EVALUATING AND IMPROVING ENERGY EFFICIENCY AT MF/UF MEMBRANE FILTRATION FACILITIES

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Introduction

Microfiltration (MF) and ultrafiltration (UF) have become viable alternatives for drinking water treatment. MF/UF can replace granular media filtration in a conventional treatment train, and in some cases can also replace or have beneficial effects on other treatment processes. For example, the bacterial/particle removal capability of MF/UF can decrease the quantity of chemicals (e.g. chlorine, chloramine) needed for disinfection in the distribution system.

A key question when deciding whether to install a new MF/UF unit process is its energy consumption. These membrane processes typically require more energy than granular media filtration, but because other unit processes are affected, it is not necessarily straightforward to predict what the overall plant energy use will be. There are enough MF/UF facilities installed in North America now that a critical mass is available to evaluate actual energy expenditures at existing facilities, which will inform future engineering decisions.

The goal of this project is to document/benchmark energy costs at a statistically significant number of full-scale drinking water treatment plants employing MF/UF membrane processes. We sent surveys to all of the plants in the AMTA database, ranging from small (e.g. < 5 MGD) to large (e.g. > 15 MGD) facilities. This allows an evaluation of the degree to which economies of scale are realized in energy consumption at membrane plants.

For some facilities a deeper analysis of energy use is being performed, taking into account the details of the treatment train. Twelve months of energy bills along with twelve months of water production (MGD) and water quality data are considered. Energy use per volume (kWh/MG) and power per flow (kW/MGD) are calculated. These data enable a comparison of current membrane filtration energy use to historically reported numbers. This study is ongoing, with preliminary results reported here. This work will help designers understand what the true energy costs will be for a new system and will help existing end-users understand whether their process is energy efficient compared with peer facilities.

Background

Filtration membranes continue to advance technologically establishing them as an increasingly prominent component in several drinking water treatment plants around the world. Membrane technologies have demonstrated success in satisfying sustainability criteria, including minimal land use, flexibility, ease of use, and adaptability, as well as an effectiveness to treat raw water (Le & Nunes, 2016). Advancements in membrane technology, including microfiltration (MF) and ultrafiltration (UF) treatment, have caused the market for filtration membranes to increase, which in turn decreases the price of membranes resulting in more drinking water treatment plants adopting membrane filtration as a treatment process. Although MF and UF are highly successful in filtering out bacteria, organic matter, viruses, and contaminating substances, their energy use is a topic of interest (Hoslett et al., 2018; Le & Nunes, 2016; Lopes, Xin, & Crespo, 2013; McEwen, 2006; Pickering & Wiesner, 1993; Smith & Liu, 2017; Yoo, Chu, Choi, Mang, & Ko, 2018; Yoon, Lee, & Kim, 2004).

In most typical municipal governments, drinking water and wastewater treatment plants are the largest consumers of energy accounting for 30 to 40 percent of total energy use. This equates to two percent of national energy consumed in the United States and roughly 45 million tons of greenhouse gases (GHGs) that enter the atmosphere (US EPA, 2021). On average, the largest energy consumers in drinking water treatment plants are generally pumping (both intake and distribution pumping) and treatment processes. In previous research, it was estimated that on average, water companies utilize 1,100-kilowatt hour per million gallons (kWh/MG) for water conveyance, 1,100 kWh/MG for treatment, and 700 kWh/MG for distribution of treated water resulting in an average total energy consumption of 2,300 kWh/MG (Young, 2015). To place 2,300 kWh/MG into perspective, the average American home consumes 11,000 kWh per year, and with most small water treatment plants treating between 0 and 5 million gallons per day, the energy consumption of the smallest treatment plants would quickly total over 4 million kWh per year.

Energy consumption at water treatment plants can be decreased by implementing more energy efficient processes within the plant, specifically related to treatment by filtration. The research being conducted focuses on gathering data for energy use at MF and UF treatment plants around the United States to enable plants to benchmark their own energy use with their peers'. The most energy efficient plants will serve as models from which to gain insights about energy reduction opportunities.

Methods

We requested a list of membrane water treatment plants in the United States from the American Membrane Technology Association (AMTA) and reached out to representatives from those plants. We requested that each plant fill out a survey to gather energy and process-related information. The questions in the survey were:

1. What is the name of your plant?
2. In what city and state are you located?
3. What is your rated capacity (MGD)?
4. What is your average daily water production (MGD)?

