My Diffuser Goes Up to Eleven (Actually Twelve)

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ABSTRACT

Fine pore membrane diffusers are used extensively worldwide for aeration of activated sludge basins. Aeration can account for as much as 60% of a plant's energy usage (Rosso, et al. 2005). Pore fouling and membrane material degradation can reduce energy efficiency of fine pore membrane diffusers to 50% of the original efficiency after just a few years of operation. This work investigated oxygen transfer efficiency of polyurethane membrane AEROSTRIP® diffusers that have been in continuous use with the original membranes at the Bremerton, Washington municipal wastewater treatment plant since 2001. Results of clean water testing and off-gas testing in 2012 and 2013 indicated that the eleven to twelve year-old diffusers were operating at ~80% of their original efficiency. A simple pressure washing technique increased oxygen transfer rate of the eleven to twelve-year old diffusers to ~90% of the original efficiency, resulted in a measured SOTE of 7.4%/m (2.3%/ft) immersion depth, and was effective in reducing header pressure by about 60 mbar (0.9 psi).

KEYWORDS: aeration, diffusers, oxygen transfer, energy, off gas testing

INTRODUCTION

The Bremerton, Washington plant was converted from a coarse bubble system to a fine pore polyurethane strip diffuser system in 2001 using labor from the plant's own operations staff. There are 140 each 15 cm x 3 m AEROSTRIP® (AquaConsult, Austria; Ovivo, Utah) diffusers operating in each of two tanks (Figure 1). The plant is non-nitrifying and currently treats about 18,925 m^3/day (5 mgd) at a mean cell residence time (MCRT) of approximately 1.5 days in two parallel 1,665 m^3 (440,000 gallon) basins operating at a diffuser immersion depth of approximately 4.15 m (13.6 ft), which is essentially the sidewater depth for these floor-mounted, thin profile diffusers. An anaerobic selector basin is present, however there was significant backflow of oxygen into this zone, and microscopic evaluation confirmed the presence of filaments. Maintenance of the diffusers over the last twelve years at Bremerton has been limited to periodic tank top hosing and brushing (using a soft bristle brush) of diffusers with a mild soap, a process that takes 2-3 hours per tank.

Figure 1. Bremerton Plant. Left photo shows the two basins. Top right photo shows the north basin shortly after installation and the bottom right photo shows the north basin immediately following the 2012 off gas testing.

Much work has been reported on oxygen transfer degradation of fine pore diffusers over time in the last two decades or so. In many systems, oxygen transfer can fall to 50% of the original efficiency after 2-5 years of operation when adequate maintenance or membrane replacement is not practiced (Rosso and Stenstrom, 2006), which can significantly increase a plant's energy usage and decrease a plant's treatment capacity. Off-gas testing is generally the best method to track oxygen transfer efficiency at an operating facility over time. On-line off-gas methods have been introduced in recent years (Leu, et al, 2009).

Propensity for fine pore diffuser fouling is affected by mean cell residence time (MCRT), presence of nitrification, presence of denitrification, presence of selectors, location of diffusers in a plug-flow tank, and other important factors (Rosso and Stenstrom, 2005). The Bremerton facility, being a non-nitrifying, short MCRT system, has a relatively high potential for pore fouling. Although an anaerobic selector was in operation, which would normally reduce diffuser pore fouling potential, there was significant backflow of oxygen into this zone, rendering it largely ineffective at controlling filaments.

Several maintenance techniques have had some success at improving field oxygen transfer rates at wastewater treatment plants, including tank top hosing, physical cleaning, and acid injection into the air header (Mueller, et al. 2002). Pressure washing has not been extensively studied as a method to restore oxygen transfer efficiency, and this technique was studied as part of this work.

METHODOLOGY

2012 Oxygen Transfer Testing

In July 2012, off-gas testing was performed at the eleven-year old, continuously operating plant. Off-gas testing was performed in the same fashion as described in previous reports and activities by the first author (Rosso et al, 2005) and is consistent with the procedures described by the US EPA (1983). It is based upon the original off-gas method (Redmon et al., 1983). A 61 x 244 cm (2 ft x 8 ft) hood was used at eight locations in each of the two tanks for each series of tests, representing about 3.8% coverage of the surface area of the tanks. The 2012 off-gas testing was performed over three days of plant operation and included five series of tests in the south basin and two series of tests in the north basin. No disruption in plant operations during the testing was noted.

Following off-gas testing, eighteen of the original eleven-year old diffusers with the original membranes were harvested for clean water testing in the factory 4.5 m x 6.5 m (14.8 ft x 21.3 ft) test tank (Figure 3) following the ASCE Oxygen Transfer Standard (2006). The first series of clean water tests was performed using the diffusers in their harvested state with no additional cleaning.

