

AN ALTERNATIVE TO MBR TECHNOLOGY: THE MULTIPLE-BARRIER TREATMENT PROCESS AT ST. HELENS WWTP, TASMANIA, AUSTRALIA

*Derek de Waal, Liquitek Pty. Ltd., Seven Hills, New South Wales, Australia
James Horton, Aqua-Aerobic Systems, Inc., Rockford, IL, USA*

Introduction

Membrane bioreactors (MBRs) have emerged as a leading-edge technology in the application of activated sludge wastewater treatment. With increased competitive pressures and advancements in system design, MBR technology has become economically viable for many segments of the activated sludge market. Membrane-coupled activated sludge processes are frequently selected as a reliable and innovative approach to provide superior effluent quality. Without question, sub-micron particle separation by membrane filtration produces a high quality effluent. However, placing the membranes in direct contact with mixed liquor is generally assumed without first considering the associated operating requirements and costs.

As an alternative to the MBR model, the Multiple Barrier Treatment Process (MBTP) offers membrane-quality effluent with lifecycle costs of 30 to 50% of those of MBR technology. MBTP integrates the biological treatment process, cloth media filtration, and membrane microfiltration into a single process schematic (Figure 1) which is capable of reducing the necessary membrane area by more than 50% of that of a typical MBR configuration. The MBTP approach can also provide multiple levels of treatment, allowing the operator to selectively discharge effluent directly from the sequencing batch reactor (SBR), the cloth media filter (CMF) or from the membrane system. Many municipal wastewater treatment systems discharge permits are seasonal, requiring different quality parameters based upon summer or winter months. With the MBTP concept, the operator can elect to operate the membranes on an as-needed basis (De Los Santos, 2008).

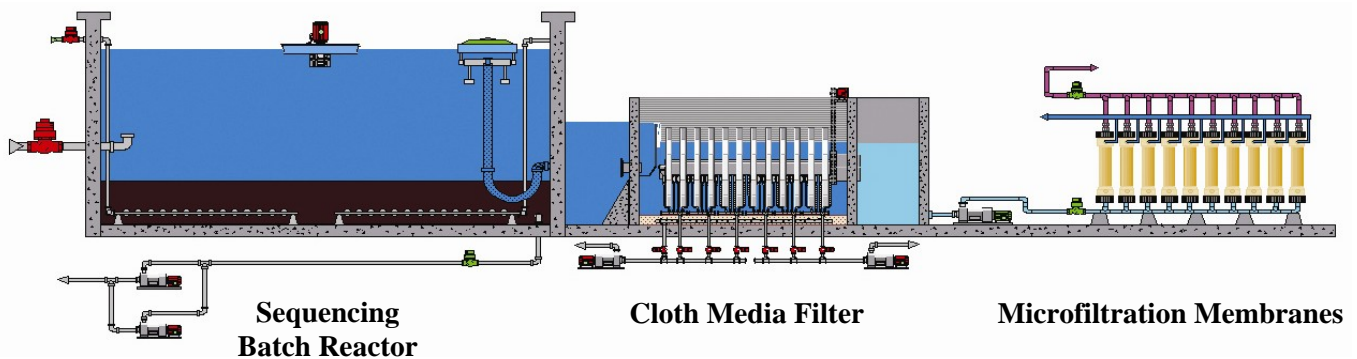


Figure 1. MBTP Schematic

An MBTP system was installed at the St. Helens WWTP in Tasmania, Australia in May 2008. The plant was designed to treat a 1.5 mega-liter (0.4 million gallon) per day average dry weather domestic sewage flow from the local community. As a vacation destination, St. Helens' population typically increases as much as 50% during peak months. The utility selected the MBTP over MBR technology in view of anticipated lower life cycle cost, operational flexibility, and ease of operation.

The St. Helens WWTP previously used basic lagoon treatment and discharged the final effluent into Georges Bay. However, due to an increase in oyster farming in the bay, lagoon treatment became increasingly unattractive. This caused the Council to seek more risk-free alternatives. Land reuse of lagoon effluent was explored extensively but was rejected because high quality effluent was required to make it practical. The Council selected membrane filtration technology which produces high quality effluent suitable for re-use and poses little risk to the oyster farms. Presently, the final effluent is discharged to Georges Bay. However, due to ongoing drought on the east coast of Tasmania, re-use (irrigation of crops and golf courses) is planned for 2010-11.



