Comparison of Extended Life Aeration Membranes

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1. INTRODUCTION

Flexible fine pore diffusers have been widely applied in the wastewater industry for efficient energy consumption associated with oxygenating the wastewater stream. It is documented that the operating efficiency of most fine pore diffusers change over time with the build-up of organic or inorganic materials on the surface or in the pores of the membrane, or through changes in membrane material properties such as extractable content, durometer, specific gravity, tensile, tear, etc.

Environmental Dynamics International (EDI) fine pore panel diffuser systems have been applied since 1993 with hundreds of thousands of membranes in service. Over the years, the aeration industry has pursued many EPDM and other polymer formulations and processes designed to deliver an efficient transfer of oxygen with minimal energy usage and extended membrane life. One EPDM panel formulation in particular has been identified as the membrane material of choice when it comes to sustained long term performance in a wide range of waste streams. This product is called the Performance Optimized Membrane – 1 (POM-1). Recently samples were pulled from a sizable municipal wastewater treatment plant after 110 months of service for evaluation. As of this report, these membranes are still in service and providing 10+ years of service.

Parallel research is being done in this area. One paper called 'My Diffuser Goes Up to Eleven (Actually Twelve)' by Michael Stenstrom and others focuses on a WWTP with AquaConsult (Reference Product) panel membranes that have been in service for approximately 12 years. A comparative analysis is presented in this report which reviews the material properties and the total energy costs of the EDI panel product and the AquaConsult panel over an equivalent extended period of time.

General Observations

It has been documented in industry literature that insitu oxygen transfer efficiency (fSOTE) can drop as much as 17% in the first 12 months and up to 25% over a 5 year period (Rosso, 2012) in a wastewater treatment environment. The two typical causes of decreased aeration efficiency are membrane fouling and changes in membrane material properties. EDI measured SOTE (Standard Oxygen Transfer Efficiency) and DWP (Dynamic Wet Pressure) on field samples which was then utilized to calculate SAE (Standard Aeration Efficiency) and assess wire power performance.

2. EXPERIMENTAL

Definitions:

SOTE (Standard Oxygen Transfer Efficiency, %): The ratio in percent between the amount of oxygen transferred and the amount supplied.

fSOTE: SOTE of a fouled membrane that has been operated in a wastewater stream.

SAE (Standard Aeration Efficiency, lbs O_2 per hp-hr): The amount of oxygen transferred to the water and the amount of energy used.

fSAE: SAE of a fouled membrane that has been subjected to a wastewater stream

DWP (Dynamic Wet Pressure, Inches of H_2O): The pressure differential (headloss) across the diffusion element when operating in a submerged condition.

Tested Materials and Products

Subject Plant - EDI POM-1 panel properties and process parameters:

EDI Panel Membrane Properties
Material: EPDM
Panel Width: 4.6 in.
Wall Thickness: 0.08 in.
Panel Length: 53.5 in.
Perforation Size: 1mm
Length of service: 110 months as of 7/2013. Membranes are still in operation.
Subject WWTP: Municipal, US Midwest Location
Plant Design Capacity: 52 MGD
Plant Type: Conventional Activated Sludge
Installed number of Panels: 3,676 full length panels plus 1,160 half length panels.
Typical Air Flux rate: 1.52 scfm/ ft^2

3. METHODOLOGY

Dynamic Wet Pressure (DWP) and Membrane Activity Measurement

Membrane DWP testing is performed to quantify diffuser headloss in a submerged condition. Tests are run over a range of different air flux rates.

Membrane Activity is defined as the percent of active perforated surface area per total perforated surface area. Activity is a qualitative value which is visually observed and assigned a percentage. Activity is an indication of oxygen transfer efficiency. Typically, the higher the activity value the higher the oxygen transfer efficiency of the diffuser.

Membrane DWP and Activity were tested under the following conditions:

1) As-Received:

Samples sent are to be undisturbed in a sealed container. Samples are tested without removing accumulated foulant to approximate the insitu field performance of the unit.