Off-gas testing at the site and clean water testing at the factory test tank in 2012 were each performed at three different membrane flux rates—approximately 16.8, 25.8, 51.5 $Nm^3/m^2/hr$ (1.0, 1.5, and 3.0 $scfm/ft^2$). The clean water testing in the factory test tank was performed at each of three different diffuser densities (8.9, 17.8, and 26.8% bottom coverage) to represent the typical range of diffuser arrangement of the tapered system at the plant. Varying bottom coverage in the factory test tank was performed by closing and opening valves to each diffuser to operate 6, 12, or 18 diffusers, as each individual diffuser had its own drop pipe.

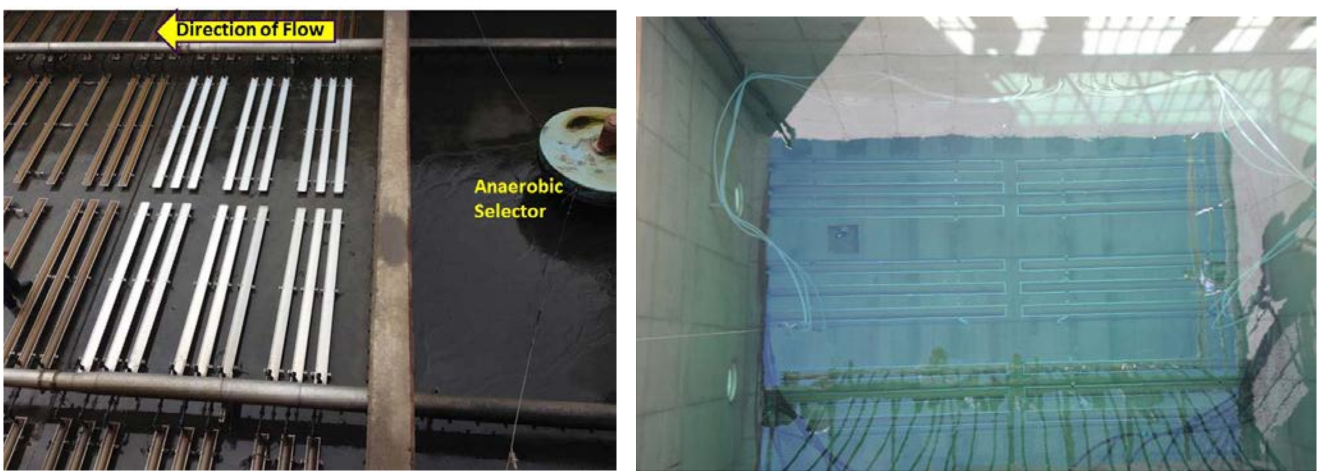

Figure 3. Left photo shows the location of the eighteen eleven-year old diffusers harvested for clean water and material strength testing (represented by replacement with the new diffusers). Right photo shows the harvested diffusers in the test tank for clean water testing

Following the initial clean water tests, a simple pressure washing technique using no chemicals was performed at the clean water test facility. Clean water tests were then repeated for the 16.8 and 25.8 $Nm^3/m^2/hr$ (1.0 and 1.5 $scfm/ft^2$) membrane flux at the 17.8% bottom coverage condition. Following the pressure washing, pattern distribution noticeably improved (Figure 4).

Figure 4. Pressure washing the eleven-year old diffusers at the factory test tank in 2012. The positive effects of pressure washing can be seen on the air distribution pattern.

2013 Oxygen Transfer Testing

In April 2013, off gas testing at Bremerton was repeated using the same methods described earlier on the now twelve-year old diffusers. Both tanks were off-gas tested on a Tuesday; pressure washing of the north tank was performed on a Wednesday; and the off-gas tests were repeated on both tanks on a Thursday. Two series of tests per tank per day were performed using the same hood and eight test locations from 2012. The north tank was selected for pressure washing since it did not contain the eighteen new diffusers that replaced the diffusers harvested from the south tank for the 2012 clean water testing.

The pressure washing technique consisted of keeping about 10 cm (4 inches) of effluent water over the diffusers, operating the diffusers with a small amount of air from the blowers, and applying a high pressure water stream through a rotating nozzle held just above the water level over the length of the diffuser (Figure 5). Typically, 2-3 passes of 1-2 seconds per pass were used for each 3 m strip diffuser. The procedure was a three person operation—one person pressure washed the diffusers, one person managed the hose and provided general assistance in the tank, and one person acted as a safety watch at the top of the tank. It took 3-4 hours using a 19 MPa (2,800 psi) pressure washer equipped with a rotating nozzle to pressure wash the entire tank equipped with the 140 ea 3m x 15 cm strip diffusers.

