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Challenge testing membrane microfilters at a wastewater facility in the New York city watershed

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ABSTRACT

The Hobart wastewater treatment plant (WWTP) was upgraded in 2002 pursuant to New York City (NYC) Department of Environmental Protection (DEP) Watershed Rules and Regulations. The upgrade work included the addition of a tertiary treatment process, whereby secondary effluent from the extended air activated sludge process now undergoes rapid mix/flocculation, sand filtration, microfiltration (MF), and ultra violet (UV) disinfection, prior to discharge into the West Branch Delaware River. The upgrade was part of a broad program to ensure that wastewater treatment facilities which discharge into the NYC Watershed upholds State Point Discharge Elimination System (SPDES) permit limits well into the future.

Sand filtration prior to microfiltration is required per DEP specifications for SPDES upgraded WWTPs to ensure a reliable process. The membrane system at Hobart was therefore designed per the specification to treat the plant's rated capacity of 180,000 gpd (681,400 lpd) with upstream media filters serving as pretreatment. The microfilter's general capacity far exceeds that for which they are applied under the design specifications thus ensuring the robustness of the tertiary treatment process.

This study was proactively conducted to challenge and verify the membrane system's capability to handle design and peak flows without the benefit of its upstream sand filtration online. In this study, the sand filters were bypassed and plant flows to the membranes was manipulated to simulate a series of peak flow events. With the sand filters offline, the plant's full hydraulic load was sent directly to the MF system following secondary clarification and coagulation. Specific objectives of the challenge test were to:

- Verify the MF system's capability to handle peak flows with the sand filters out of service.
- Verify effluent quality and SPDES permit compliance using only the MF for filtration.
- Provide plant operations personnel with the experience and confidence to successfully operate the membrane system through extreme conditions.
- Generate full scale plant data to support current and future technical design specifications for membrane systems applied to SPDES upgraded WWTPs in the NYC Watershed.

Keywords: Microfiltration; Sand filter; Flux; SPEDS; EFM

1. Background

In 2002, the Hobart Wastewater Treatment Plant selected hollow fiber microfiltration as the primary component of a tertiary treatment upgrade. The purpose of the upgrade was to ensure plant compliance with DEP Watershed Rules and Regulations. The 180,000 gpd (681,400 lpd) WWTP discharges effluent directly into the West Branch Delaware River, which ultimately feeds the Cannonsville Reservoir, one of six NYC reservoirs in the Catskill/Delaware watershed. The Village of Hobart was required and funded under provisions in the DEP 1997 Memorandum of Agreement to further treat its extended aeration activated sludge effluent to meet monthly average SPDES permit limits for $CBOD_5$ (25 mg/l), SS (10 mg/l), P (0.5 mg/l), N (8.2 mg/l as NH_3), and fecal coliform (200 coliforms/100 ml). The plant was subsequently upgraded with tertiary treatment, which included coagulation/flocculation, multimedia filtration, hollow fiber microfiltration, and low-pressure UV disinfection.

1.1. The NYC water supply system

New York City has the largest unfiltered surface water supply in the world providing 1.3 billion gallons (4.9 million cubic meters) per day from a vast reservoir system to eight million New York City residents and an additional one million consumers in four counties north of the City. The New York City Water Supply System includes a watershed of 1,969 square miles (5,100 square kilometers) across eight counties as far as 125 miles (200 kilometers) north and west of the City (Figure 1).

The City currently operates under a conditional EPA Filtration Avoidance Determination (FAD) which allows the City to continue to provide unfiltered water from the Watershed providing strict water quality criteria are upheld. To meet and maintain FAD requirements, the City embarked on an aggressive Filtration Avoidance Program in the early 1990's which included identifying potential pollution sources, developing strategies to ensure long-term protection of the watershed, and addressing existing sources of contamination in the watershed.

The 1997 Memorandum of Agreement (MOA), negotiated between the City, New York State, EPA, and the Watershed communities, allowed the City to advance its watershed protection program while protecting the economic viability of watershed areas.

1.2. Wastewater treatment plant upgrade program

Under the MOA, the City implemented and funded a Wastewater Treatment Plant Upgrade program for existing non-City owned public and private wastewater treatment plants in the Watershed. The Village of Hobart was one of several municipalities with a publically-owned system that benefited from this program. Under the program, DEP mandated and funded a plant upgrade which included the addition of tertiary treatment based around membrane microfiltration technology in addition to other plant improvements. These plant upgrades under the MOA are known as SPDES upgrades.

2. Spdes upgrade

The Hobart plant was upgraded with tertiary treatment designed around the Pall Microfiltration System. A flow diagram for the new process is shown as Figure 2. Clarifier effluent from secondary treatment is treated with poly aluminum chloride (PACl), rapid mix, and flocculation. Sand filtration then follows, and effluent from the sand filters is sent to a clearwell which feeds the microfiltration system. Microfiltration filtrate is then treated by a UV disinfection system which replaced preexisting chlorine contactors.