Figure 2. Aerial View of St. Helens MBTP

The main objective of this paper is to summarize and discuss the operating data gathered during a 90-day MBTP performance evaluation at St. Helens WWTP. The study's effluent quality, power and chemical consumption, and membrane reliability results all demonstrate the system's capabilities and operational flexibility. The MBTP is presented as an alternative to MBR technology for providing membrane quality effluent at the lowest possible life cycle cost.

Plant Description

The St. Helens MBTP components consist of an aperture-perforated inlet screen, two sequencing batch reactors (SBRs), an effluent equalization (or Post-EQ) tank, a flocculation tank, a nominally rated 10 μ cloth media filter, a nominally rated 0.10 μ microfiltration membrane system, and a UV disinfection system. The plant also incorporates aerobic sludge digestion (Figure 2 & 3). Sodium carbonate is available to adjust alkalinity in the biological reactors. Aluminum sulfate (alum) is dosed into the biological reactors and/or into the flocculation tank for phosphorus removal. Chemicals for membrane cleaning processes include citric acid, sodium hydroxide, and sodium hypochlorite.



Figure 3. St. Helens MBTP – SBRs, CMF, and Membranes

Plant Performance

During the 90-day MBTP study, the plant operated in a single basin SBR mode due to low influent hydraulic loading. In this mode, one reactor tank (SBR#1) was used for influent equalization to allow interruption of flow during the non-filling phases of the second reactor (SBR#2), which served as the processing bioreactor. The plant was therefore capable of treating 50% of its hydraulic and organic design loads. The plant received an average of 36% of its 1.5 ML/d (0.4 MGD) hydraulic design flow, but since it was operating in a single-basin SBR mode, it actually treated an average 72% of the design flow.

Table 1. Influent Flows

Parameter	Nov	Dec	Jan	Design
Average, ML/d (MGD)	0.50 (0.13)	0.57 (0.15)	0.55 (0.15)	1.50 (0.40)
Minimum, ML/d (MGD)	0.42 (0.11)	0.33 (0.09)	0.45 (0.12)	-
Maximum, ML/d (MGD)	0.81 (0.21)	1.02 (0.27)	0.66 (0.17)	3.00 (0.80)
Total, ML/month (MGD/month)	14.85 (3.92)	17.57 (4.64)	17.01 (4.49)	-

Additionally, the plant received 39% of its design influent BOD and therefore actually treated an average 78% of the single SBR basin's design load. Average plant loads are summarized in Table 2.

Table 2. Influent Loadings

Parameter	Nov	Dec	Jan	Design
BOD ₅ , kg/d (%)	110 (31.9)	140 (40.6)	156 (45.2)	345
TSS, kg/d (%)	84 (37.3)	104 (46.2)	113 (50.2)	225
TKN, kg/d (%)	23 (29.5)	26 (33.3)	30 (38.5)	78
TP, kg/d (%)	3.8 (25.3)	4.4 (29.3)	5.1 (34.0)	15

Note:

1. Parameter (%) relates to design load.

As expected, a gradual increase in loads occurred with seasonal population influxes.

Plant Performance

Daily measurements of key influent and effluent parameters were performed during the entire evaluation period. Samples were analyzed in accordance with the site's permit requirements. The results show the plant was 100% compliant with respect to all effluent quality parameters during the course of the evaluation.

Table 3. Effluent Quality vs. Permit Requirements

Parameter	Min		50-percentile		90-percentile		Max	
	Value	Limit	Value	Limit	Value	Limit	Value	Limit
BOD ₅ , mg/l			1	2	1	4	2.1	10
TSS, mg/l			0.2	4	0.2	5	1	10
NH ₃ -N, mg/l			0.1	0.7	0.3	0.8	0.5	1.0
TN, mg/l N			4.2	7	6.4	10	6.9	15
TP, mg/l P			1.0	1	2.2	3	3.8	5
<i>E. coli</i> , org/100 ml							0	10
O&G, mg/l			1	2	2	5	4	10
Turbidity, NTU			0.12		0.18		0.37	
pH, std. units	6.7	6.5					8.0	8.5