2) Manually Cleaned (standard field cleaning procedure)

Manual cleaning uses low pressure hosing and scrubbing with a medium/coarse nylon brush. Positive air pressure is maintained in the diffuser unit during cleaning.

3) Acid Cleaned and Mechanical Cleaning (multiple step laboratory cleaning process)

The membrane is cleaned with acid in addition to manually cleaning. This technique involves applying Muriatic Acid (20^0 Baume Hydrochloric Acid 31.45% by weight) directly to the membrane surfaces after the manual cleaning procedure followed by rinsing with a low-pressure hose. The membrane is then mechanically washed. Mechanical washing consists of washing the sample membranes using warm water (100°F) and household detergent.

Oxygen Transfer Testing

EDI conducts Steady State Oxygen Transfer Efficiency (OTE) tests on aeration equipment using a 3.14 ft ID X 16.58 ft depth tank in conjunction with the Aerator-rator Offgas Analyzer. This testing method is consistent with the procedures as described by the American Society of Civil Engineers "Standard Guidelines for In-Process Oxygen Transfer Testing" (ASCE 18-96). The offgas method samples offgas from the test vessel after being diffused through the water column. By measuring the oxygen content of the offgas and inlet reference air, the oxygen being transferred to the water can be determined.

Testing was done on a new membrane to establish a baseline. The next set of tests were performed on a returned membrane, beginning with the as-received condition, followed by manually cleaning, acid cleaning and mechanical wash cleaning. The membranes were tested at 1.0, 2.1 and 4.1 scfm/ft^2 air flow flux rates.

Physical Measurement and Material Testing

Material properties of the samples were measured. These tests include Tensile, Elongation, Tear, Compression Set, Tension Set, Extract and others. Testing follows the appropriate ASTM test methods. TensiTech tensiometer with extensiometer and Mettler Toledo scales were used accordingly.

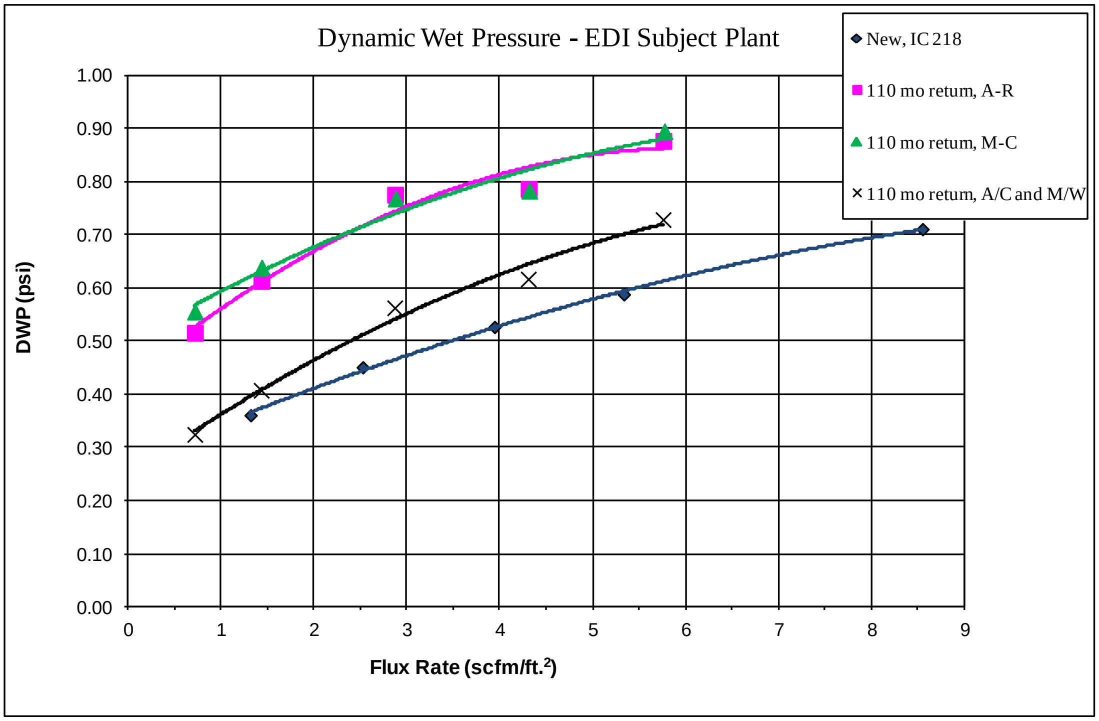
Physical dimensions were measured using a flexible scale for circumference, digital calipers for wall thickness in multiple places along with a steel rule for membrane length.