The overall system also incorporates backwash recovery. Backwash discharge from both the sand filters and the two primary membrane skids is directed to a mudwell. The mudwell feeds a third membrane slave unit. Filtrate flow from the two primary systems and the slave unit are blended prior to the UV contactors. Backwash discharge from the slave unit is sent to a sludge holding tank for further processing. Decant from the sludge tank then flows to the front end of the tertiary treatment system and sludge is sent to a plate and frame press for dewatering.

2.1. Microfiltration system

The MF system (Figure 3) consists of two primary racks, and a secondary slave unit to handle backwash from the primary racks and sand filters. The two primary racks consist of a total of 40 hollow fiber membrane modules. The polyvinylidene fluoride (PVDF) membrane pore size is rated at 0.1 µm. Each six-inch diameter module contains a fiber bundle made up of approximately 6100 fibers, each 1.3 mm in diameter for an effective filter area of 538 square feet (50 square meters) based on the outside diameter of the fibers. The primary system is designed per DEP Watershed Rules and Regulation, and rated accordingly at 180,000 gpd (681,400 lpd).

Automatic controls efficiently operate the microfilters through the cycle of filtration, air scrub, and backwash and collect turbidity, flow, and pressure data that can be used to monitor performance. Remote monitoring

Fig. 1. New York City's Water Supply System – *New York City DEP*.

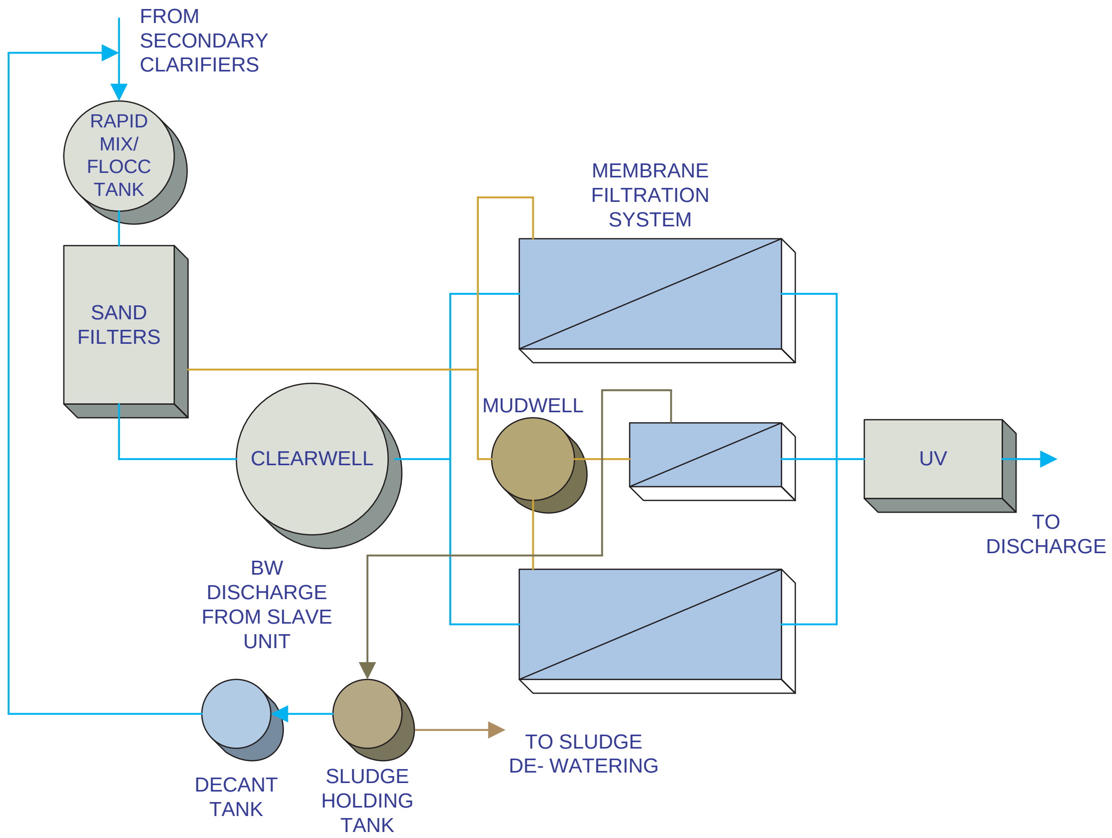

Fig. 2. 2002 Tertiary treatment upgrade.

capabilities allow plant operators or the manufacturer's engineers to access, monitor, and control the plant via a modem connection.

In addition to hydraulic backwashing, the system can be modified to include the enhanced flux maintenance (EFM) process to supplement the backwash regime with a chemically assisted process. EFM typically uses sodium hypochlorite at 300–500 mg/l circulated through the membrane rack and can be used on a daily basis to help control fouling. Due to sufficient conservatism already built into the system, fouling is minimal and there are no immediate plans to add EFM capability to the Hobart MF system.