Figure 5. A worker pressure washing the 12-year old diffusers in the north tank in 2013. It took 3-4 hours to pressure wash the entire tank.

2012 Material Testing

Tensile testing was performed on a random selection of the eighteen diffusers harvested in 2012. For tensile testing, dog-bone samples were cut from the eleven-year old diffusers as shown in Figure 6. In addition, a similar dog-bone sample was removed from an unused membrane which was produced in the same production run as the original membrane and had been stored in the factory storage area since 2001. Five specimens per membrane were prepared for the test. The specimens were left in the laboratory which was air conditioned at 23 °C overnight before testing. Tensile strength and elongation was measured using the tensile tester, type BD0-FB0.5TH, manufactured by Zwick GmbH & Co. KG, Germany. Tensile speed was 500 mm/min per ISO37.

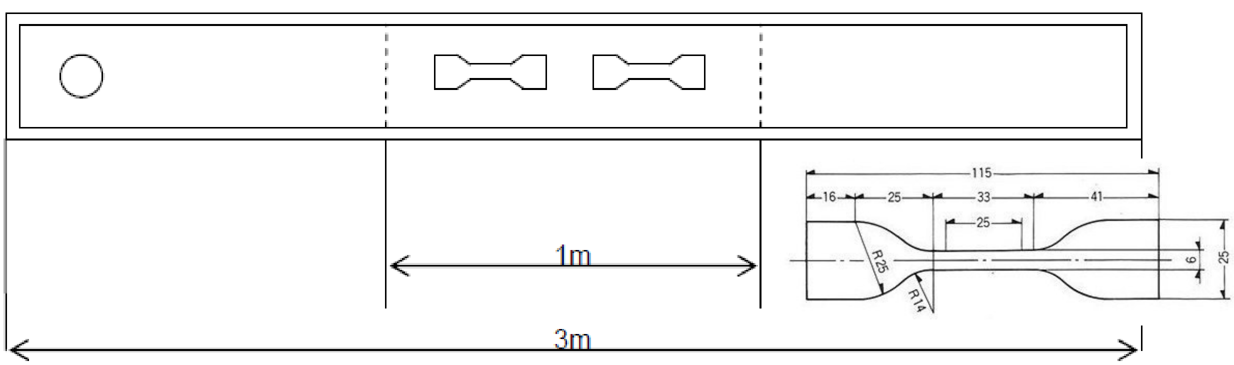

Figure 6. Membrane samples for tensile strength and elongation testing

RESULTS

Off Gas Testing

Average αFSOTE from the site off-gas testing was 13.4% and 12.6% in 2012 and 2013, respectively, for all tests performed prior to pressure washing (for 2012, all tests; for 2013 all south tank tests and Tuesday's north tank tests). In 2013, the average αFSOTE for the north tank was 12.0% on Tuesday (before pressure washing) and 14.9% on Thursday (following pressure washing). Results are presented in Table 1. In addition, the header pressure dropped from about 485 to 425 mbar (7.1 to 6.2 psi) as a result of the pressure washing as read on the installed pressure indicators. No attempt was made to verify accuracy of these installed pressure indicators, but results are generally consistent with those obtained during the clean water tests, at least following pressure washing.

Table 1. Summary Results of Off Gas Testing. Tests 3N and 4N represent measurements following in basin pressure washing of diffusers; all other results are before pressure washing.

2012 Data

Test	OTE (%)	aSOTE (%)	α	Air Flux (scfm/ft²)	Air Flux m³/m²	DO (mg/L)	Uptake (mg/L-hr)
1	7.47	12.61	0.47	0.32	0.10	4.31	29.7
2	10.8	12.94	0.48	0.22	0.07	1.56	29.9
3	6.70	8.39	0.31	0.36	0.11	2.21	29.8
4	16.4	17.84	0.66	0.12	0.04	0.69	23.9
5	13.64	13.96	0.52	0.09	0.03	0.23	15.1
6	7.81	13.28	0.49	0.18	0.06	4.33	17.7
7	10.1	14.71	0.54	0.48	0.15	3.28	60.5
Overall	10.4	13.4	0.50	0.25	0.08	2.37	29.5

