Membrane Bioreactor Energy Consumption: Helping Utilities Understand And Manage Cost Savings

Marie-Laure Pellegrin and David J. Kinnear

Early in the life cycle of a wastewater treatment project, there will be facility managers, operators, and designers who select a treatment process alternative among competing feasible technologies. The process selection decision process balances trade-offs, such as capital and operating costs, with multiple required performance factors, such as treatment effectiveness to meet effluent permit limits, ease of operation, etc. Proven technologies, such as conventional activated sludge (CAS) treatment, offer decades of operating data on which to base life cycle cost estimates, providing confidence in them. Newer technologies, such as membrane bioreactors (MBRs), lack the depth of available capital and operation cost data on which to base project lifecycle costs.

The technology of MBRs has evolved over the last decade to include improvements intended to reduce energy consumption. Published energy consumption values show considerable variability. Attempts to reconcile energy consumption discrepancies in operating MBR facilities are discussed and should provide decision makers with increased confidence in operating cost estimates for this technology in order to develop accurate life cycle costs.

Objective and Method

Energy consumption of operating MBR wastewater treatment plants (WWTPs), mostly in North America, were summarized and evaluated. Data were gathered from the literature and directly from WWTP records to compare unit energy consumption in kilowatt hours per million gallons (kWh/MG) of wastewater treated, and was compared on a plant-by-plant basis. The literature reports MBR energy consumption ranges from 1,170 to 20,300 kWh/MG. This represents a factor of twenty and demonstrates the difficulty in developing accurate estimates (Gellner and Riddell, 2008; Hribljan and Reardon, 2007; Pawloski et al., 2007; Stone and Livingstone, 2008; van Bentem et al., 2007; Williams et al., 2008). Variability in system size, treatment process units used besides MBR, design variations, and individual operation techniques accounts for this wide range of unit energy consumption.

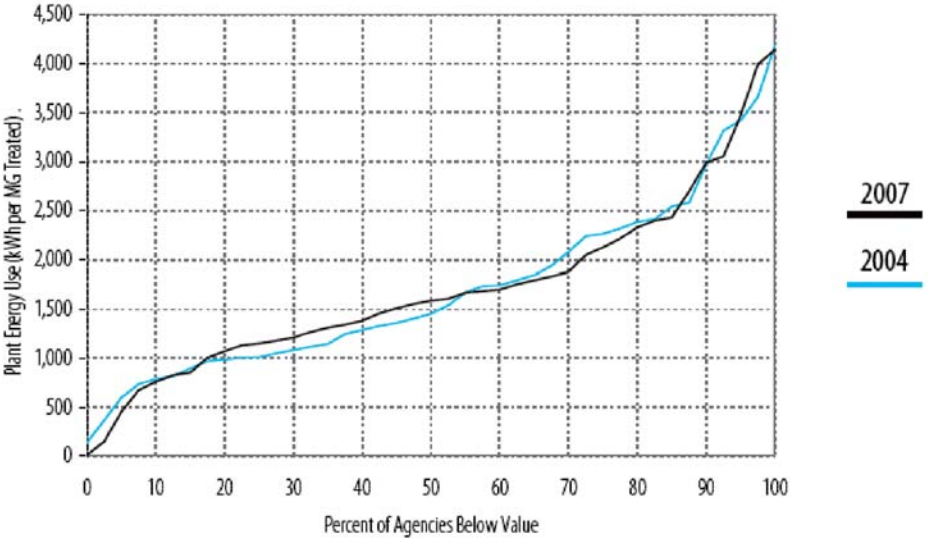

Figure 1. Distribution of Unit Energy Consumption (kWh) Per Million Gallons Treated

Source: 2008 NACWA Financial Survey (54 Agencies Reporting Data)

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For comparison, the National Association of Clean Water Agencies (NACWA) reported an average consumption of 1,766 kWh/MG for wastewater treatment facilities in its 2008 financial survey summary. The survey included 101 agencies representing over 67 million people, primarily from secondary treatment CAS facilities, and considered in-plant energy consumption only. Figure 1 shows the distribution of energy consumption for 54 of the surveyed WWTPs. The data show that 90 percent of the surveyed facilities operate at energy levels of 3,000 kWh/MG or less and 50 percent operate at less than 1,500 kWh/MG.