Notes:

1. The laboratory limit of detection (LOD) for BOD₅ was 2 mg/l. Where BOD₅ is reported as 1 mg/l, the lab results were simply given as <2 mg/l.
2. The laboratory LOD for TSS was 3 mg/l. Since all final effluent levels were <3 mg/l, TSS values were estimated by multiplying the NTU turbidities by a factor of 2.
3. Whereas the laboratory reported the *E.coli* populations as <1 organism/100 ml, they appear here as 0 organisms/100 ml.
4. The laboratory LOD for oils and greases (O & G) was 2 mg/l. Where O & G is reported as 1 mg/l, the lab results were simply given as <2 mg/l.

In addition to meeting these parameters, the plant's discharge permit also requires non-detectible levels of the following pathogens:

- Bacteria: Thermo-tolerant coliforms, *Salmonella*, *Shigella*, *Vibrio cholerae*
- Protozoa: *Entamoeba histolytica*, *Cryptosporidium*, *Giardia* cysts
- Helminths: *Ascaris* and *Taenia ova*
- Viruses: Enteroviruses

Chemical Consumption

Phosphorus Removal

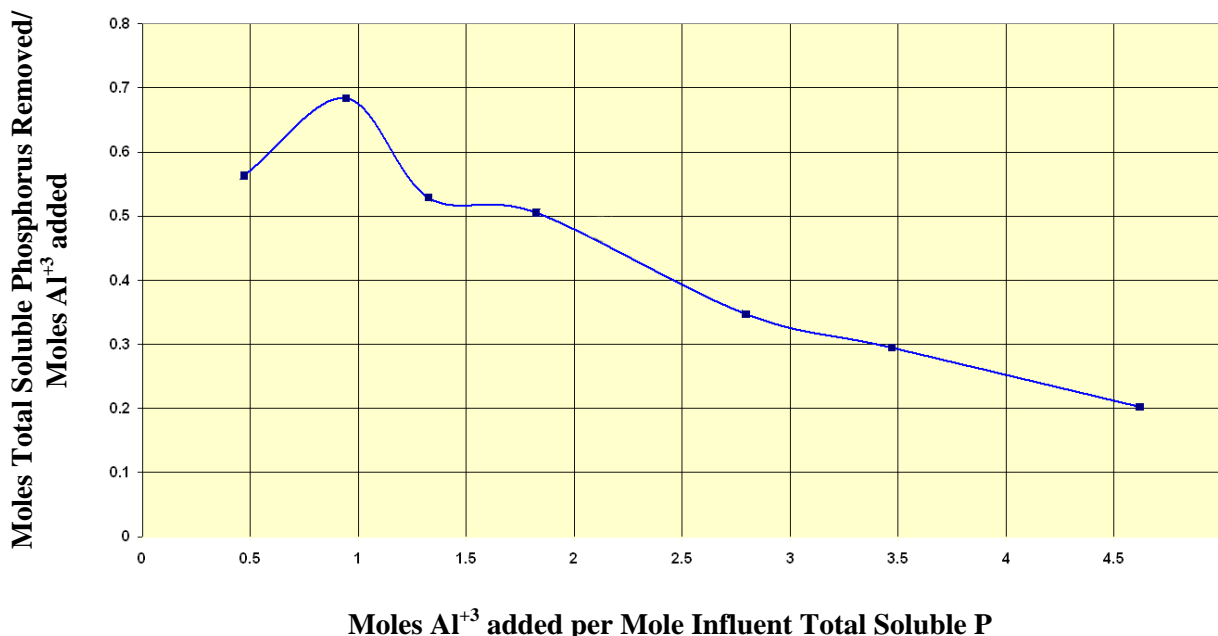
During the study, there was no need to dose alum upstream of the cloth media filter since the total phosphorus (TP) limit was achieved by injecting the chemical into SBR#1 (influent equalization) and the SBR#2 biological reactor during the react phase. With a total alum dose of 70 mg/l (as 48% alum

solution), the SBR effluent typically contained 2 to 3 mg P/l. It was difficult to assess the degree of biological phosphorous removal that occurred, but based on alum use, at least 50% of the TP was eliminated biologically. The cloth media filter provided an additional 50% reduction of the remaining particle-associated phosphorus.

