Spikes up to 15,000 mg TSS/L were experienced on multiple occasions due to mechanical failures with the RAS flow control system with no irreversible fouling occurring to the membranes. A heat exchanger was installed to cool the RAS stream, since high biological activity in the aeration tank creates extremely high temperatures, up to 127°F (53°C), if left unattended. Filtrate was pulled from the membranes using a Gould's self-priming centrifugal pump and air was supplied using a Gardner Denver Sutorbilt positive displacement rotary lobe blower. Cleanings were done using RO permeate fed by the filtrate pump (re-valved to pump water into the fiber lumen) mixed with chlorine dosed by an Iwaki metering pump.



**Figure 3. Membrane Tanks during Clean Water Testing of Modules**

Solid waste from the MBR was treated using an Adritz Bird sludge decanter centrifuge with 4000 RPM, 30 hP Viscotherm scroll drive and 10 hP pump. This replaced the screw press used in the DAF system. The decanter centrifuge typically operated at 45 gpm for approximately 24 hours per week dewatering sludge wasted from the membrane tanks. The final dewatered sludge was typically around 18% solids and was discarded directly to the dumpster. The excess water was sent to the equalization tank to be re-processed.

### ***RO System***

The RO system was installed to further treat the MBR filtrate for re-use purposes within the brewery. The RO system was designed for 40 gpm (218 m<sup>3</sup>/day) feed at 75% recovery. The system was arranged in a two stage configuration using a 5 x 3 array with six elements per vessel. Hydranautics ESPA2-LD4040 elements were chosen as they have a high tolerance to biofouling and colloidal fouling typically seen with wastewaters. The elements were low fouling spiral wound composite polyamide membranes containing 80 ft<sup>2</sup> (7.43 m<sup>2</sup>) of surface area each. The feed spacer had a thickness of 34 mil and contained a biostatic agent to deter biofouling. The nominal permeate flow for one element was 7.57 m<sup>3</sup>/day (2000 gpd) and

nominal rejection was 99.6%. A filtrate sample from the MBR (shown in Table 4) was taken as soon as the MBR start-up was completed to obtain design parameters for the RO system.

**Table 4. MBR Filtrate Water Quality Immediately After Start-Up**

Parameter	Unit	Value
pH	s.u.	6.66
Conductivity	$\mu\text{mhos}$	1635
Na	ppm	240
Ca	ppm	88.1
Mg	ppm	43.2
SiO <sub>2</sub>	ppm	27.6
PO <sub>4</sub>	ppm	70.8
Cl	ppm	154
K	ppm	52.2
SO <sub>4</sub>	ppm	306
TOC	ppm	37
Alkalinity	ppm as CaCO <sub>3</sub>	366

Due to the high phosphate levels in the MBR filtrate at the beginning of operation, the pH was adjusted to 6.0 using sulfuric acid as needed and Avista Vitec 3000 antiscalant was added to prevent calcium phosphate scaling. The high phosphate levels were due to the overdosing of phosphoric acid in the aeration tank. This has since been stopped, when it was found that sufficient phosphorous was present in the feed due to the use of phosphoric acid in some of the cleanings done in the brewery. MBR filtrate water was sent to a holding tank and then through 5 micron Cuno Aquapure cartridge filters prior to being sent to the RO. The system started at a feed pressure of 120 psi (8.3 bar) and temperature of 92°F (33.3°C).



#### Figure 4. RO System

The RO permeate was sent to a holding tank and reused in multiple processes in the brewery facility. It was first chlorinated to 0.4 ppm chlorine and blended with concentrate from another RO system used for treating tap water to make purified water for brewing. The final reusable product had a TDS of 100-125 ppm.

The concentrate stream was sent to the sewer drain at a flow rate of 10 gpm when the RO was running at full capacity, but varied depending on water usage in the plant. The typical discharge to the sewer was 10,000-15,000 gpd. The RO concentrate water quality (shown in Table 9) easily met the requirements set by the City for BOD and TSS.

### Results

The plant experienced many issues with the DAF system; however, the main item of concern for the plant was the effluent quality being discharged to the sewer. The City imposed fines for any violations and it also was a bad mark on the brewery's otherwise environmentally friendly image. Effluent was discharged to the sewer at a rate of 25,000 gpd with the average water quality shown in Table 5.