This analysis included, when available, a breakdown of energy consumption rates for individual unit operations and unit processes. Normalized unit energy consumption was analyzed to evaluate MBR energy demands as a function of flow rate. The effect of flow rate on MBR energy consumption depends on the number of membranes tanks in service and the scour air requirements. Matching flow rate to membrane tanks in service can become challenging when pronounced diurnal and seasonal variation occurs.

Results and Conclusions

The nine plants that were investigated used membranes from three vendors: GE/Zenon, Siemens/Memcor and Enviroquip/Kubota. The plants investigated using published literature data included Fowler, Pooler, and Cauley Creek in Georgia; Dundee in Michigan; and Varsseveld in the Netherlands. Data investigated directly from the facility operating data included Healdsburg in

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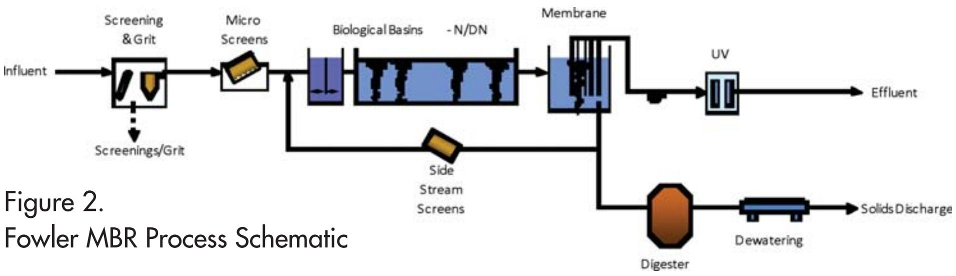