2013 Data

Test	OTE (%)	αSOTE (%)	α	Air Flux (scfm/ft²)	Air Flux (m³/m²)	DO (mg/L)	Uptake (mg/L-hr)
1N	7.83	10.93	0.40	0.28	0.086	2.84	23.2
1S	8.45	11.40	0.42	0.23	0.071	2.68	21.2
2N	9.62	13.05	0.48	0.19	0.059	2.66	19.4
2S	10.51	13.63	0.50	0.17	0.052	2.38	18.7
3N	10.25	14.27	0.53	0.17	0.052	2.98	19.8
3S	9.31	13.01	0.48	0.20	0.060	3.03	19.4
4N	9.15	15.45	0.57	0.18	0.055	4.41	18.8
4S	9.17	13.63	0.50	0.20	0.062	3.47	20.2
Avg N	9.04	13.11	0.49	0.22	0.066	3.22	20.64
Avg S	9.28	12.83	0.48	0.20	0.062	2.89	19.98
Overall	9.2	13.0	0.48	0.21	0.064	3.05	20.32

The pressure washing improved the transfer efficiency more at the front end of the tank compared to the back end of the tank (Figure 7). Typically, diffusers in the influent end of plug flow systems have the greatest propensity for fouling so they stand to benefit most from effective maintenance procedures (Leu, et al, 2012).

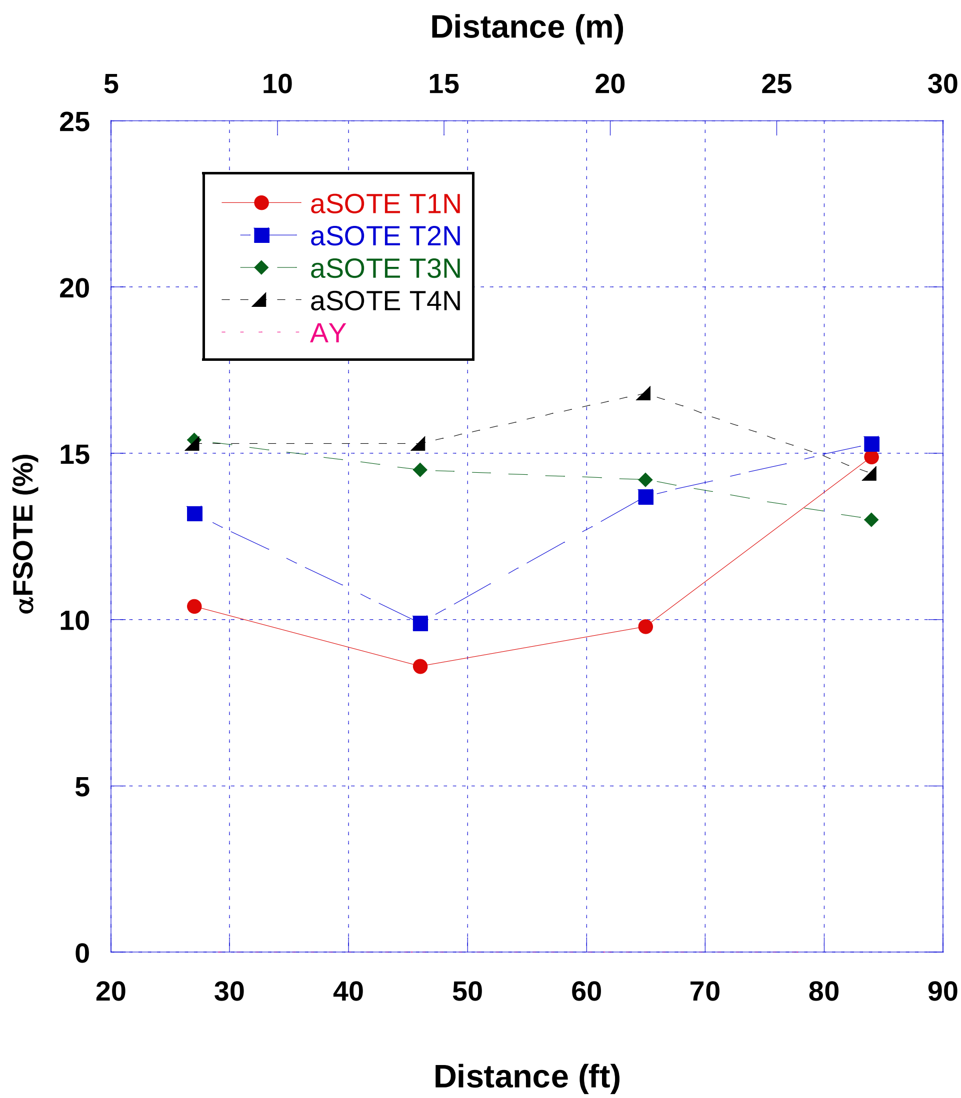

Figure 7. 2013 North Tank αFSOTE (%) versus tank distance measured from the influent end (tests 1N, 2N are before pressure washing; tests 3N, 4N are after pressure washing)

Taken as a whole, the results indicate an αFSOTE after 11-12 years of operation of about 3.3%/m (1%/ft) immersion depth in this 1.5-SRT system. For conventional, short SRT treatment plants (SRT 1 to 6 days), this system performed better than all previously tested used fine pore systems and better than most new fine pore diffuser systems tested by the first author (Figure 8).