In order to demonstrate the plant’s ability to achieve very low TP values, the MBTP was monitored further over a 40-day period that followed the initial 90-day process evaluation. The goal was to inject alum into the flocculation tank and determine the dosing regime required to achieve a final 0.1 mg/l value while meeting all other effluent quality limits. It was found that a 21 mg/l alum dose in addition to about 70 to 83 mg/l into the SBRs consistently achieved the 0.1 mg/l target. It should be noted that these dosages are expressed as the 48% bulk product rather than as 100% alum.

A limited set of grab samples were analyzed to establish phosphorous speciation. The resulting ortho-P to TP ratios sampled from the effluent equalization, cloth media filter effluent, and microfiltration membrane effluent were 0.75, 0.58 and 0.83, respectively. While not conclusive, this limited data set indicates the potential for further TP reduction by focusing on chemical precipitation of the reactive ortho-P.

On average, nearly 50% additional alum was required to reduce the final effluent TP from 1.0 to 0.1 mg/l. This increased dosing did not adversely affect any of the plant’s permit parameters although a slight reduction in the volatile fraction of the mixed liquor suspended solids was recorded. The additional dosage requirements to reach such low range TP levels were anticipated. While the theoretical stoichiometric molar requirement of Al to P is 1:1, competing reactions and interference from other reactor constituents require increasing dosages of alum as the targeted effluent TP is approached (Figure 4).



Note:

1. Aqua-Aerobic Systems process design curve from the EPA Design Manual Phosphorus Removal (EPA, 1987).

Figure 4. Alum Dosage Requirement

Figure 5 summarizes the TP reductions achieved through the MBTP during the 90-day and subsequent 40-day testing periods. Figure 6 summarizes the typical alum dosing regime required to achieve the respective TP target values.