Figure 2.
Fowler MBR Process Schematic

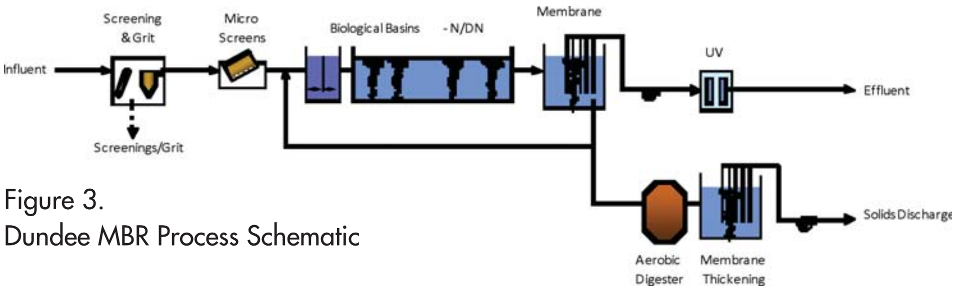

Figure 3.
Dundee MBR Process Schematic

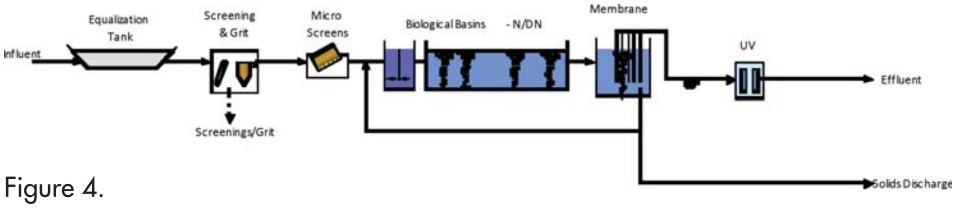

Figure 4.
Pooler MBR Process Schematic

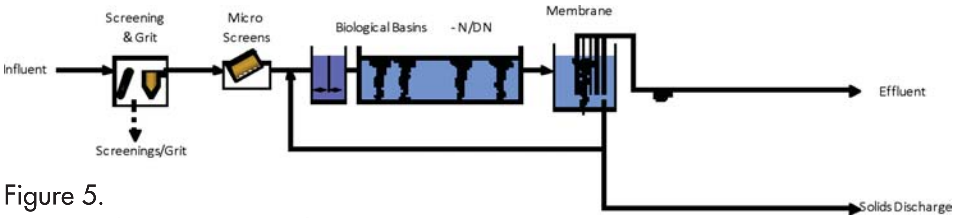

Figure 5.
Varsseveld MBR Process Schematic

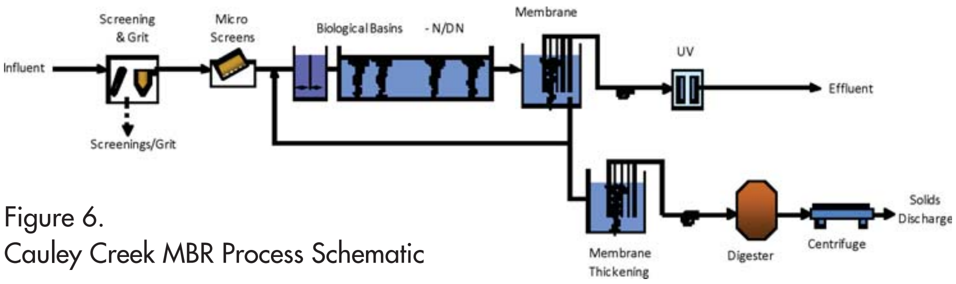

Figure 6.
Cauley Creek MBR Process Schematic

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California; Delphos in Ohio; Lacey, Olympia, Turnwater, and Thurston (LOTT) in Washington; and Bonita Springs in Florida.

Fowler: Georgia MBR Wastewater Treatment Plant (Cooper et al., 2006; Williams et al., 2008)

The Fowler plant has been in operation since 2004, with a rated treatment capacity of 2.5 million gallons per day (mgd), average daily flow (ADF), and serves southern Forsyth County, located approximately 20 miles north of Atlanta. Effluent is reused for irrigation and disposal at dedicated drip irrigation fields. GE/Zenon provided the membranes for this facility. The plant consists of a headworks with fine screens, anoxic reactors, aerobic reactors, membrane tanks, ultraviolet (UV) disinfection, side stream screens, aerobic digesters, and a biosolids dewatering system (see Figure 2).

Dundee: Michigan MBR Wastewater Treatment Plant (Stone and Livingston, 2008)

The Dundee plant has been in operation since 2005, with a rated treatment capacity of 1.5 mgd, ADF, and 3.0 mgd sustained peak day flow (PDF). Enviroquip/Kubota provided the membranes for this facility. The plant consists of a headworks with fine screens, anoxic reactors, aerobic reactors, membrane tanks, aerobic digesters, and membrane thickeners (see Figure 3).

Pooler: Georgia MBR Wastewater Treatment Plant (Pawloski et al., 2007)

The Pooler plant has been in operation since 2004, with a rated treatment capacity of 3.0 mgd, ADF, and 4 mgd PDF, and also serves the city of Bloomingdale. Effluent is discharged to Hardin Canal, a tributary to the Ogeechee River. GE/Zenon provided the membranes for this facility. The plant consists of an equalization (EQ) tank, and a headworks with coarse and fine screens, anoxic reactors, aerobic reactors, membrane tanks, and UV disinfection (see Figure 4).

Varsseveld: The Netherlands MBR Wastewater Treatment Plant (van Bentem et al., 2007)

The Varsseveld plant has been in operation since 2004, with a rated treatment capacity of 1.3 mgd, ADF, and 4.8 PDF, and was used as a research tool to advance MBR technology in Europe. GE/Zenon provided the membranes for this facility. The plant consists of a headworks with coarse and fine screens, anoxic zones and aerobic zones in a circuit system, and membrane tanks (see Figure 5).

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Cauley Creek: Georgia MBR Wastewater Treatment Plant (Williams et al., 2008)

The Cauley Creek scalping plant has been in operation since 2002, with a rated treatment capacity of 5.0 mgd, ADF. Effluent is reused for the reuse distribution system or is discharged directly to Cauley Creek. GE/Zenon provided the membranes for this facility. The plant consists of a headworks with fine screens, five-stage Bardenpho biological treatment, membrane tanks, UV disinfection, solids dewatering using centrifuges, and odor control (see Figure 6).