2.2. Microfiltration system specifications

The Hobart MF system was designed in accordance with NYC Watershed WWTP Upgrade Program Model Equipment Prepurchase Specification which includes the following requirements:

- A maximum membrane design flux of 23.3 gfd (39.6 lmh) based on peak hourly flow.
- A fully redundant membrane unit and the ability for the microfiltration system to treat peak hourly flow with the redundant unit out of service without exceeding 23.3 gfd (39.6 lmh) flux rate on the main unit.
- Sand filtration upstream of the microfiltration membrane units.
- A slave unit or other equivalent process is required for the backwash reject water as an integral component of the process.

2.3. Redundancy and conservatism

The DEP specifications are sufficiently conservative to ensure microfiltration reliability when the unit is operated under normal conditions. This has been fully demonstrated by more than 6 years of dependable full-scale plant operation and SPDES compliance at Hobart.

During this time, the MF system has experienced daily peak flows which have exceeded rated capacity of 180,000 gpd (681,400 lpd). Maximum peak flow events were documented in March, 2007 when daily

Fig. 3. Pall Microfiltration System.

flows reached as high as 250,000 gpd (946,400 lpd). During these peaks flow events, the microfiltration flux remained below 13 gfd (22.1 lmh) and transmembrane pressure remained below 14 psi (96.5 kPa) both of which are well below the 23.3 gfd (39.6 lmh) and 43.5 psi (300 kPa) limits for flux and transmembrane pressure respectively. Following the peak flow events, the membrane operation fully recovered to normal TMP level without the need for chemical cleaning.

The ability for the membrane system to operate effectively under these extreme conditions without exhibiting significant fouling, underscores the conservatism of Hobart's MF system design. Specific features of the membrane plant design, and operational practices which contribute to the plant's robustness are explained as follows.

- The microfilters employed at Hobart have a long operating history on wastewater applications where operating flux rates typically exceed the 23.3 gfd (39.6 lmh) flux specification.
- The microfilters can be applied directly to secondary effluent without coagulation or pre-filtration. The use of PACl coagulation at Hobart for phosphorus removal has the added benefit of enhancing filterability of the MF feedwater. The inclusion of sand filters upstream of Hobart's membrane system further reduce the solids loading that would otherwise be applied to the membranes, thereby providing further resistance to fouling of the microfilters.
- It is common practice at Hobart as well as other installations to operate the redundant membrane rack in conjunction with the primary rack as opposed to having it on standby. Therefore, during normal operation, membrane flux rates are essentially reduced by 50% thereby minimizing membrane loading and fouling, thus further increasing the system's reliability.
- During much of the year, the plant is operated at less than 40% of its design flow. When the MF system is operating with its redundant rack online, the flux rate can be 5 gfd (8.5 lmh) or less.

3. Challenge test methodology and preparation

Historical data shows high flow events at the Hobart WWTP typically occurring over a 2–3 day period. To simulate such an event, challenge preparation and testing was conducted over a four day period in spring, 2008. The month of June was selected as it has typically received the greatest amount of precipitation in recent years based on facility operation reports.

3.1. Check/restore permeability

The permeability of the membranes was evaluated prior to beginning the challenge testing to determine the state of fouling and if a CIP was desired. Prior to the start of this test, the test rack was operating below 5 psi (34.5 kPa) of TMP with one rack offline. Considering the membrane can operate up to 43.5 psi (300 kPa), the default transmembrane pressure was not a concern, therefore CIP was not initiated.

3.2. Integrity test

A direct pressure hold integrity test was performed on Rack A, the main test rack to ensure membrane integrity prior to the testing. In general, direct integrity testing is a physical test that is able to detect and isolate an integrity breach and is typically much more sensitive than indirect integrity testing methods based on water quality parameters. The pressure hold test confirmed membrane integrity.

3.3. System reconfiguration

Historical data indicates average daily flows during May and June of approximately 62,000 gpd (234,700 lpd). Therefore, to achieve membrane flux rates at the design value; a number of membrane modules were taken offline to adjust the membrane area so that design flux rates could be achieved. Of the full compliment of 40 membrane modules, all but 7 would be taken offline. This facilitated operation near 8.7 gpm (32.9 lpm) per module to achieve a flux rate of 23.3 gfd (39.6 lmh).

On June 1, 2008; the membrane system was reconfigured by removing 13 modules from the primary skid, Rack A (see Figure 4). The redundant membrane skid, Rack B, was left intact with its full compliment of 20 modules which could easily be taken offline via the system's controls. In the final test configuration, the MF plant could be operated with either rack online.

4. Test execution and discussion

Prior to initiating the challenge tests, the MF system was operated normally with its full complement of 40 modules online. The recorded membrane flux and transmembrane pressure were approximately 3.5 gfd (6.0 lmh), and 2.5 psi (17.2 kPa) respectively during the early part of the day. These operating values are typical and conservative for this plant when compared to the regulatory flux limit of 23.3 gfd (39.6 lmh), and TMP operational limit of 43.5 psi (300 kPa). These limits are indicated in the following graphs to provide perspective for the membrane performance during the challenge test.

At mid-day on June 1 (Day 1), Rack A was taken offline for aforementioned reconfiguration and Rack B remained online to handle the full plant flow of approximately 50 gpm (189 lpm) with 20 modules. At a flux of 6 gfd (10.2 lmh), and TMP of less than 4 psi (27.6 kPa), the microfilters were still being run conservatively.