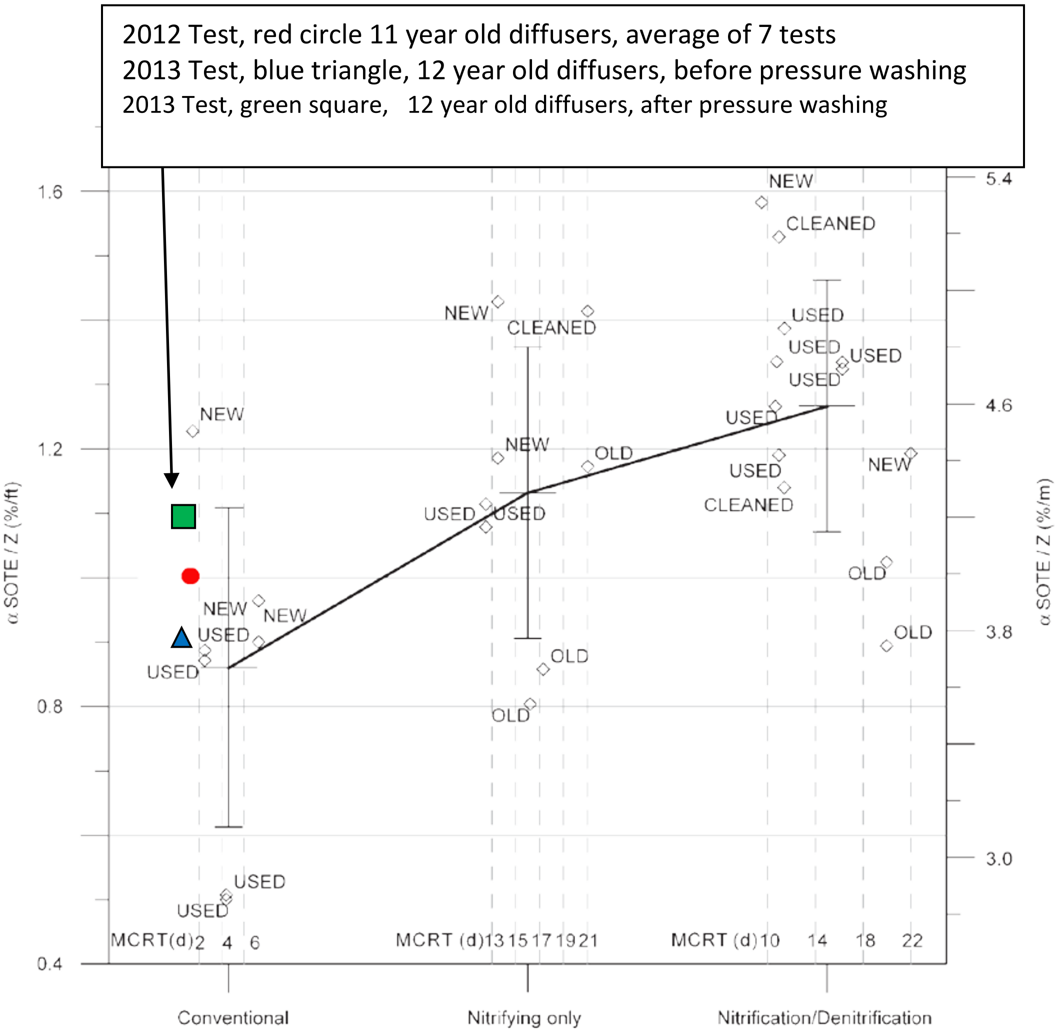

Figure 8. Results of off gas testing at Bremerton with 11-year old polyurethane strip diffusers with original membranes plotted in color with historical data from other plants collected by the first author. Historical "used and old" data points are generally from diffusers <5 years old.

Clean Water Testing

Average SOTE from the all clean water tests performed using the eighteen harvested eleven-year old diffusers with the original membranes averaged 27.2%, or approximately 6.6%/m (2.0%/ft) immersion depth. The test results do not show the typical trend of increasing SOTE with decreasing air flux or increasing SOTE with increasing diffuser floor coverage. The reason for this may be the differences in individual diffusers. From observing the diffusers from the tank top during testing it was clear that some diffusers had better and worse air distribution. There was one observable small leak in one diffuser. The differences in transfer efficiencies caused by diffuser condition are probably greater than the difference one would have observed with varying air flux and floor coverage. Results of the clean water testing before pressure washing are presented in Table 2.