4. RESULTS AND DISCUSSION

<u>DWP and Activity Testing Results</u>

For purposes of DWP and SOTE testing, the EDI test samples were cut down to 24" length to accommodate testing. Figure #1 illustrates the differences in DWP for a new membrane as compared to a membrane in the as-received condition after 110 months of service. The membrane DWP was measured after each cleaning step to determine the impact of the accumulated foulant and to assess how well the membrane can be restored as compared to the original new condition. Baseline data in all cases refers to the same part number as the membrane that was tested after service.

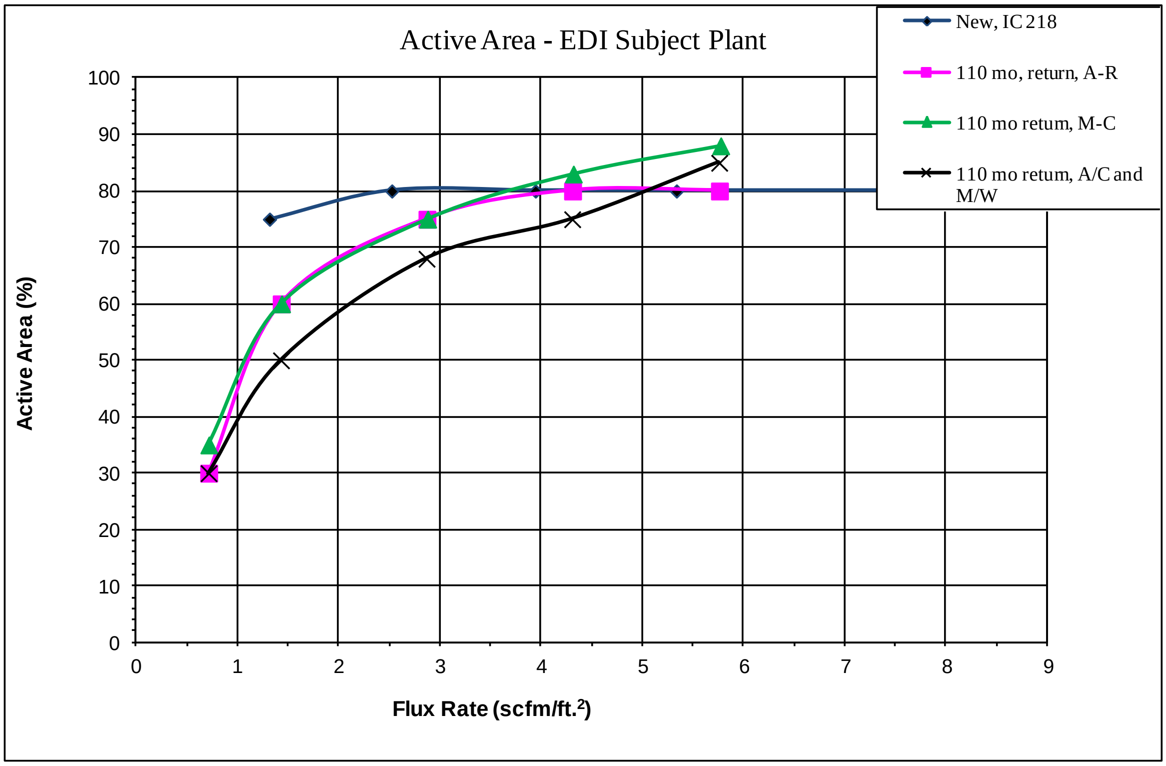
Figure #1



As observed from Figure #1, there was 0.25 psi (6.9 H_2O) increase in DWP over a 110 month period at an air flow flux of 1.5 scfm/ ft^2. After cleaning, the non-restorable DWP increased 0.08 psi (2.2 in. H_2O) as compared to the new condition.