4.1. Challenge A: Simulating sand filter failure

With Rack B online, the sand filters were bypassed at approximately 4:00 p.m. to simulate a failure of the pre-filtration process, thereby allowing secondary effluent to enter the clearwell feeding the MF system. The coagulation and mixing process remained intact to assess the MF system's ability to independently handle and remove phosphorus in a direct coagulation mode using the standard dose of PACl.

Rack B with its compliment of 20 modules remained online overnight while secondary effluent gradually displaced an estimated 29,000 gallons (109,800 liters) of sand filter effluent in the clearwell to progressively challenge the membrane system. In the hours that followed, no apparent change in performance, increase in TMP, or other adverse effect of bypassing the sand filters was evident during Day 1 or the early part of Day 2 (see Figures 5 and 6).

4.2. Challenge B: Design and peak flow with sand filters offline

By the morning of Day 2, the clearwell was filled completely with secondary effluent. Rack B was taken offline at approximately 7:30 a.m. and Rack A was placed online with its remaining 7 modules. The MF system was processing 50 gpm (189 lpm), but the module reduction effectively increased flux to approximately 19 gfd (32.3 lmh lmh). The TMP values at the increased flux were stabilized at approximately 5.5 psi (37.9 kPa).

Fig. 4. Pall Microfiltration System – Rack A reconfiguration.

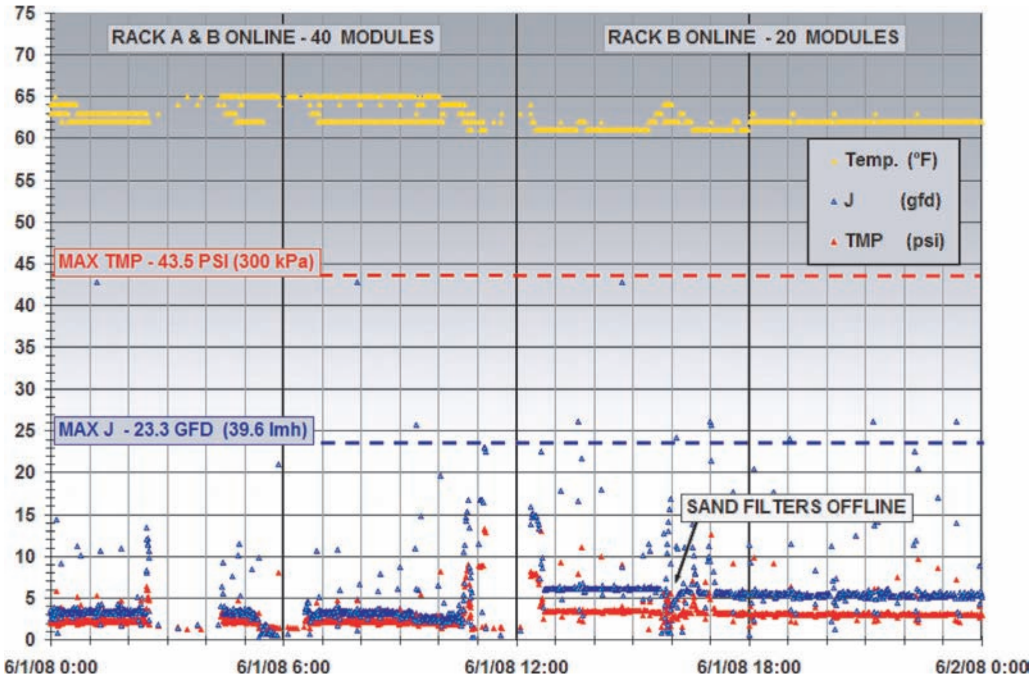

Fig. 5. Day 1 test data.