5. Briefly describe the treatment train at your plant. (For example: screens/rapid mix/flocculation/plate sedimentation/strainers/membranes/disinfection/distribution).
6. Select the type of filtration your plant uses.
7. Who is the manufacturer of your membranes and what is the model or trade name?
8. What are the membranes at your plant (Select all that apply)?
9. What is your average monthly energy use [kWh]?
10. What is your average monthly energy use ($ USD)?
11. Do you have a way to measure or estimate the energy cost of the membrane filtration process, separate from other plant operations?
12. If there is any other information about your plant that is unique or you think the survey team should know, please use the space below.
13. Can a member of the survey project team reach out to you to follow up?
14. If there is another employee at your plant who would be willing to talk to the project team, please provide their contact information below.

We are in the process of conducting follow-up interviews with the contact person at several of the plants, and a few others identified after the survey. The interviews are intended to be a discussion between the AWWA MPC team and each plant contact to increase understanding of the plant's treatment train, treatment history, water characteristics (including raw, in-plant, and finished), energy usage, and any pertinent operation and maintenance information. The interviews are held through a video conference or phone call. At the end of each interview, the AWWA MPC team requests that the plant contact forward any engineering design reports, 12 months of electricity bills, and 12 months of monthly operating reports (MORs) containing water quality and chemical dosing information. Additional email exchanges may occur after the interview to clarify any forwarded data from the plant or if more data are needed to conduct a complete analysis of the plant's energy usage. Five interviews have been conducted to date, with three plants providing a complete data set after the interviews.

Once the requested data from each plant has been collected, an in-depth analysis of 12 plants will be orchestrated to determine any trends between filtration method and energy usage, potential cost expenses or savings, and environmental footprint in terms of kilograms of CO_2-equivalent (kg CO_2-eq). Examples of data points that will be studied in the analysis include, but are not limited to, membrane flow, membrane flux, clean in place (CIP) scheduling, and total plant energy use. Data will be organized and evaluated in categories of both filtration method and size of the plant.

To draw conclusions that are focused on the relation between filtration type and energy usage, one specific note must be made: although the influent raw water will not be uniform for all treatment plants participating in the study, the research will place more emphasis on the overall energy consumption and large contributors to the energy usage rather than investigate specific characteristics of the influent water that may potentially affect plant energy consumption.

Results and Discussion

After survey distribution, 25 responses were received from various facilities across the country. The treatment plants were categorized based on capacity and filtration type. It was preferable that there be at least seven plants in each of three set capacity ranges - less than 5 million gallons per day (MGD), 5 to 15 MGD, and greater than 15 MGD. Regarding filtration type, it was preferable that the treatment plants have either MF or UF filtration alongside a conventional granular media filtration treatment train or had transitioned from conventional treatment to either MF or UF treatment. The water production capacity, filtration types, and locations of the plants are shown in Figures 1 through 3, respectively.

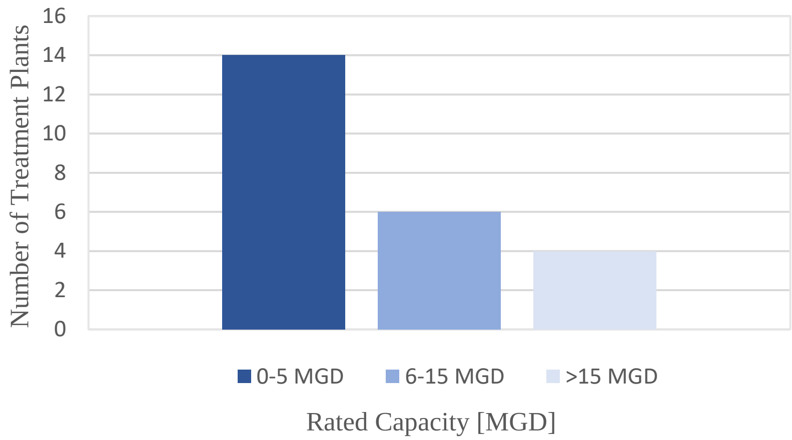

Figure 1. Water production capacity of the plants represented by survey respondents.

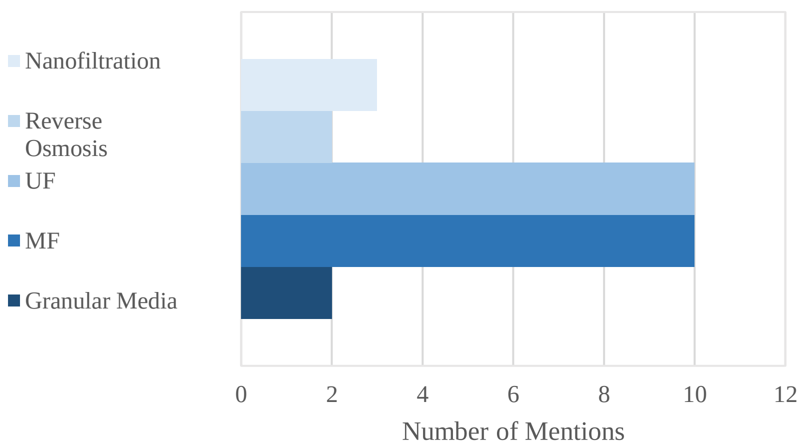

Figure 2. Filtration types at the plants represented by survey respondents.