Table 2. SOTE measured for harvested eleven-year old diffusers at varying bottom coverage (6 diffusers=8.9% BC; 12 diffusers=17.8% BC; 18 diffusers=26.8% BC) and varying membrane flux rates during the clean water tests before and after pressure washing

Test No.	No Strips	K_La_{20} (1/hr)	$C^*_{\infty 20}$ (mg/L)	Flow Rate (SCFM)	Flux (SCFM/ft^2)	Flow Rate (m^3/min)	Flux (m^3/m^2-hr)	Tank Flux (SCFM/ft^2)	Tank Flux (m^3/m^2-hr)	SOTE (%)
1	18	12.6	10.4	121	1.44	3.43	26.32	0.39	7.2	26.9
2	18	12.1	10.5	118	1.40	3.35	25.70	0.38	6.6	27.0
3	18	12.0	10.7	118	1.40	3.35	25.65	0.38	6.6	27.2
4	12	7.2	11.0	79	1.40	2.23	25.63	0.25	4.8	25.5
5	12	9.0	10.7	147	2.63	4.18	48.03	0.47	8.4	27.6
6	6	8.0	10.7	79	2.83	2.25	51.77	0.25	4.8	28.0
7	18	20.7	10.6	212	2.51	6.00	45.98	0.67	12.6	27.5
8	18	7.4	10.5	79	0.94	2.24	17.20	0.25	4.8	25.4
9	12	5.0	10.7	53	0.95	1.51	17.41	0.17	3	26.1
10	12	3.6	10.7	34	0.61	0.97	11.15	0.11	1.8	29.8
11	12	8.4	10.5	79	1.40	2.23	25.63	0.25	4.8	28.0

Clean water testing was not performed on the new diffusers in 2001; however, it would be expected to have been 33-34% based on factory curves and similar witness tests performed previously by the first author. Thus, the SOTE measured during this test on unwashed (other than brushing) eleven-year old diffusers represents about 80% of the expected original clean water transfer efficiency of new diffusers of this type.

After pressure washing, pattern distribution improved and the SOTE increased about 4 percentage points (a 15% increase in transfer efficiency) on average. Results are presented in Table 3. This increase in SOTE during clean water testing was similar to the increase observed at the front end of the basin during the off-gas testing after pressure washing (Figure 7). This is consistent with the fact that the diffusers used for clean water testing were harvested from the front end of the tank. Pressure was reduced by 108 mbar, or 1.6 psi. The trans-membrane pressure drop following pressure washing is similar or slightly less than that measured for new diffusers of this type.

Table 3. "SOTE" measured for harvested eleven-year old diffusers at bottom coverage of 17.8% and membrane flux rate of 25.8 $Nm^3/m^2/hr$ (1.5 $scfm/ft^2$) during the clean water tests before and after pressure washing. Static pressure head is about 407 mbar (5.9 psi)

Before Pressure Washing

	SOTE (%)	SOTE (%/m)	SOTE (%/ft)	Manifold Pressure (mbar)	Manifold Pressure (psi)
Test 4	25.5	6.2	1.9	536	7.9
Test 11	28.0	6.8	2.1	560	8.2
Average	26.8	6.5	2.0	548	8.1

After Pressure Washing

	SOTE (%)	SOTE (%/m)	SOTE (%/ft)	Manifold Pressure (mbar)	Manifold Pressure (psi)
Test 12	30.4	7.3	2.2	441	6.5
Test 13	30.7	7.4	2.3	441	6.5
Test 14	31.2	7.5	2.3	438	6.4
Average	30.8	7.4	2.3	440	6.5

Operational Results

From the off gas and clean water testing, average *alpha* factor was calculated to be ~0.5. This represents a true *alpha* since the SOTE data used in the alpha calculation represented transfer efficiency of uncleaned diffusers that would be in the same condition as the diffusers in the basin during off gas testing. The *alpha* value measured during this testing is consistent with values previously reported for non-nitrifying, low MCRT systems (Rosso, et al. 2005)

Plant historical data is shown in Figure 9. Very little variation in long term airflow (other than some seasonal variations due to varying operational strategies) is observed in the historical trend, which is consistent with the oxygen transfer testing performed as part of this work.