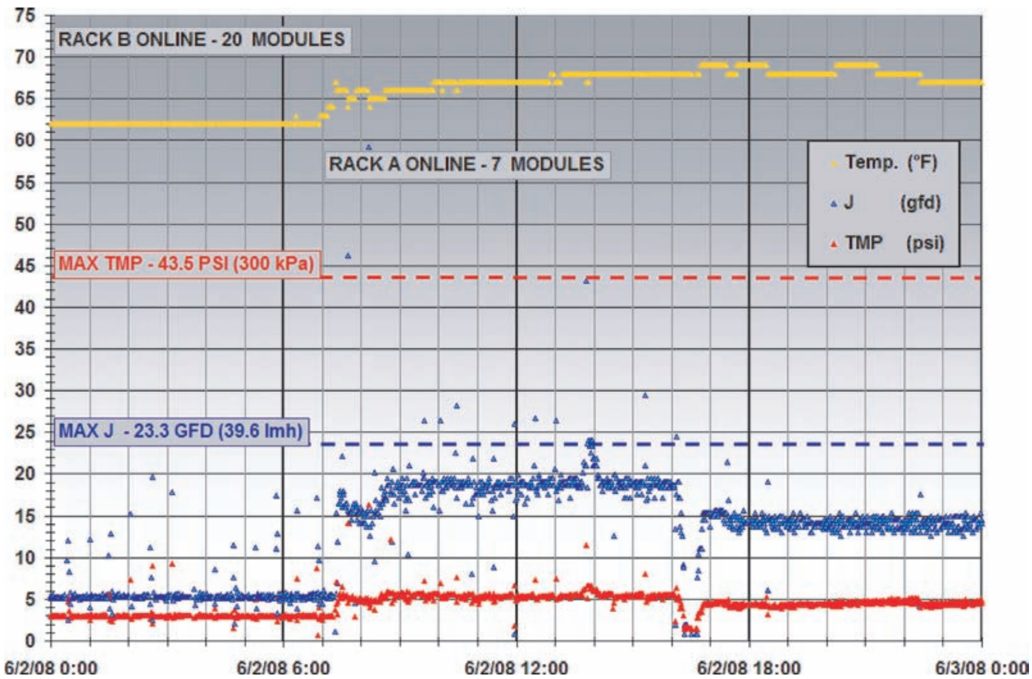

Fig. 6. Day 2 test data.

To generate higher flux rates, the plant's equalization tanks were filled with raw water at night so that the plant throughput could be turned up during the day, thus allowing the membrane system to operate at maximized flux rates for the final 2 days of the test. On Day 3 around 9:00 a.m., the inflow through the plant was increased utilizing the reserve volume. The MF system was run at flux rates between 23 and 29 gfd (39.1 and 49.3 lmh)

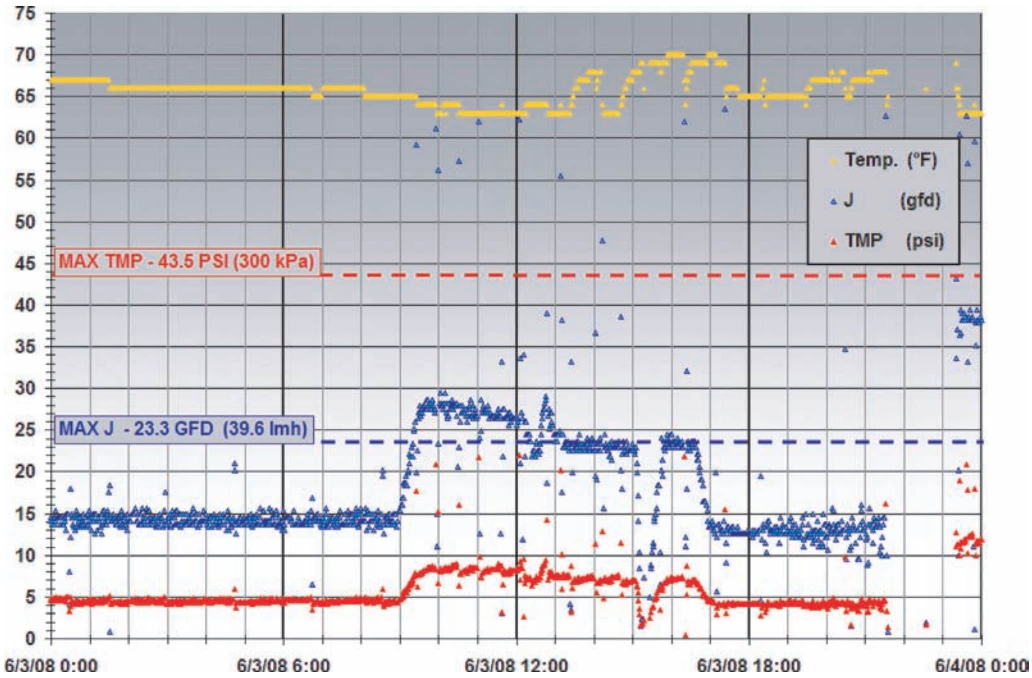

Fig. 7. Day 3 test data.