**Table 5. DAF Effluent Water Quality**

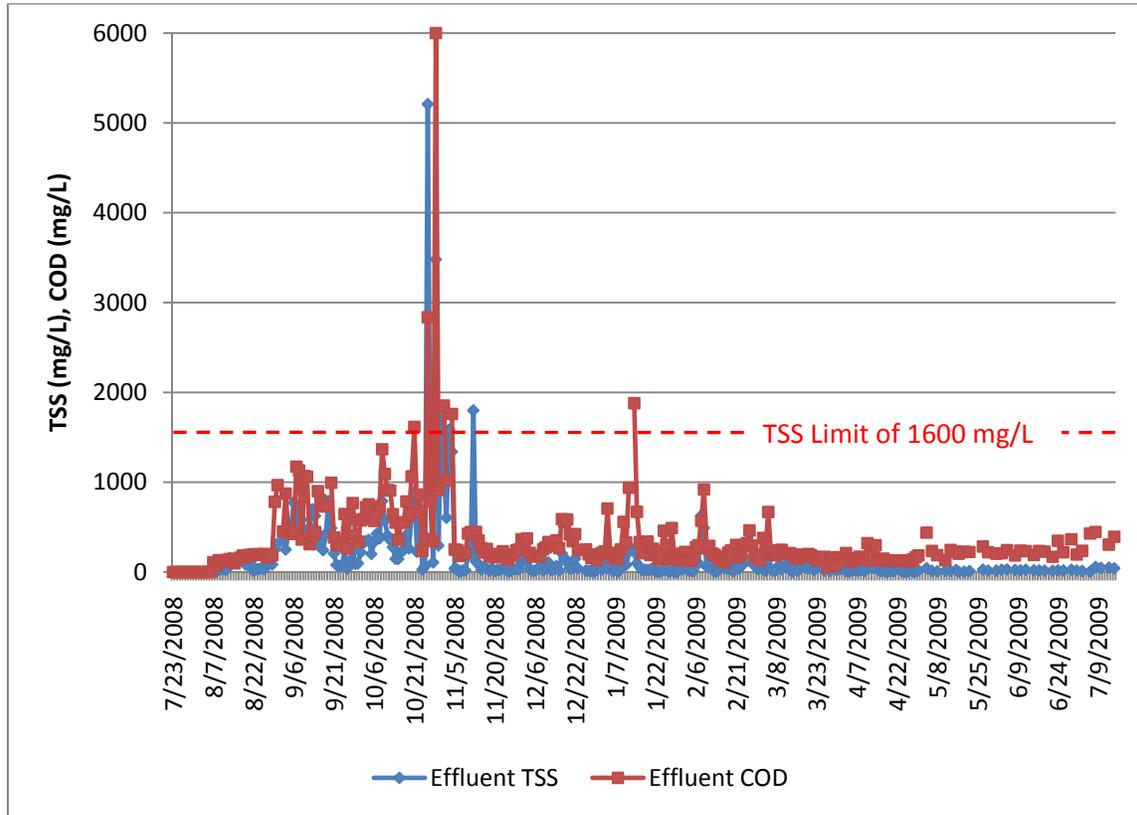
Parameter	Unit	Value <sup>3</sup>
COD	mg/L	354.8
TOC	mg/L	86
TSS	mg/L	164
pH	s.u.	7.2
Temperature	°F	99.3

The TSS and BOD limits from the City were both 350 lb/day, meaning that on average, the limits were being met, but high fluctuation in the readings would lead to sporadic infractions that were difficult to anticipate or control. The TSS could not exceed a concentration of ~1600 mg TSS/L, since the plant was constantly discharging at the maximum allowable volume of 25,000 gpd. The maximum value the effluent TSS reached in the year of operation was 5,210 mg TSS/L and there were several instances where it exceeded or came very close to exceeding the limit, as shown in Figure 5. The BOD loading exceeded the limit mostly due to the proximity of the inlet and outlet ports in the aeration tank, which resulted in short residence times. The BOD<sub>5</sub>/COD ratio for industrial effluents with COD and TOC in the range seen at this plant can be 0.45-0.65 (Eckenfelder 1970). The plant only took COD measurements, so the COD limit was higher than the TSS, in the range of 2450-3550 mg COD/L. The highest COD reading recorded was 6000 mg COD/L and remained at very high levels for a majority of the time of operation, surpassing

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<sup>3</sup> Average over one year of operation, including start-up

the limit on multiple occasions. Every violation cost the brewery an undisclosed amount in fines from the City.



**Figure 5. DAF System Effluent Quality**

The system was more under control after the first six months of operation, but the plant still had to watch the system very closely so as not to allow an upset or exceedance. The plant was also discharging at the maximum allowable volume and spending a large amount on chemicals and hauling, so keeping the system running was constantly a struggle for the operators.

Once the MBR system was installed, meeting the City’s limits was no longer an issue. The membrane provided an absolute barrier so that essentially no TSS was discharged. The raw feed water to the MBR remained mostly unchanged from the raw feed sent to the DAF; however, a grab sample of the feed water was taken more recently, two years into operation, with the results shown in Table 6. Strength and solids content of the feed changes drastically from day to day at the plant, depending on the water usage for cleanings and beer production rate.