Figure #2 shows the activity of the membrane in a new membrane condition compared to a membrane in the as-received condition after 110 months of service, and after cleaning. The data is used to quantify how well the membrane can be restored to the original new condition.

Figure #2



At lower flux rates, there was a decrease in surface active area as compared to a new membrane. However at low flux rates, airflow distribution along the length of the membrane surface was not adversely impacted. At higher flux rates, the greater membrane activity is observed with most of the improvement in distribution across the width of the diffuser.

Material Testing Results

Table #1 illustrates the comparison of the material and physical changes in membrane properties of a new membrane as compared to the EDI Subject Plant membrane that was pulled after 110 months of service.

Table #1

Physical Changes - EDI Subject Plant membrane			
I/C Code 218	**Baseline**	**Return**	**% Change**
Length (in.)	53.5	53.0	-0.9%
Wall Thickness (in.)	0.078	0.076	-2.4%
Inside Diameter (in.)	4.60	4.74	2.9%
Durometer (Shore A)	58	66	13.8%
Tensile Strength (psi)	1453	1715	18.0%
Elongation (%)	664	458	-31.1%
Trouser Tear (lbs/in.)	89	92	2.5%
Compression Set, 100°C (%)	74.6	74.9	0.4%
Tension Set, 100°C (%)	45.6	57.5	26.1%
Extract (%)	15.93	13.73	-13.8%
Specific Gravity	1.0800	1.1523	6.7%

From this data a slight increase in diameter, increase in hardness, tensile, tear and specific gravity accompanied by a decrease in elongation and extract was observed. These changes are typical for a membrane that has long term exposure to municipal wastewater. These property changes are related to the reduction of extractable content which makes the membrane harder and stiffer. The changes are viewed as minor for a membrane that has been in service for 110 months.

Data Review

Long term material changes as presented in literature (Stenstrom, et al 2013) suggest that the relative change noted for the POM-1 material are significantly less than other materials. From Table #2, the measured change in tensile for the EDI Subject Plant membrane is 36% of the value for the Reference Product. Similarly the measured change in elongation is 77% as compared to the Reference Product.

Table #2

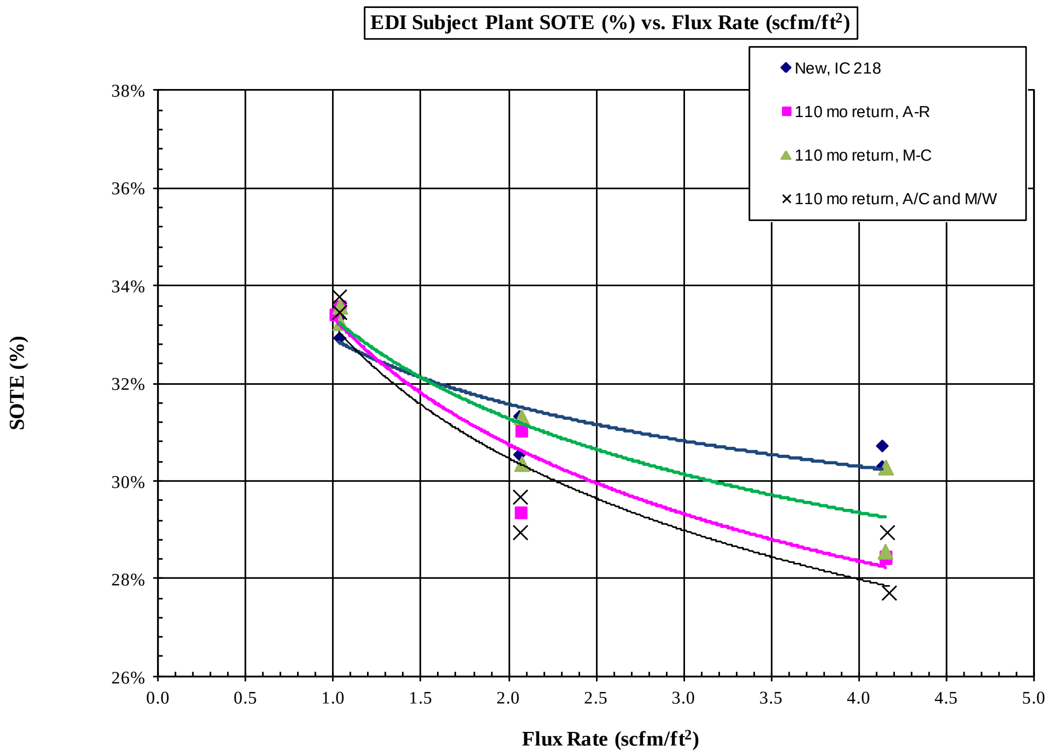
Physical Changes Comparison of EDI Subject Plant (9.2 yr) and Reference Product (11 yr)		
Test	**EDI Subject Plant**	**Reference Product**
Tensile Strength (% change)	18.0%	-50.0%
Elongation (%)	-31.1%	-40.2%