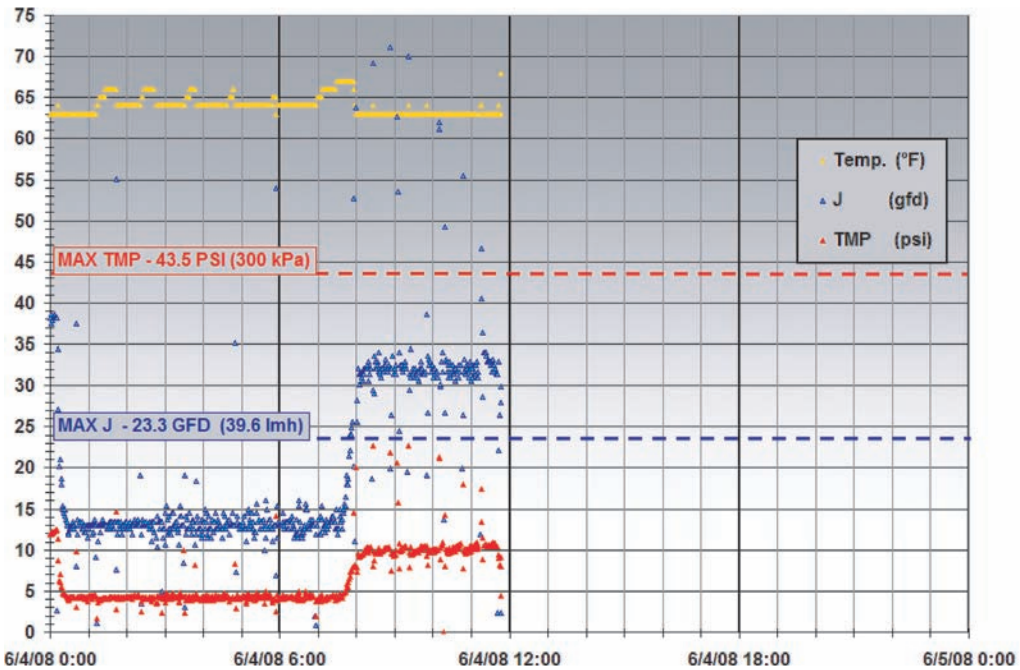

Fig. 8. Day 4 test data.

for approximately 7 hours. Corresponding TMP ranged between 7–9 psi (48.3–62.1 kPa) as seen in Figure 7.

This procedure was repeated for the final day of testing—reserve flow was collected overnight then sent through the plant beginning 8:00 a.m. on Day 4. A flux rate of 32 gfd (54.4 lmh) was achieved and sustained for approximately 4 hours. Corresponding TMP during this 4 hour period was approximately 10 psi (68.9 kPa) as seen in

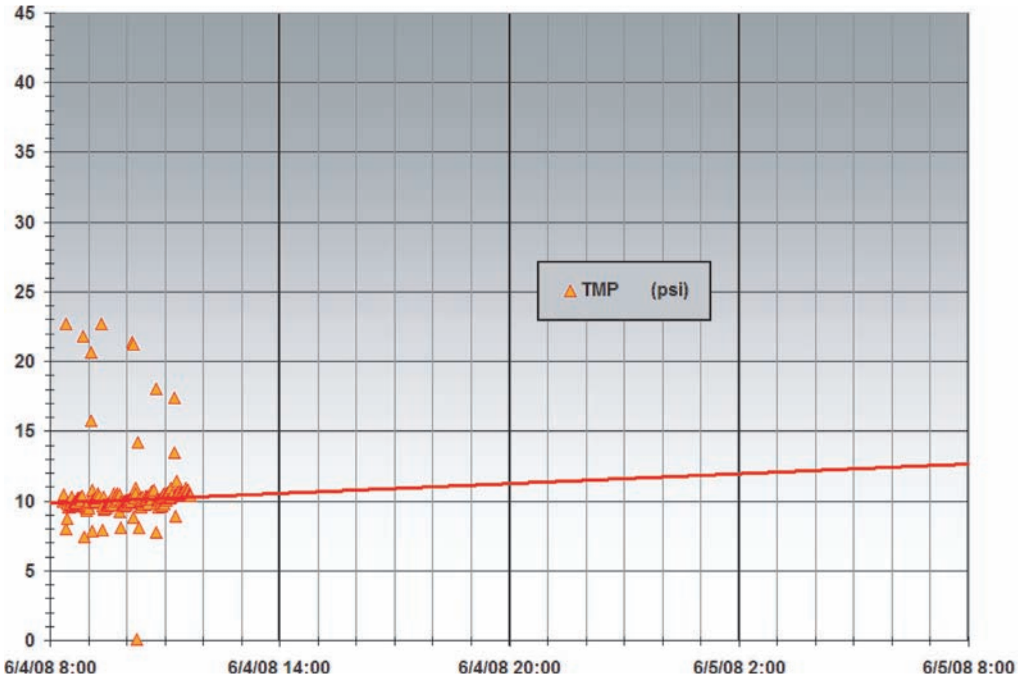

Fig. 9. Day 4 extrapolated data.

Figure 8. The challenge testing was concluded at 12:00 p.m. on June 4. Rack A was then restored to its original configuration and normal operation resumed at the plant.

4.3. Day 4 extrapolation

At the 32 gfd (54.4 lmh) flux rate achieved on Day 4, corresponding TMP levels were approximately 10 psi (68.9 kPa) and exhibited a slightly positive slope over the 4-hour simulated peak flow event. In Figure 9, a regression line is fitted to the TMP data and extend to project the increase in TMP had the peak flow test been continued for a 24-hour period. The resulting slope was 2.8 psi (19.3 kPa) per day suggesting that the system could have continued for up to 12 days under these conditions before reaching the maximum TMP limit assuming the slope remained relatively constant.

Throughout the challenge test period, air scrub (AS) and reverse filtration (RF) intervals and flow rates generally remained on a fixed volume basis of 2250 gallons (109,800 liters). On a timed basis, this equates to a frequency of 28.4 minutes to 69.5 minutes given process flow range between 33 gpm (125 lpm) and 83 gpm (314 lpm). The membranes used at Hobart can be routinely backwashed as frequently as 15–20 minutes and as low as 12 minutes under extreme circumstances.