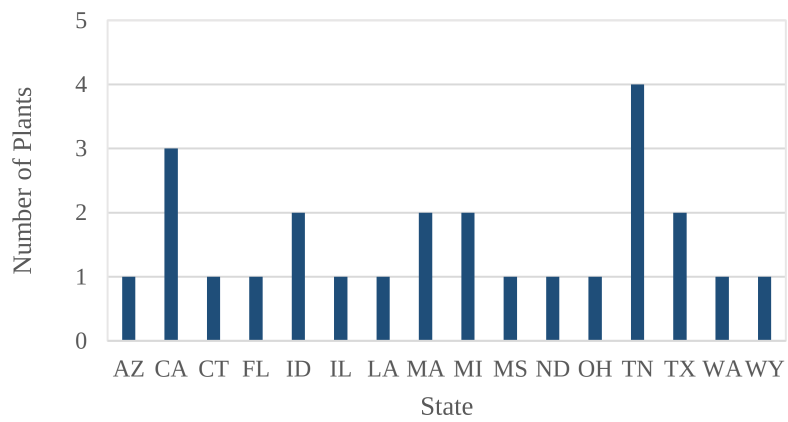

Figure 3. Location of treatment plants represented in survey data.

Data were analyzed to determine the energy use required to produce a unit of clean water. Of the 25 respondents, only 15 had usable data for both energy use and water production. Some of the respondents did not answer one or both of the questions, or there appeared to be a number that was unrealistically high or low. The 15 usable data points are plotted in Figure 4 in terms of (a) energy use vs MGD or energy use vs m^3. The slope of these plots were 1074 kWh/MG and 0.24 kWh/m^3, respectively. In the Background section we cited a study that reported 1,100 kWh/MG as a typical water treatment energy use. The overall number from our survey is quite similar; however, it should be noted that there is wide variability in energy use per water production, depending on the plant. Further, the energy use numbers from each plant likely include different unit processes. For example, some plants may have their raw-water pumps on site and included in the electricity bill, while others may deliver water from a separate location having a separate meter for billing.

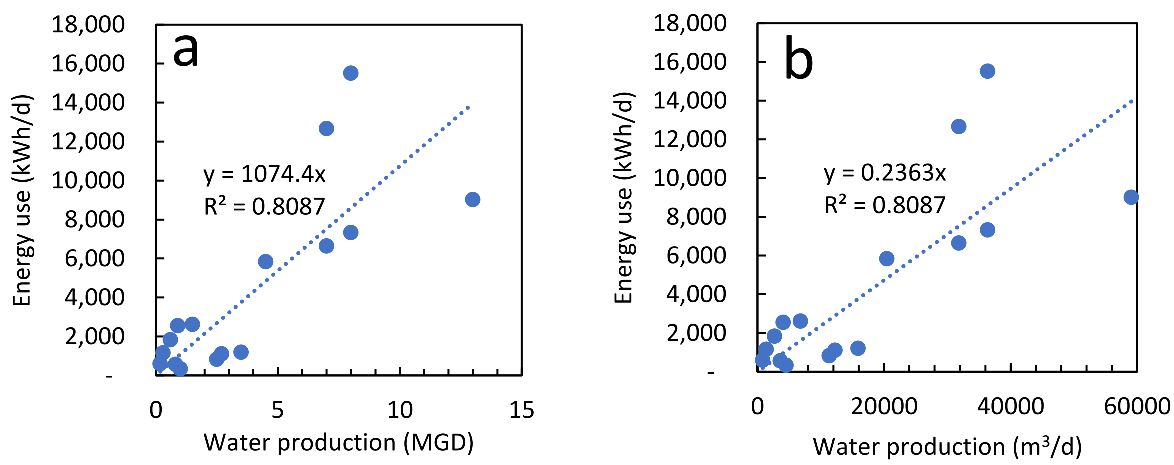

Figure 4. Energy use (kWh/d) vs. water production in (a) MDG and (b) m^3/d.

Using the survey data we were able to explore whether economies of scale are active in membrane plant energy use. Figure 5 shows the energy use in kWh per m^3 of produced water versus the size of the plant measured by daily water production (MGD). The plants with the highest normalized energy use (between 0.6 and 0.9 kWh/m^3) were those with low water production (less than 1 MGD), but the plants with the lowest normalized energy use were not the largest plants surveyed; in fact, the three lowest energy users (0.07, 0.07, 0.08, and 0.09 kWh/m^3) were plants having relatively low production (1, 2.5, 3.5, and 2.7 MGD, respectively).