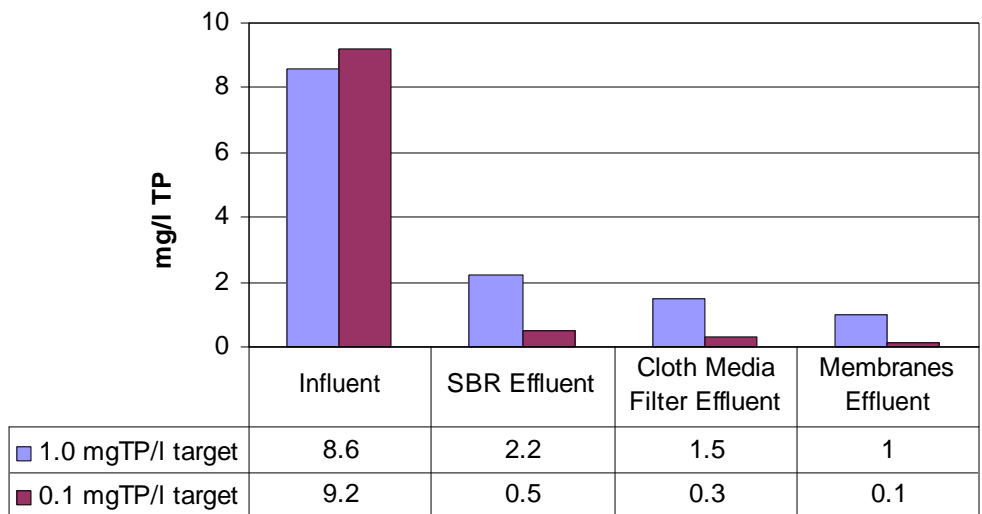


Figure 5. TP Reduction Throughout the MBTP

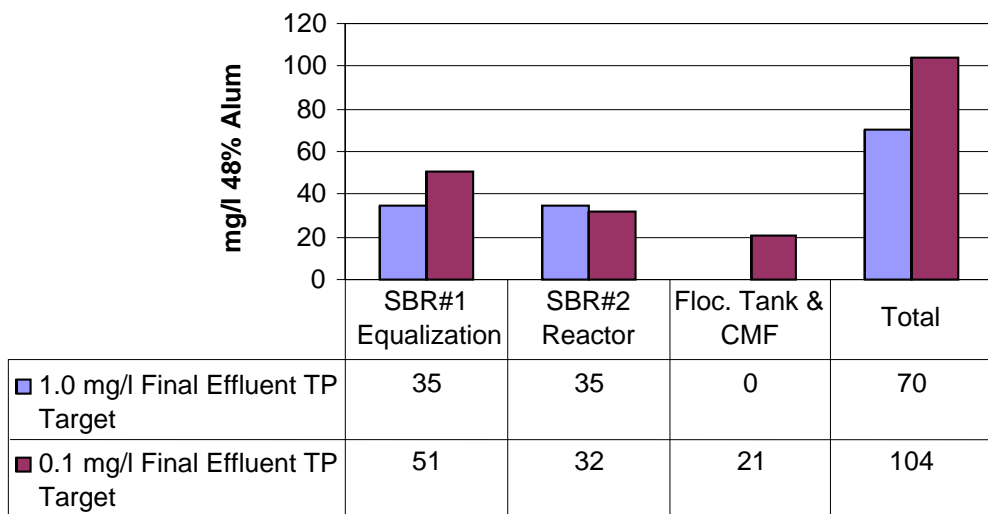


Figure 6. Alum Dosing Regime to Achieve Respective TP Targets

About 15-20 mg/l of sodium carbonate was required to maintain a proper alkalinity level within the SBR since the influent values were relatively low, varying between about 140 and 200 mg/l CaCO₃.

Membrane Maintenance

There was no need to chemically clean the membranes over the 90-day MBTP evaluation despite the fact that cleaning at 30 to 60 day intervals was predicted during the project design stage. This was likely due to the high quality feed from the cloth media filter and because the mechanical cleaning regime of air scrubbing, reverse filtration, and enhanced flux maintenance (which uses a small amount of sodium hypochlorite) provided sufficient cleaning to maintain the transmembrane pressure at “as new” values.

Solids Handling

Sludge handling at the St. Helens facility incorporates aerobic digestion with alkalinity supplementation, settling, and supernatant draw-down. Digested sludge is conveyed to the decommissioned lagoons for long-term storage and extended volatile solids destruction. This practice has been approved by the local EPA and is planned to continue for six to eight years until the lagoon capacity is reached. Typical digested sludge volatile fractions varied between 61 and 73% during the process evaluation.

Power Consumption

The plant’s power consumption was monitored in order to insure that it met the contracted acceptance criteria for the project. By recording the overall power consumption and the operational run-times of all mechanical equipment, it was possible to calculate the power consumption per unit process. For assessment purposes, the plant was divided into the following unit processes:

- Inlet works – including inlet screen/grit removal system, odor scrubber, SBR feed pumps;
- SBRs and Post EQ – including SBR blowers, SBR mixers, waste sludge pumps, Post EQ blower, soda ash make-up and transfer system;
- Cloth media filter and flocculation tank – including filter drive and backwash/sludge waste pump, flocculator mixer, Post EQ feed pumps;
- Membranes – including feed pump, water heater, cleaning skid transfer pump, waste transfer pumps, compressors; and
- UV disinfection system.

The findings are summarized in the Figure 7 pie chart.