From Table #2, it is evident that there is a significant change in material properties. These changes could lead to variable diffuser performance including premature membrane failure if not monitored closely.

SOTE Testing Results

Figure #3 shows the SOTE performance of the EDI Subject Plant membrane at various flux rates. This graph compares the SOTE values of the membrane at different cleaning stages as compared to a new membrane.

Figure #3



The EDI Subject Plant membrane shows a 0% ~ 8% drop in OTE over the tested gassing range. This compares favorably to industry data which reports as much as a 20% decrease.

SAE Performance

It has been reported that the Reference Product as a very high efficiency product. Further review of the report by Michael Stenstrom (Stenstrom, et al, 2013) yielded fSOTE values for the Reference Product after 11 years in service. The report emphasizes the improved SOTE efficiency and reduction in pressure after pressure wash (PW) cleaning. One aspect that is important to review is the mass of oxygen transferred per unit energy consumed or overall aeration efficiency (SAE).

In Figure #4, oxygen transfer efficiency and pressure data were combined to show the impact of membrane changes on overall aeration efficiency (SAE). Data for Standard Aeration Efficiency (SAE) and fSAE after the membrane has been in service are shown.

Figure #4

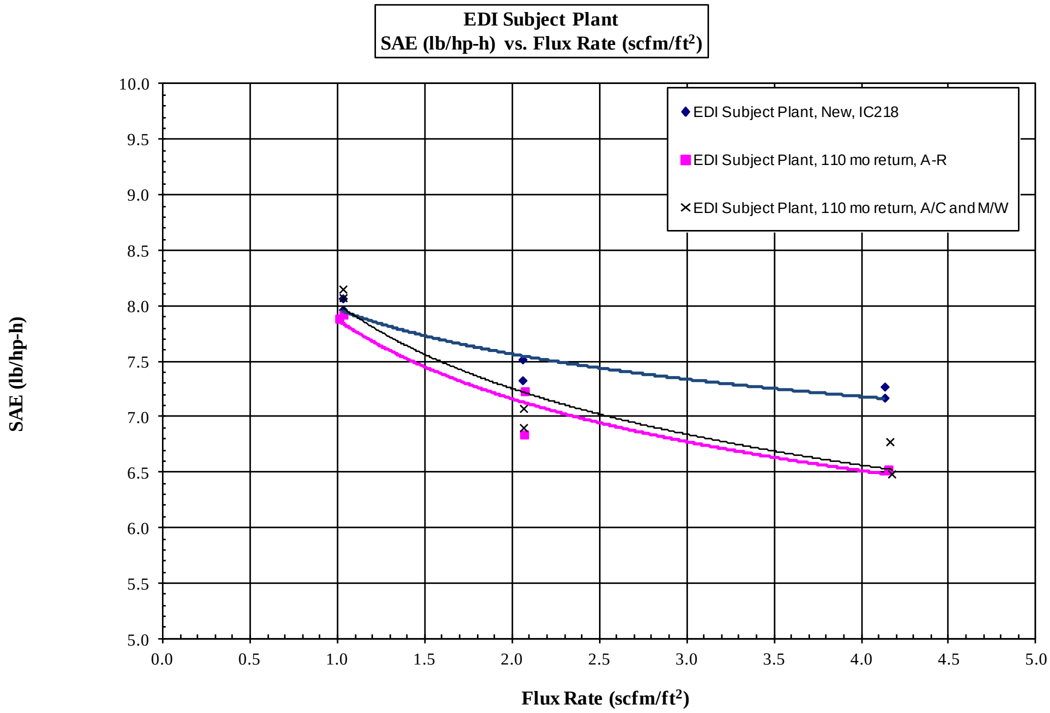
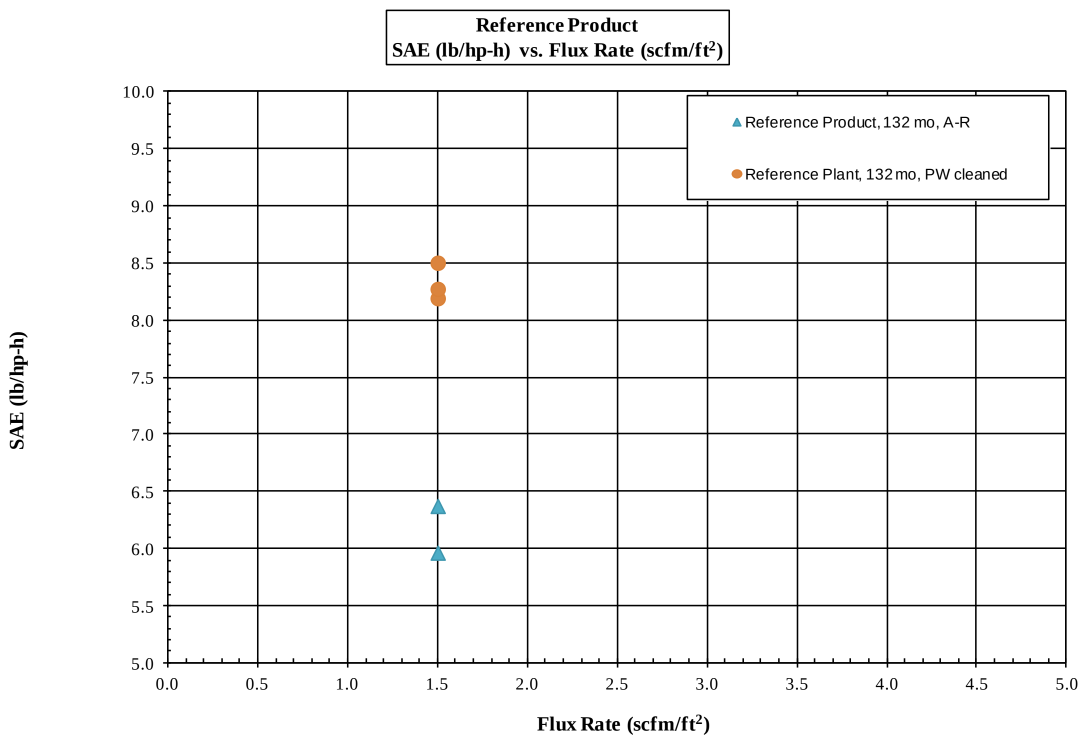


Figure #5



From Figure #4, there is a reduction in standard aeration efficiency between the original and field samples for the EDI Subject Plant. This parallels literature reports of performance changes with membrane age. It can also be noted that cleaning the membrane after 110 months of service only slightly improves the fSAE. The decrease in the fSAE value varies from no net change at low flux rates, to 7% ~ 10% at moderate to high flux rates.