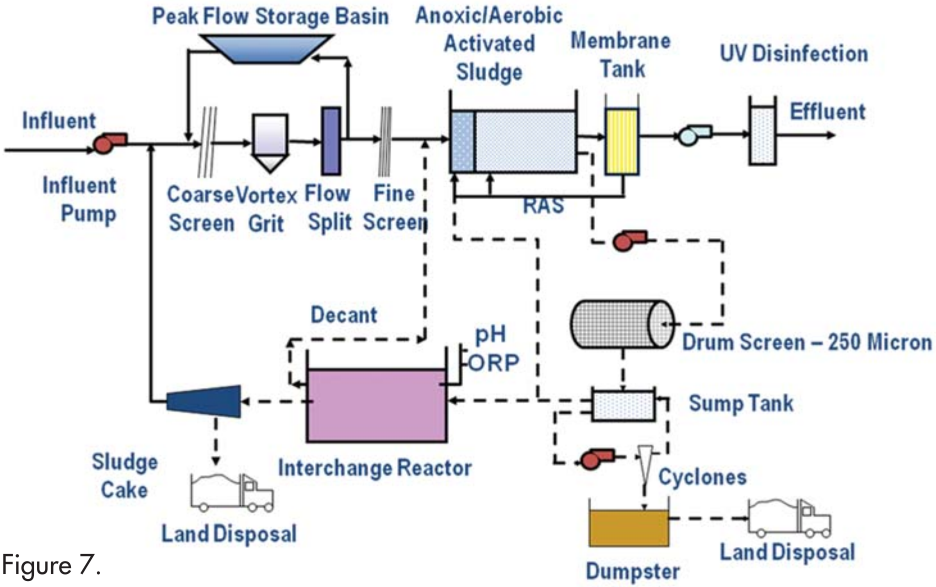

Figure 7.
Healdsburg MBR Process Schematic

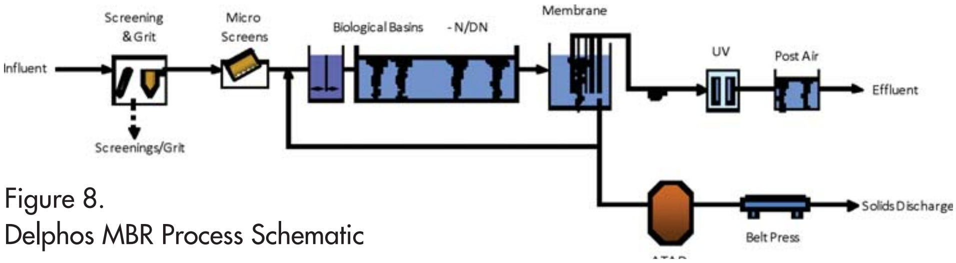

Figure 8.
Delphos MBR Process Schematic

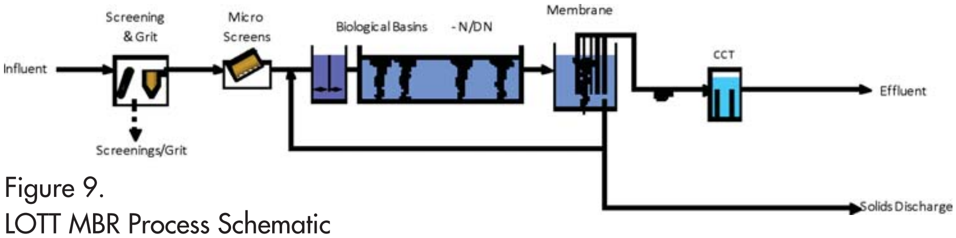

Figure 9.
LOTT MBR Process Schematic

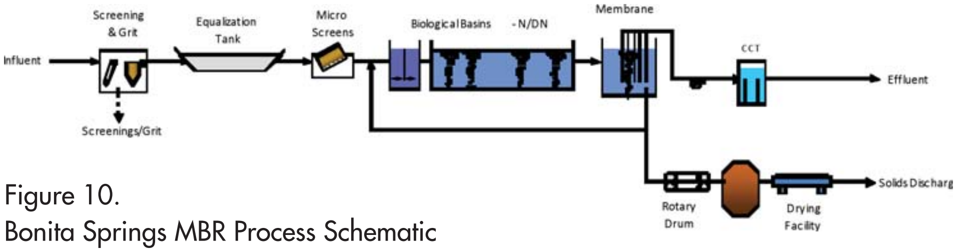

Figure 10.
Bonita Springs MBR Process Schematic

Healdsburg: California MBR Wastewater Treatment Plant

The Healdsburg plant has been in operation since 2004, with a rated treatment capacity of 1.6 mgd, ADF, and 4.0 mgd sustained PDF. Siemens/Memcor provided the membranes for this facility. The plant consists of a headworks with coarse and fine screens, pre anoxic reactors, anoxic reactors, aerobic reactors, membrane tanks, UV disinfection, the Cannibal sludge management process, and centrifuge for biosolids dewatering (see Figure 7).