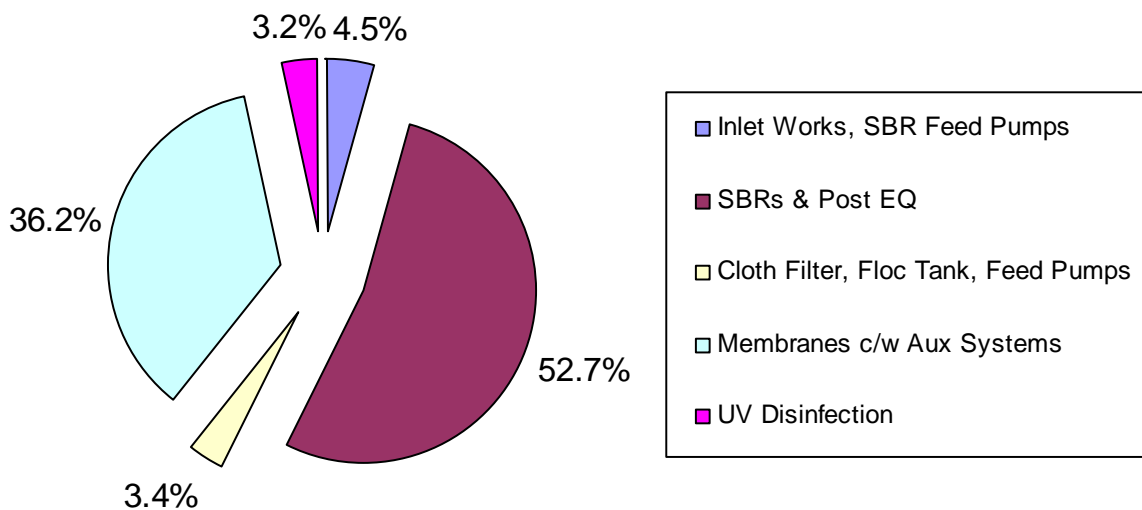


Figure 7. Power Consumption per Unit Process

Due to independent aeration and mixing capabilities in the SBR and to adjustable aeration timing, it was possible to minimize aeration power consumption. This flexibility allowed the blowers to operate only

when BOD₅ and ammonia oxidation was required and the mixers to operate only during non-settling and anoxic phases.

A further breakdown of power consumption for the SBR/Post EQ unit processes, as illustrated in Figure 8, shows that almost 60% of the consumption was associated with aeration within the SBR.

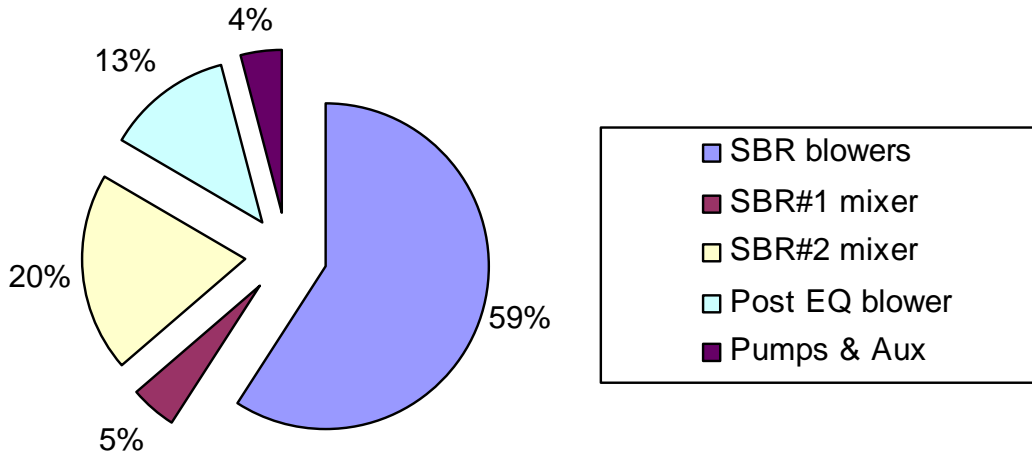


Figure 8. Power Consumption of SBR/Post EQ

The average power consumption for the MBTP over the 90-day process evaluation was approximately 1,100 kWh/ML (4.1 kWh/1,000 gal) treated effluent. This compares favorably to similarly-loaded MBRs as noted in Table 4. The present energy utilization is attributed to the low flow condition and single basin operating strategy. It is generally known that small systems will experience a power penalty under similar operating conditions (McCandless, 2009 & SBW Consulting, Inc., 2002).

Table 4. Unit Energy Requirements

Process Type	Unit Energy
MBR	530 – 1,700 kWh/ML (2.0 – 6.4 kWh/1,000 gal)
Conventional Activated Sludge	200 – 500 kWh/ML (0.75 – 1.9 kWh/1,000 gal)

Membrane Reliability

The St. Helens WWTP had been operational for approximately five months when the 90-day MBTP evaluation commenced. Due to reduced hydraulic plant loads, the typical recorded membrane flux rate was 25 L/m²-h compared to the 100 L/m²-h design value. The maximum recorded flux rate to process one SBR decant batch has been 36 L/m²-h. Average membrane recovery rates of 94 to 96% have been recorded.