**Table 6. MBR Raw Feed Water Quality**

Parameter	Unit	Value
TOC	mg/L	1220

COD	mg/L	6800
sCOD	mg/L	3000
TSS	mg/L	1580
T-N	mg/L	200
NH <sub>3</sub> -N	mg/L	0.6
ortho-P	mg/L	52.0
SO <sub>4</sub>	mg/L	0
pH	s.u.	6.4

The MBR filtrate quality, shown in Table 7, illustrates the large difference in effluent quality from the MBR and the DAF. The key parameters for this system to be successful are TSS and BOD, the latter of which was monitored via COD and TOC readings. When the conversion to the MBR system was done, the piping in the aeration tank was changed to pump influent and RAS to the bottom of the tank instead of at the top, next to the overflow to the membrane tanks as it was previously. This greatly improved the residence time of the influent with the biomass, providing better COD and BOD removal.

**Table 7. MBR Filtrate Quality**

Parameter	Unit	Value
TOC	mg/L	22.8
COD	mg/L	73
TSS	mg/L	1
T-N	mg/L	29
NH <sub>3</sub> -N	mg/L	0.3
ortho-P	mg/L	0.9
SO <sub>4</sub>	mg/L	320
pH	s.u.	5.8
Color	units	16.6

With the MBR system, effluent COD, TOC and TSS values were considerably lower than with the DAF system. The effluent TSS saw the largest improvement, with a 99.4% lower average concentration compared to the DAF system average. The COD and TOC values may have changed slightly from day to day depending on influent quality and performance of the biological system, but the TSS was consistently in the range of 0-2 mg/L.

The second most important issue that the brewery had to face with the DAF was process control. The solids would not form well-defined flocs that could float to the top of the DAF and easily be removed. This meant numerous batches sent to the DAF could not be processed and instead had to be completely drained out of the unit. The waste was hauled off by tanker trucks at an average rate of 10,000 gpd costing the brewery approximately \$8500 per week. Doing this was also extremely labor intensive utilizing several operators for hours at a time in order to drain the DAF into several dumpsters, clean up spilled sludge and restart the unit. Moreover, the system originally sized for 150 gpm could only process 20 gpm

of wastewater, which was not enough for the brewery which had plans to expand its production in the near future.

The process control improved when conversion to a MBR system was complete. The membranes were able to operate at a higher MLSS concentration, eliminating the need to haul away sludge that could not be processed in the DAF system. The MBR system was able to produce up to 60 gpm in order to meet the brewery's production plans. Furthermore, there were no more hauling fees associated with getting rid of sludge that could not be processed, resulting in huge cost savings for the plant.

The DAF system also had major issues with foaming and overflows. A spray nozzle system was installed to reduce foam levels in the aeration tank; however, they found that a dense layer of yeast resided at the top of the sludge blanket, blocking a majority of the foam and making the method useless for foam control. Controlling foaming, dealing with overflows and other mechanical issues with the DAF made the system incredibly labor intensive, which took time and resources away from other parts of the brewery.



**Figure 6. Top of Aeration Tank during Foaming Event**

There were still foaming issues in the MBR system, which is common in aerobic systems, but it was able to be kept under better control due to the ability to more effectively control SRT, MLSS and F/M ratio. The brewery also installed an automatic antifoam dosing system into the recirculation line to combat foaming at the first sign of high foam level in the aerobic tank. The operators no longer had to manually deal with foaming events and the overflow events were less frequent. The membranes did not have any moving parts, require high chemical dosing or need special attention to process sludge like the DAF, which made the operation much easier and less time consuming to deal with.

The DAF required a large amount of polymer and coagulant, typically 2.3 gpd and 9.9 gpd, respectively, to allow flocs to form that were large enough to float. The type of polymer changed throughout the year to find one more suitable for the application and coagulant addition did not begin until seven months after the system was commissioned so it is difficult to track the exact concentrations used. The plant used the same polymer in the sludge decanter used for dewatering and the total cost of polymer and coagulant was

approximately \$10,000 per month. The sludge decanter was not well suited for the high solids content seen in the system and it had trouble removing much of the water, typically getting the solids to 1-5% TSS as thickened sludge. This sludge was disposed of to the dumpster, which left unsightly piles of sludge and runoff in the parking lot.



**Figure 7. Dewatered Sludge by Screw Press at Stone Brew Co. WWTP**

A decanter centrifuge replaced the screw press when the MBR system was installed and was much more suitable for the high solids sludge produced. Dewatered sludge was thickened to 18% on average, producing much less volume overall and was much easier to handle in general. Only a small amount of polymer was used for dewatering, typically at a rate of 1.7 gpd, significantly less than with the DAF system and screw press. Consequently, the plant spent only \$500 per month on polymer.