Delphos: Ohio MBR Wastewater Treatment Plant

The Delphos plant has been in operation since 2006, with a rated treatment capacity of 3.8 mgd, ADF, and 12.0 mgd PDF. Enviroquip/Kubota provided the membranes for this facility. The plant consists of a headworks with fine screens, anoxic reactors, aerobic reactors, membrane tanks, UV disinfection, post aeration, autothermal thermophilic aerobic digestion (ATAD), and belt filter presses for biosolids dewatering (see Figure 8).

LOTT: Washington MBR Wastewater Treatment Plant

The LOTT Martin Way scalping plant has been in operation since 2006, with a rated treatment capacity of 2.0 mgd, ADF. Siemens/Memcor provided the membranes for this facility. The plant consists of a headworks with fine screens, anoxic reactors, aerobic reactors, membrane tanks, and chlorine contact chamber (see Figure 9).

Bonita Springs: Florida MBR Wastewater Treatment Plant

The Bonita Springs scalping plant has been in operation since 2007, with a rated treatment capacity of 4.1 mgd, ADF. GE/Zenon provided the membranes for this facility. The plant consists of a headworks with fine screens, EQ tank, anoxic reactors, aerobic reactors, membrane tanks, chlorine contact chamber, rotary drum thickener, centrifuge, and dryer for biosolids management (see Figure 10).

Energy Consumption Summary Results

The process aeration and air scour blowers consumed the most energy at all the facilities evaluated (Figures 11-14 summarize the energy consumption at four of the facilities evaluated). Based on energy consumption observations at MBR facilities, recent research efforts have focused on reducing air scour energy requirements without increasing membrane fouling.

Unit flow energy consumption for the nine plants evaluated decreased as the flow increases. Reported unit energy consumption at these facilities is shown in Figure 15. As additional membrane trains come into service, and as flow increases closer to the design flow rates, the energy consumption decreases. This phenomenon is also due to recent energy reduction improvements that were made by MBR manufacturers that include the 10/10 or 10/30 aeration strategy by GE/Zenon, the change in air scouring flow rate based on flux from Enviroquip/Kubota, and the Mempulse strategy from Siemens/Memcor.

The MBR energy consumption based on Figure 15 ranged from 2,500 kWh/MG to 25,000 kWh/MG for MBR WWTPs operating between 1 and 5 mgd. Published operating data from NACWA presented earlier in Figure 1 indicates that 85 percent of the 54 CAS WWTPs consume 2,500 kWh/MG or less. Although MBRs still consume more power than CAS treatment systems, recent design improvements have decreased unit energy consumption rates. When considering sustainability, decision makers must consider the benefit of the superior effluent quality compared to increased energy consumption and carbon dioxide emissions.

Figure 16 presents cumulative energy consumed in kWh as a function of cumulative flow rate treated for eight of the facilities evaluated. The plant with the highest overall energy consumption is Fowler, which consumed 16,000 kWh/MG on average, based on power cost data from January 2005 to July 2007. As previously shown in Figure 11 for the Fowler plant, 34 percent of the overall energy consumption is due to membrane processes and 20 percent is due to activated sludge process. Based on Williams et al. (2008), the Fowler plant has not yet implemented the newest air scouring strategy. The facility is using the 10/10 Zenon strategy and is operating at low flux of 5.8 gallons per square foot of membrane surface area per day (gfd). Additional reductions in energy consumption may be achieved by implementing the Zenon 10/30 strategy and increasing operating flux if membrane performance would allow.