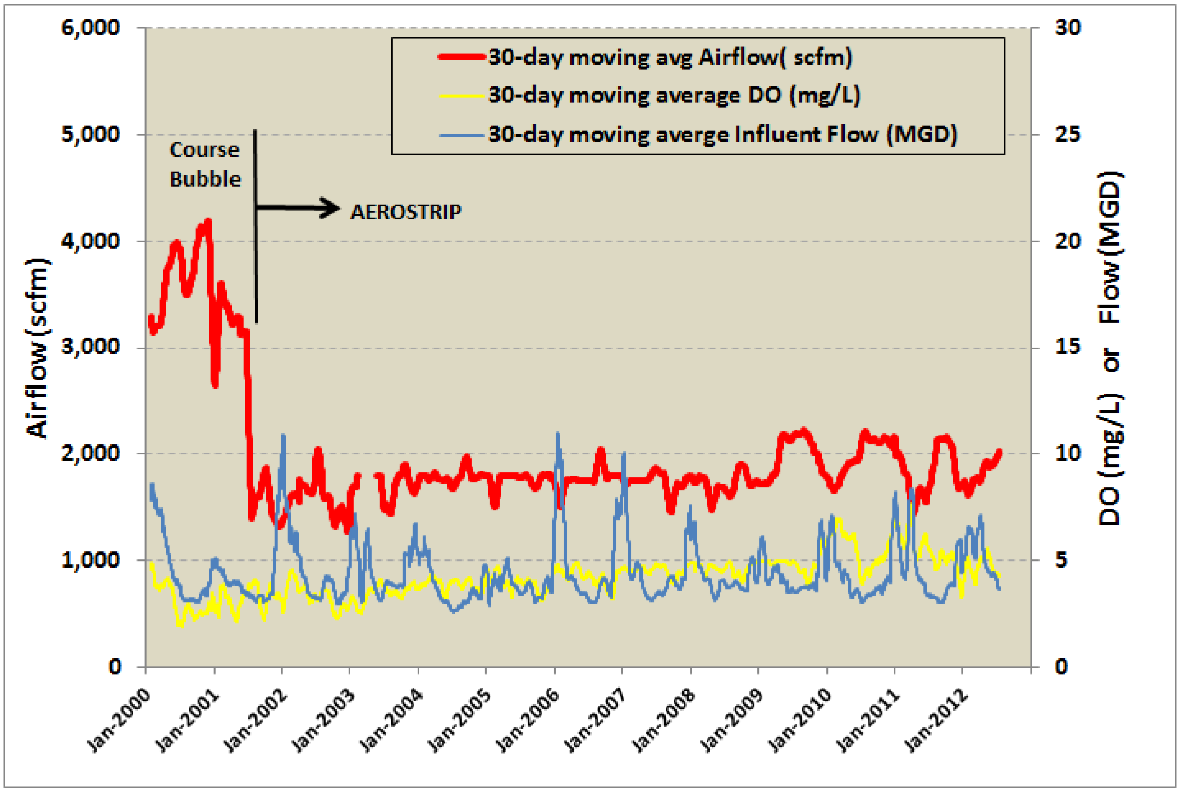

Figure 9. Long terms operational trends taken from the Bremerton plant's operational logs.

Membrane Material Testing

Elongation and tensile strength testing of the eleven-year old polyurethane membranes was performed and compared to the original, unused material which had been stored at the factory since 2001. Tensile tester used was type BD0-FB0.5TH, manufactured by Zwick, GmbH & Co. KG, Germany. The average measured tensile strength of the eleven-year old membranes was 9.0 MPa, approximately 50% of that of the original, stored material (Table 4).

Table 4. Results of tensile strength of eleven-year old Bremerton membranes compared to an unused sample from the original production run

Sample Name	Tensile Stress (MPa)	Strain (Elongation) (%)
68586-13-6 (original; unused)	18.0	254
68585-11-2 (used)	8.3	121
68585-8-5 (used)	9.4	159
68585-8-4 (used)	9.8	189
68585-9-1 (used)	8.8	139
68585-12-1 (used)	8.6	151

The reduced tensile strength after eleven years is still over three times greater than the loads imparted to the membrane at the design flux rates during operation in a heavily fouled condition, estimated at 2.4 MPa (350 psi). This value was determined as follows:

Tensile strength tests were performed on the five membrane samples as previously described. The circular arc, specifically the curve radius of the membrane, was calculated as a function of the elongation. Differential pressure was calculated from tensile strength (stress), curve radius, and thickness of the membrane using Equation 1 and plotted in Figure 10.