The membrane plant is configured to conduct integrity testing on a weekly basis. To date, no integrity breach has occurred, indicating no membrane fibers have failed. Other than sampling and testing, the owner has not performed any additional maintenance.

The lack of fiber failures and minimal chemical cleaning requirements illustrate the reliability and durability of the membrane system. This can be attributed, in part, to the fact that the cloth media filter reduces the solids loading to the membranes, allowing them to process effluent of a relatively constant 2 NTU quality.

Life Cycle Operating Cost

The breakdown of operating cost is illustrated in Figure 9. The cost basis is calculated using a 7% rate of return on a 20-year period based on the design flow, resulting in an amortized annual cost of \$80,042. The distribution of the costs is consistent with what would be anticipated in our industry. This summary excludes all capital and installation costs.

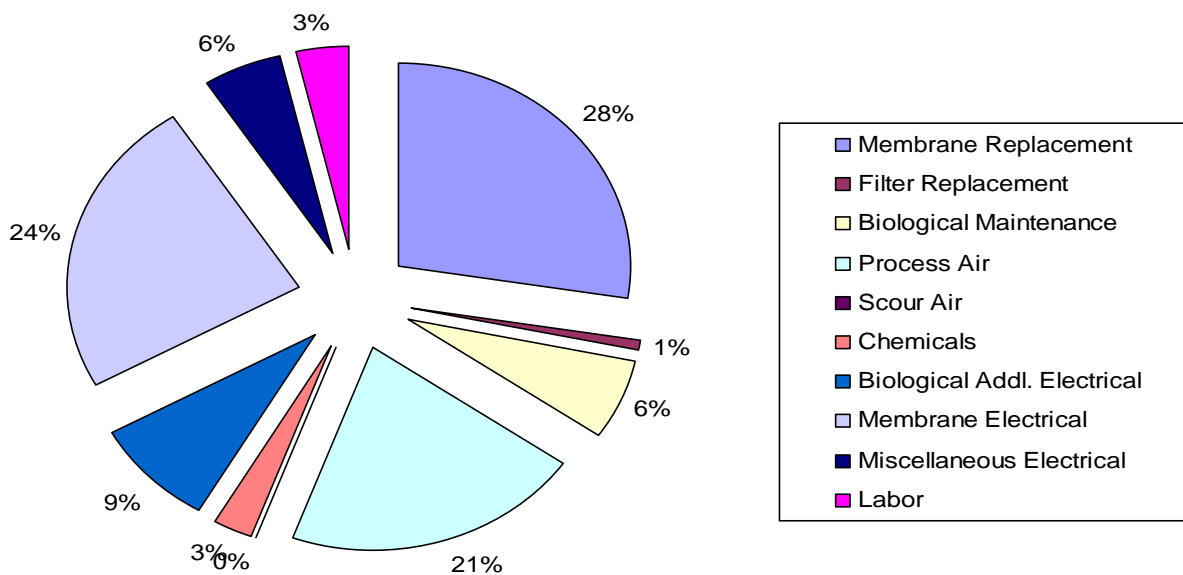


Figure 9. MBTP Operational Cost Distribution.

Conclusions

Results generated during the 90-day performance evaluation at the St. Helens WWTP indicate the MBTP process is a viable alternative to MBR technology. The 50 percentile effluent quality produced during the study was <2 mg/l BOD₅, <1 mg/l TSS (<0.2 NTU turbidity), <5 mg/l TN, and <1 mg/l TP. These levels are well within the plant's permit limits and represent performance consistent with a well designed and operated MBR system. During the subsequent 40-day test, it was possible to consistently achieve a <0.1 mg/l effluent TP value while remaining compliant to all other discharge parameters.

MBTP power consumption during the investigation was similar to MBRs, however, the amortized annual operational costs are lower for WWTPs of similar size and loading conditions.

Alum consumption rates for phosphorus reduction were comparable to or lower than those published for similar systems.

The membrane microfiltration system performed without any integrity breach and did not require chemical cleaning. The high degree of reliability is due in part to the pre-filtration provided by the cloth media filter.

No scheduled or corrective maintenance was conducted on any of the plant equipment over a period of more than eight months, which highlights the high degree of reliability of the MBTP.

References

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