Of the remaining plants evaluated, the Delphos plant reported an average unit energy consumption of 9,900 kWh/MG followed by Healdsburg, with 6,900 kWh/MG, using power cost data from December 2007 to September 2009 for Delphos and May 2008 to August 2009 for Healdsburg. There was no reported individual power consumption data available from the membrane process itself. Both of these plants operate solids stream process that increase overall power consumption rates (i.e., ATAD for Delphos and Cannibal for Healdsburg). Additionally, both plants operate at low fluxes (10 gfd for Delphos and 8 gfd for Healdsburg). Additional reduction on power cost could be achieved by increasing operating flux if membrane performance allows.

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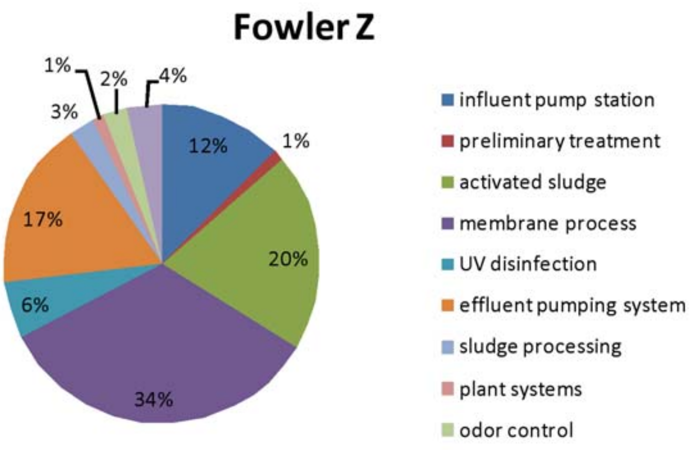

Figure 11. Fowler MBR Unit Energy Consumption by Unit Operation and Process (Williams et al., 2008)

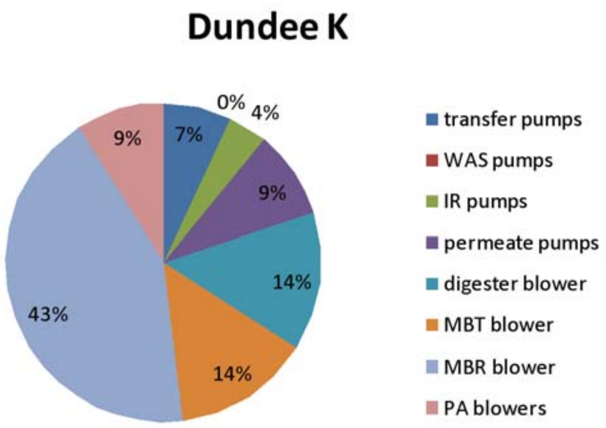

Figure 12. Dundee MBR Unit Energy Consumption by Unit Operation and Process (Stone and Livingstone, 2008)

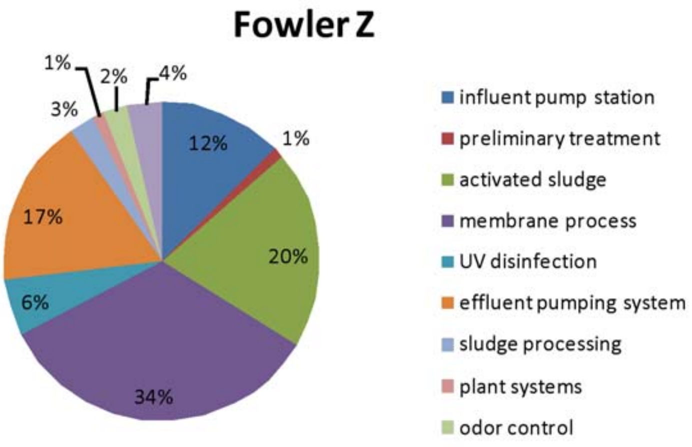

Figure 13. Pooler MBR Unit Energy Consumption by Unit Operation and Process (Williams et al., 2008)