Table 1 represents the operating parameters at during Day 4 peak flow testing. While the flux rates were varied during the challenge testing, overall recovery remained generally fixed at 98%. This recovery is actually higher than the recovery under normal operation. For example, when the unit is processing 71,500 gpd (270,700 lpd) using both racks at 3.3 gfd (5.6 lmh), the corresponding recovery is 97%.

Based on this table, Rack A could potentially process upwards of 325,000 gpd (1,230,000 lpd) given its full complement of 20 membranes if operated on a 24 hour basis.

4.4. Sampling and analytical results

Analytical sampling was performed during the Challenge test on raw water, secondary effluent, and MF filtrate. In addition, DEP performed routine sampling on the plant's final effluent on Day 4 while the MF unit operated at its peak test flux rate. The analytical results from both sample sets pertaining to the SPDES permit are presented as Table 2. The results confirm that the SPDES discharge limits were upheld during the challenge tests.

5. Supplemental data

The membrane technology used in Hobart's MF system has a long history of application to secondary

Table 1
Day 4 operating parameters (7 modules).

Filtrate Flow (gpm)	83.0	Membrane Area (ft^2)	3,766
SASRF, RF, Feed Flush		Flux (GFD)	31.7
SASRF-RF Interval (gal)	2,250.0		
SASRF-RF Interval (min.)	28.4	**EFM**	
Filtration Duration Per Cycle (min.)	27.1	EFM Interval (hours)	0.0
Air Only Duration (sec.)	20	EFM Solution Volume (gal. of filtrate)	0.0
AS Duration (sec.)	20	EFM Drain time (sec.)	0.0
AS-RF Rate (gpm/mod.)	41.00	EFM Fill time (sec.)	0.0
AS-FF Rate (gpm/mod.)	0.00	EFM Circulation/Soak Duration (min.)	0.0
Flush Duration (sec.)	38	EFM AS-RF Duration (sec.)	0.0
RF Rate (gpm/mod.)	50.00	EFM AS-RF Rate (gpm/mod.)	0.0
FF Rate (gpm/mod.)	0.00	EFM RF Duration (sec.)	0.0
Waste Per Cycle (gal.)	45.33	EFM RF Rate (gpm/mod.)	0.0
SASRF-RF Cycles Per Day	50.7	Forward (feed) Flush Duration (sec.)	0.0
SASRF-RF Time Per Day (min.)	65.9	Forward (feed) Flush Rate (gpm/mod.)	0.0
Filtrate to Waste Per Cycle (gal.)	45.3	Use Filtrate for EFM (1-yes, 0-no)	0.0
Feed to Waste Per Cvcle (gal.)	0.0	EFM Cycles Per Day	0.00
Filtrate to Waste Per Day (gal.)	2,297.9	EFM Time Per Day (min.)	0.0
Feed to Waste Per Day (gal.)	0.0	Filtrate to Waste Per Cycle (gal.)	0.0
		Feed to Waste Per Cycle (gal.)	0.0
On-line Time Per Day (min.)	1,375.1	Filtrate to Waste Per Day (gal.)	0.0
Gross Filtrate per Day (gal.)	114,051	Feed to Waste Per Day (gal.)	0.0
Total Feed Per Day (gal.)	114,051		
Net Filtrate Per Day (gal.)	111,753		
Recovery	**98.0%**		

Table 2
Analytical results.

	Units	Spdes limit	Plant Lab *						Dep Lab**
			3-Jun			4-Jun			4-Jun
			Raw	2nd Eff	MF Filt.	Raw	2nd Eff	MF Filt.	MF Filt.
CBOD	mg/l	25	477	4	<1	146	<4	<4	<3
TSS	mg/l	10	230	12	<3	117	10	<3	–
TOTAL P	mg/l	0.5	7.8	0.78	0.05	5.6	0.98	0.12	0.13
NH_3AS NH_1	mg/l	8.2	42.6	<1	<1	27	<1	<1	<0.2
FECAL COL.	mpn/100 ml	200	>4000	>400	<2	>4000	>4000	<20	–
	cfu/100 ml	200	–	–	–	–	–	–	<10

* Midstate Environmental Laboratories, Clifton Springs, NY.
** NYC-DEP Bureau of Water Supply Grahamsville Laboratory, Grahamsville, NY.

effluent in a number of wastewater installations and feasibility studies. For the basis of comparison, the following series of graphs are presented. This data was collected during a 2004 pilot study using the same PVDF membrane as those used at Hobart. The pilot system was operated downstream of an extended air WWTP under various pre-treatment conditions. Operating conditions of the pilot test worth noting are as follows:

- The pilot study was conducted using a single module with the same dimensions, and membranes as those used at Hobart.
- The pilot test unit was operated at 15 minute backwash intervals.
- The secondary effluent feeding the MF was not pre-treated with coagulant.
- The pilot unit was operated with daily EFMs using a solution of 0.1% NaOH and 0.1% NaOCl