**Figure 8. Dewatered Sludge by Decanter Centrifuge and Centrifuge at Stone Brew Co. WWTP**

Another eco-friendly benefit the plant experienced was the ability to reuse a significant portion of the treated effluent in their facility. The MBR filtrate quality was good enough to directly treat with a RO system. However, 5 micron cartridge filters were installed in between the MBR and RO systems as a

precaution. The reclaimed water was used in the boiler feed, cooling tower makeup, tank rinsing, centrifuge rinsing, floor wash-downs, outer bottle rinsing and keg rinsing. The plant was able to utilize 30,000 gpd of reclaimed water instead of using it straight from the tap, saving the brewery close to \$34,000 per year at the current water rate of \$3.10/kgal. Most importantly, it allowed the plant to stay within the allotted amount of 25,000 gpd discharge to the sewer so they had room to increase production if needed. The only stream discharged to the sewer was the RO concentrate stream at a rate of 10,000-15,000 gpd. The RO concentrate stream, detailed in Table 9, had essentially undetectable concentrations of BOD and TSS, making meeting the City requirements an easy task.

The RO feed and permeate quality were sampled simultaneously after the RO system started up on July 23, 2010 and compared to the results obtained by Hydranautics IMSD (Integrated Membrane System Design) software. The results were very close, but the software was slightly conservative with its calculations. The TOC removal seen in the sample was 99.9% and the chloride rejection was 96.9%. Additionally, the software predicted a pressure differential (dp) of 20 psi which was exactly what the system started up at; however, it estimated a feed pressure of 95 psi, where the system was actually running at 112 psi.

**Table 8. IMSD 2010 Projected RO Permeate Quality Versus Actual Permeate Quality**

Parameter	Unit	Feed	Permeate (projected)	Permeate (actual)
Na	ppm	264	9.20	8.54
Ca	ppm	61.1	0.45	0.025
Mg	ppm	31.9	0.24	0.013
SiO <sub>2</sub>	ppm	22.3	0.53	0.36
K	ppm	26.0	1.14	1.61
Cl	ppm	125	3.8	1.79
PO <sub>4</sub>	ppm	38.5	N/A	0.074
SO <sub>4</sub>	ppm	449	3.46	0.48
TOC	ppm	58.2	N/A	0.05
Alkalinity	ppm as CaCO <sub>3</sub>	366.0	20.0	24.0

After 18 months of operation, another sample was taken from the RO system and analyzed with results given in Table 9.

**Table 9. RO System Water Quality after 18 Months of Operation**

Parameter	Unit	Feed	Permeate	Concentrate
TDS	ppm	501	17.6	1893
TOC	ppm	23.8	0.1424	NT
Color	units	16.6	0	NT

NT- not tested

The analysis showed that the RO system was still performing well, removing 96.5 % TDS, 99.4% TOC and 100% color. Feed pressures varied from 120 psi up to ~155 psi when a cleaning was needed.

## **Discussion and Conclusion**

Upgrading the WWTP from a DAF solid separation unit to a MBR system solved water quality issues and enhanced process control allowing 75% of the treated water to be reused in other processes in the plant while saving the brewery hundreds of thousands of dollars per year on costly chemicals, waste hauling and fines. The system was also much easier to operate mechanically, upsets no longer caused violations in permit requirements and did not result in the plant spending thousands of dollars in hauling fees. The plant has saved \$442,000 per year in hauling fees, \$114,000 per year in chemical costs, \$34,000 per year in water savings, and an undisclosed amount in fines from the City when permit violations occur, resulting in a total of approximately \$600,000 per year. One year of operation more than covered the cost of installing the MBR-RO system, including the cost of membranes (MBR modules and RO elements).

When comparing the DAF system to the MBR system, the results showed a significant improvement in performance: 97.0% COD removal in the DAF compared to 99.7% in the MBR and 97.7% TSS removal in the DAF compared to 99.9% in the MBR. Although it may seem like a small difference, it made a huge impact on whether or not the plant met its discharge requirements or not. This was an advantage that the MBR system could provide which a conventional system could not. It is one of the reasons why the popularity of MBR systems has been increasing in recent years, causing industrial MBRs to comprise of approximately 27% of all commercial MBR installations as of 2000 (Brindle, et al. 2000).

The RO system provided even further removal of color, TDS, TOC and other organic compounds to allow full re-use of the treated permeate. The plant saved 11 MG per year in water that would normally be taken from the city water supply by using the reclaimed water in their plant. The RO system ran well at a low differential pressure and provided the plant with the ability to continue at their current maximum production capacity. In the end, installing the MBR-RO system was the solution needed for the plant to stay in business at the current location.

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