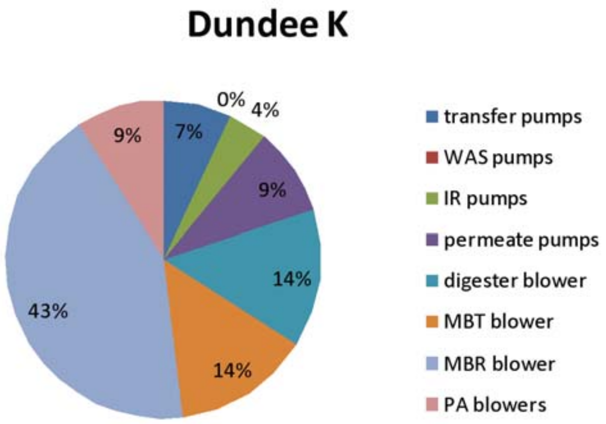

Figure 14. Varsseveld MBR Unit Energy Consumption by Unit Operation and Process (van Bentem et al., 2007)

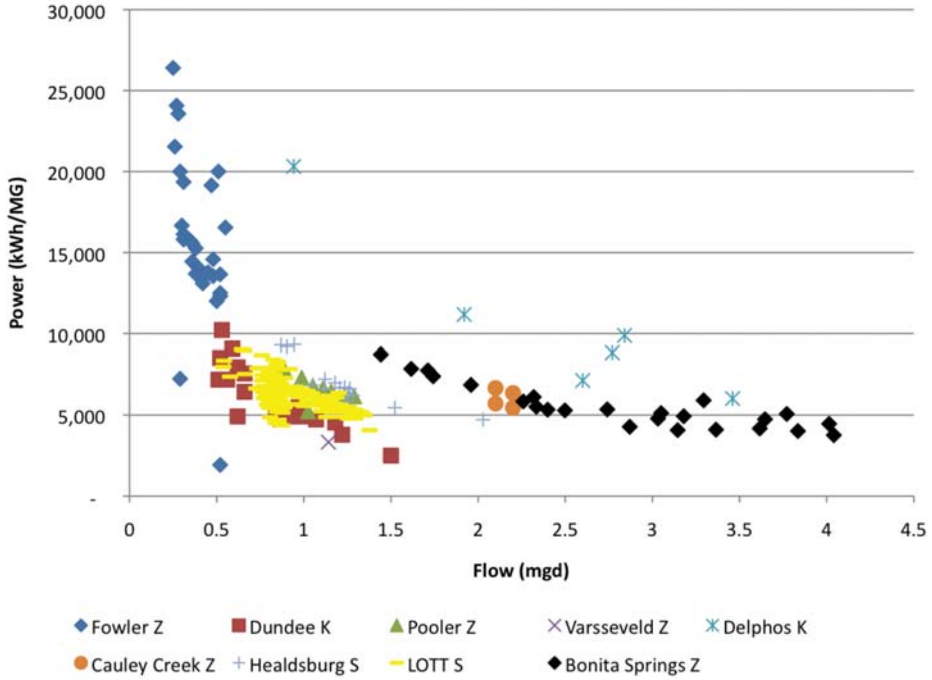

Figure 15. MBR Energy Usage in kWh/MG as a Function of Flow from Fowler, Dundee, Pooler, Varsseveld, Delphos, Cauley Creek, Healdsburg, LOTT, and Bonita Springs. S = Siemens, Z = Zenon, K = Kubota