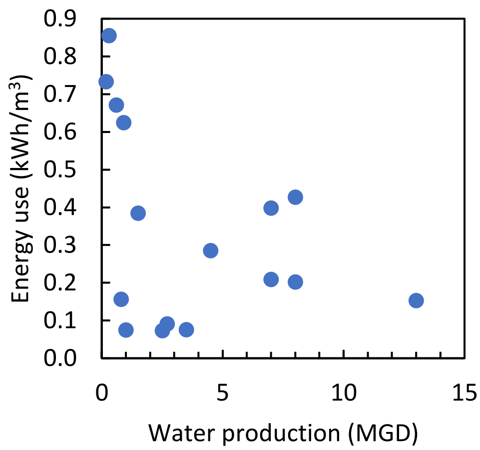

Figure 5. Energy use normalized to volume of water treated (kWh/m^3) compared with daily plant production (m^3/d).

The foregoing analysis shows the wide variability in reported energy use numbers via the survey mechanism. This motivates the second phase of the project, which is to interview plant staff and collect more granular data about energy use and water production, in light of the processes used at the plant. As an example of what can be learned with such an analysis, Figure 6 shows four years of energy use and water production data for one of the interviewed plants. The energy use at the plant tracks water production fairly well, but it is interesting to note that during the winter months the normalized energy use is higher than in the summer. This could be due to the higher costs of heating buildings at the plant, higher cost for heating clean-in-place tanks, higher viscosity of water requiring greater pressures to drive flux, or other factors.

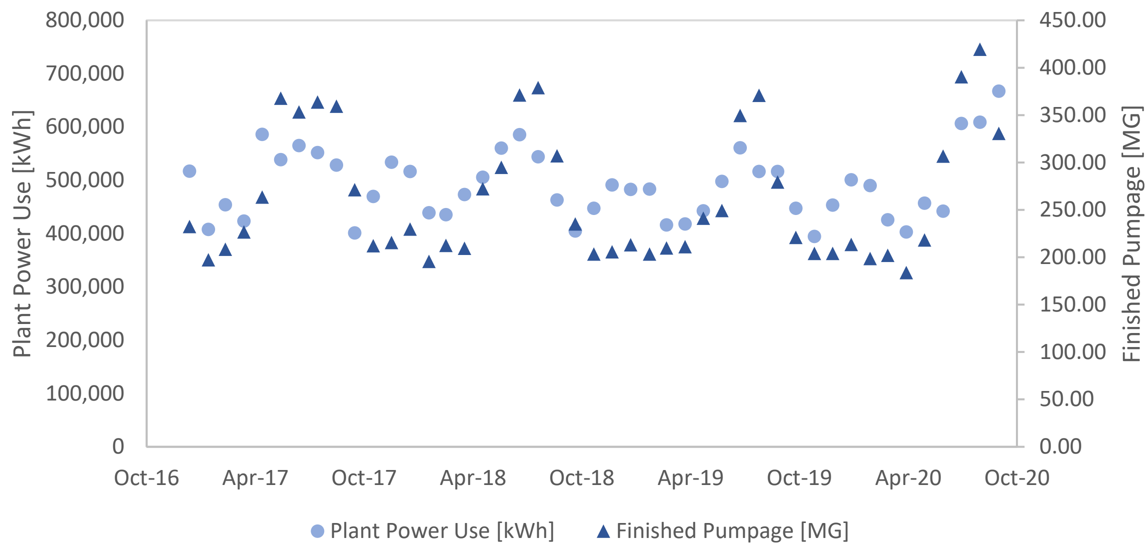

Figure 6. Approximately four years of monthly energy and water production from one of the interviewed plants.

Conclusions and Future Outlook

The main finding of the interim results reported here is that drinking water treatment plants using membranes tend to use 1074 kWh/MG (0.24 kWh/m^3) on energy to treat water. This is in line with data for conventional plants found in the literature, suggesting that water conveyance or other energy costs are more important than the energy for the membrane process in setting overall plant energy use numbers. Ongoing work will refine these data using in-depth interviews and analysis of more granular data.

This project will create a set of concrete data about energy use at real membrane filtration plants. This will serve to validate and update data collected by others in previous years and will allow an analysis of whether energy performance has improved with recent changes in membrane technology and processes. More importantly, we will develop a cataloged set of recommendations about how to improve energy efficiency. The information can be incorporated into manuals of practice or other publications/presentations serving as a benchmark and guide book upon which the membership can rely for accurate energy cost numbers and recommendations for improvement.

Acknowledgments

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