(1) Stress = Differential Pressure x Curve Radius / Membrane Thickness

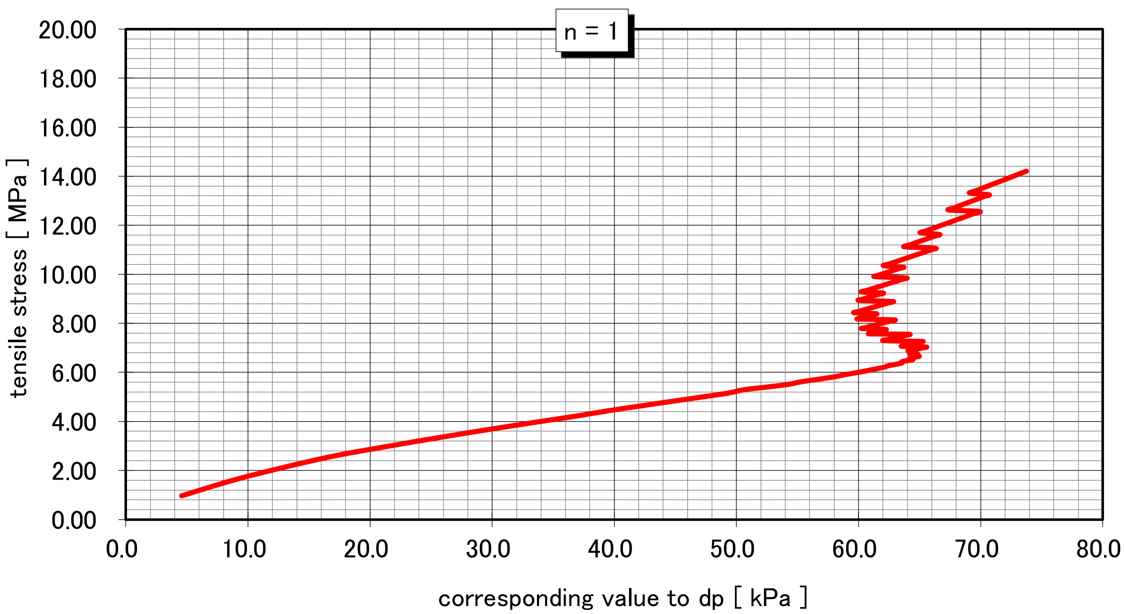

Figure 10. Relationship between tensile stress and membrane pressure loss (dp)

A pressure drop of 15 kPa (2.2 psi), which was measured for the fouled diffusers operating at the front end of the tank before pressure cleaning (Table 3), represents a conservative value in estimating the resulting tensile stress. Accordingly, a pressure drop of 15 kPa (2.2 psi) corresponds to a tensile stress of 2.4 MPa (260 psi). This is lower than the average measured tensile stress of 9.0 MPa of the eleven-year old membranes.

The results are consistent with observations of the operating staff (who have worked at the plant during the entire life of the diffusers) that 5-8 (out of 280) membranes have required replacement in the first eleven years of operation. In all cases, operators used entire diffuser spares provided by the manufacturer in 2001 for replacement.

SUMMARY

This work offers a unique look at the efficiency of eleven- to twelve-year old continuously operating membrane fine pore diffusers. Because the AEROSTRIP diffusers are floor-mounted, may be installed in high bottom coverage arrangements due to their rectangular shape, and they use fine perforation technology, they have a greater potential to transfer high amounts of oxygen into the wastewater compared with most fine pore diffuser systems. This study confirmed the efficiency of these diffusers over an extended life of twelve years was high at the Bremerton facility.

SOTE averaged 26.8% before pressure washing and 30.8% after pressure washing for the eleven-year old harvested diffusers tested in the factory test tank at a membrane flux of 25.8 $Nm^3/m^2/hr$ (1.5 $scfm/ft^2$) and a bottom coverage of 17.8%. From off-gas testing, the αFSOTE was 13.3% on eleven-year old diffusers before pressure washing, 12.6% on twelve-year old diffusers before pressure washing, and 14.9% on twelve-year old, pressure washed diffusers. The positive effects of pressure washing were greater at the front end of the tank compared to the back end of the tank. Calculated *alpha* was ~0.5 for this non-nitrifying facility. Immersion depth was 4.15 m (13.6 ft).

Selection and maintenance of diffusers can have a profound effect on energy usage at wastewater treatment plants. At this plant, pressure washing reduced air requirements from ~3,167 Nm^3/hr to ~2,850 Nm^3/hr (2,000 scfm to ~1,800 scfm) and reduced header pressure from ~485 to ~425 mbar (~7.1 to ~6.2 psi), which would reduce energy usage from about 60 to 48 kW (81 to 65 HP) when DO control is implemented. At 10 cents/kW-hr, this results in about $10,000 per year in energy savings realized by pressure washing, and this on a system that was already operating substantially more efficiently than all other non-nitrifying plants previously tested by the first author.

Oxygen transfer studies of membrane diffusers of this age generally do not exist in the literature. Generally speaking, the measured oxygen transfer rates at Bremerton were very high for membrane diffusers in use for more than five years (in this case twelve years) in non-nitrifying facilities.

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