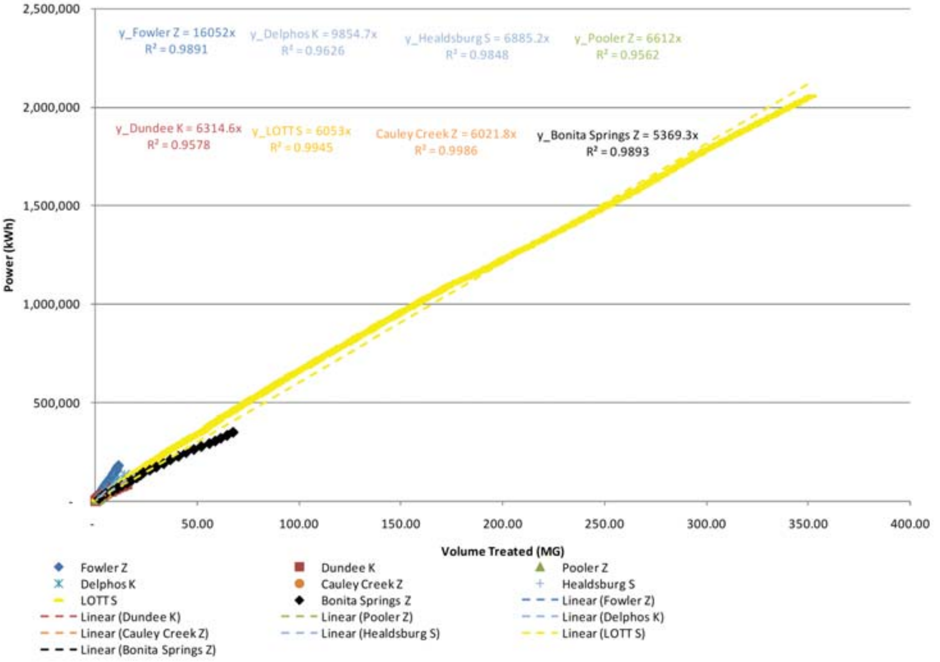

Figure 16. MBR Energy Usage Trend in kWh as a Function of Wastewater Treated from Fowler, Dundee, Pooler, Varsseveld, Delphos, Cauley Creek, Healdsburg, LOTT and Bonita Springs. S = Siemens, Z = Zenon, K = Kubota

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The Pooler facility used 6,600 kWh/MG on average, using power cost data from January to November 2005. As previously shown in Figure 13, 42 percent of the power is consumed by the membrane air scouring process and 30 percent is due to process air. Williams et al. (2008) reported that Fowler implemented the Zenon 10/30 strategy, which helped reduce their overall power costs.

The Dundee facility consumes 6,300 kWh/MG on average. As previously shown in Figure 12, 43 percent of the power consumed is due to membrane air scouring and 9 percent is due to permeate pumping. This plant is also using membranes to thicken sludge and accounts for another 14 percent of the power costs for the membrane blower and 14 percent for the digester blower.

The lowest unit power consumption rates of the nine plants evaluation were the scalping plants. Each of these plants was designed to operate at a relatively constant flow rate. The LOTT facility consumes 6,100 kWh/MG on average, using power cost data from December 2008 to December 2009. The Cauley Creek plant consumes 6,000 kWh/MG on average, using power cost data from June 2003 to December 2003. The Bonita Spings plant consumes 5,400 kWh/MG on average, using power cost data from January 2008 to January 2010. No breakdown of the costs from individual unit operations and unit processes was available to understand how much of the overall energy is due to membrane process. The LOTT information does not include biosolids processing at its facility, but operates at low flux of 6.2 gfd. Williams et al. (2008) reported that at Cauley Creek, 80 percent of the overall plant power accounts for the MBR system. Bonita Springs includes a pelletizer facility. A breakdown of this plant would be useful to identify which portion of the total power cost is due to the MBR system.

Conclusion and Perspective

From the nine MBR plants investigated, average unit energy consumption ranged from 5,400 kWh/MG to 16,000 kWh/MG. Selected plants of those evaluated could reduce energy consumption by implementing the new air scour strategies, or by operating their plant closer to design fluxes if the membrane performances allow. Power consumption data reported was for the overall plant. Since the treatment process elements varied significantly among the nine plants evaluated, a more detailed evaluation would be useful that is based on individual unit process and unit operations to further quantify energy consumed for the membrane bioreactor only.

Facility managers must also consider other factors that influence process selection, including meeting local regulatory effluent limits and/or effluent quality requirements for reuse applications.

A unit energy consumption rate of 5,400 kWh/MG, on average, was the lowest rate observed for the nine plants evaluated. 2,500 kWh/MG was the lowest monthly average reported (Figure 15). All of the 54 CAS WWTPs reported by NACWA consumed less than 5,400 kWh/MG and 85 percent consumed 2,500 kWh/MG or less.

Increased energy consumption can occur due to limitations on air scour blower turndown capability. Optimal energy consumption occurs when an MBR operates close to the design flow based on the number of membrane trains in operation.

To optimize energy consumption for MBR systems, adequate turndown capability and modular construction with multiple trains should be provided. Operating strategies should attempt to optimize the number of trains in operation to maximize membrane utilization. Influent flow equalization could be provided to decrease the amount of membrane surface area provided, thereby decreasing the energy demands for air scouring. This requires close operator attention, since as the flow increases through the membranes, the opportunity for fouling increases.

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