From Figure #5 which is based on information presented in literature (Stenstrom, et al 2013), the change in standard aeration efficiency for the Reference Product was almost 26%. This is attributed to a 277% increase in membrane pressure and a 13% reduction in SOTE. Since no data was presented for a new Reference Product panel, a comparison to original performance could not be developed. The report also states that maintenance over the last 12 years of the membranes “has been limited to periodic tank top hosing and brushing of diffusers with a mild soap, a process that takes 2-3 hours per tank”. The frequency of the maintenance was not presented. The EDI Subject Plant membranes were not cleaned during their 110 month operating period leading up to the procurement of the membrane samples.

Using the fSAE data, the impact of fouling on the operating cost of wastewater treatment plant can be estimated. We can then calculate the true cost of the EDI Subject Plant panel product and the Reference Product panel based on the two evaluated products in this report. A hypothetical population of one million people was used to calculate the long term financial impact on the municipality. Figure #7 presents this model.

Figure #6

ENERGY COST COMPARISON

Assume a population of 1,000,000 people for this exercise

1M people O_2 requirement (SOR, lbs O_2/hr): 29,050

Average electric utility rate: $0.0679/kW (Industrial) from US Energy information website (www.eia.gov/electricity/data.cfm - Sales (Average Retail Price)

Combined motor and blower efficiency: 65%

Air Flow: 1.5 scfm/ft^2

Cost of Power ($/hp-yr): 444

Membrane	*SAE (lb O2/hp-hr)	Aeration Cost (mem) $/yr/1M people	**Cost of fouling over 10 yr period
EDI Subject Plant - New	7.73	$1,668,590	
EDI Subject Plant - A-R	7.43	$1,736,979	$341,944
EDI Subject Plant - A/C and M/W	7.55	$1,709,454	
Reference Product - A-R	6.37	$2,026,281	
Reference Product - PW	8.32	$1,550,264	$2,380,083

*SAE for both EDI Subject Plant panel and Reference Product are adjusted for 10 years service.

**Estimated 10 yr cost of fouling: Averages the cost of fouling between new and as-received in half, then muliply that cost by 10 years.

From Figure #6, it is evident that the cost of a fouled EDI Subject Plant panel membrane over a 10 year period is approximately $341,944. We see the use of the Reference Product panel would cost a municipality $2,380,083 over a similar time frame. This is assuming that no service has been performed on either membrane over the same period.

Both the EDI Subject Plant panel and Reference Product panel start out with relatively high efficiencies, however, the significant increase in pressure of the Reference Product panel membrane greatly impacts the fSAE value in a negative manner.

5. SUMMARY

This analysis offers an in depth review of the EDI Subject Plant panel membrane with over 9 years of service in a municipal plant. This report also goes beyond the typical fSOTE efficiency and DWP pressure assessment and reviews the combined impact on energy consumption. Using fSAE provides an all encompassing value to better evaluate the economic impact of the aeration device over an extended period of time.

Based on the data presented in this report and information presented reference materials, the fSAE performance for the EDI Subject Plant panel product at 1.5 scfm/ft^2 varies by <5% on an SOTE/SAE basis whereas the Reference Product panel changes by more than >25% on an SOTE/SAE basis.

SAE change - EDI Subject Plant vs Reference Product
(lb/hp-hr @ flux: 1.5 scfm/ft^2)

SAE value	EDI Subject plant product	Reference Product
New Panel*	7.73	8.32
Used Panel - A/R	7.43	6.17
SAE Loss (%)	**-4%**	**-26%**

* Assumes PW cleaned Reference Product panel will perform similar to a new Reference Product panel.

In addition to the impacts on energy consumption, the direct and indirect costs for maintenance should be quantified. This comparison was not completed due to insufficient information. Further, variations in operating pressure may also be significant. Blower components should be appropriately selected and sized to account for variations in oxygen transfer efficiency and pressure. In general, the blower technology used to support the low pressure air requirements for a diffused air system do not normally support widely varying operating pressure demands.

REFERENCES

ASCE Manual (18-96), Standard Guidelines for In-Process Oxygen Transfer Testing

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