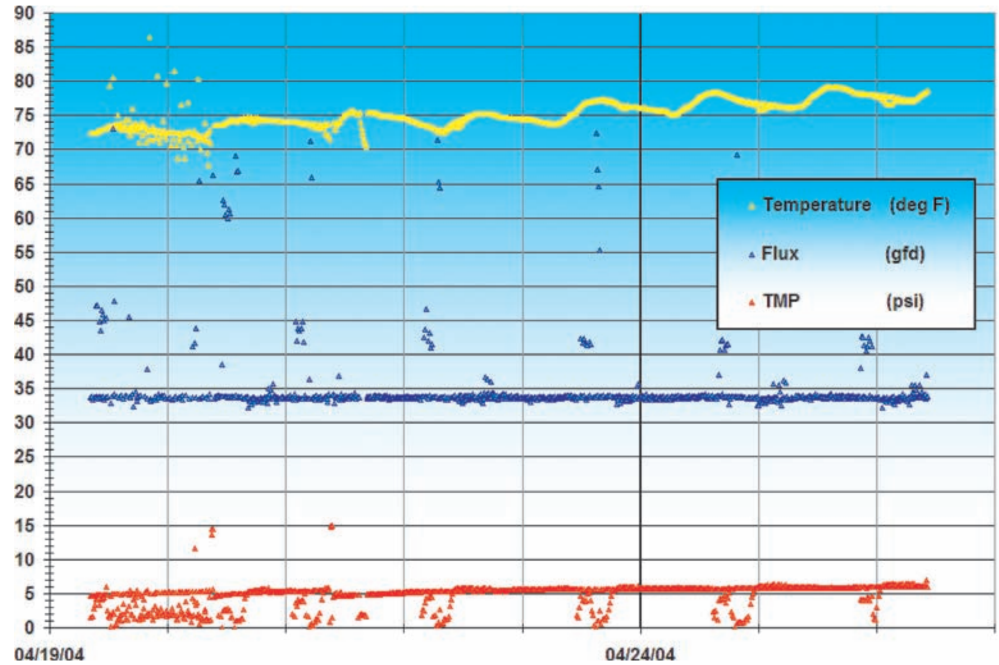

Fig. 10. Pilot condition 1.

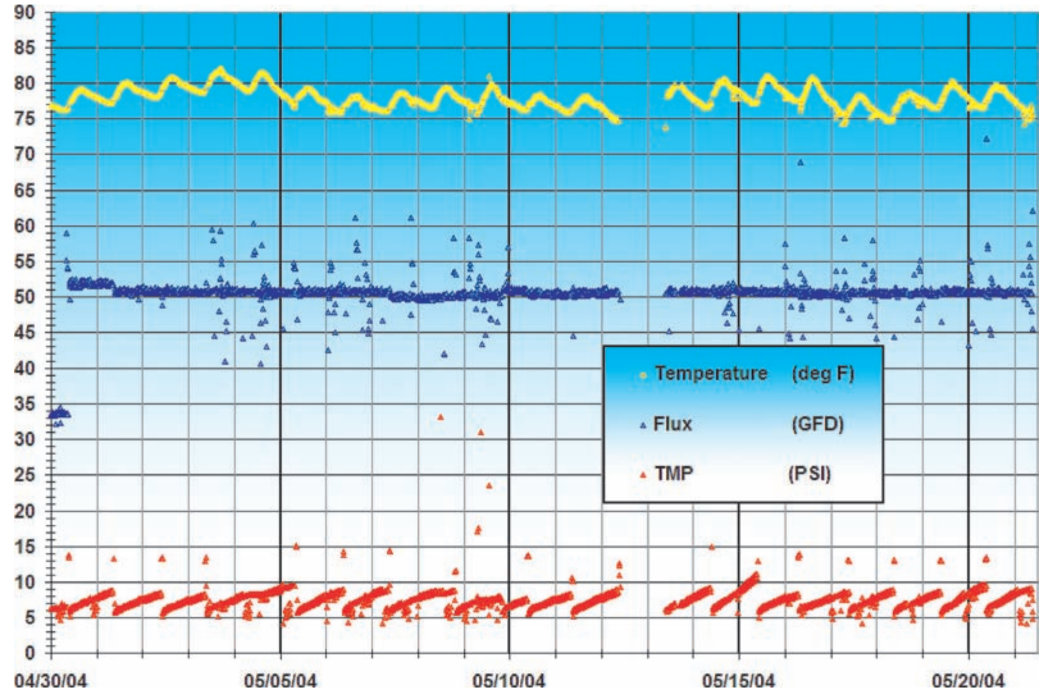

Fig. 11. Pilot condition 2.

for the two of the three conditions presented here.

5.1. Condition 1: 33 gfd (56.1 lmh), 93.9% recovery—pre filtration bypassed, EFM disabled

Condition 1 most closely replicates the Day 4 Challenge conditions in terms of operating flux, pre filtration conditions, and the non-use of EFM. In Figure 10, a single module pilot unit was operated at 33 gfd (56.1 lmh) with pre-filtration bypassed. The pilot test continued at fixed conditions for approximately one week demonstrating a low and stable TMP range between 4 and 6 psi (27.6 and 41.4 kPa). This illustrates the low TMP potential over extended periods of time and supports

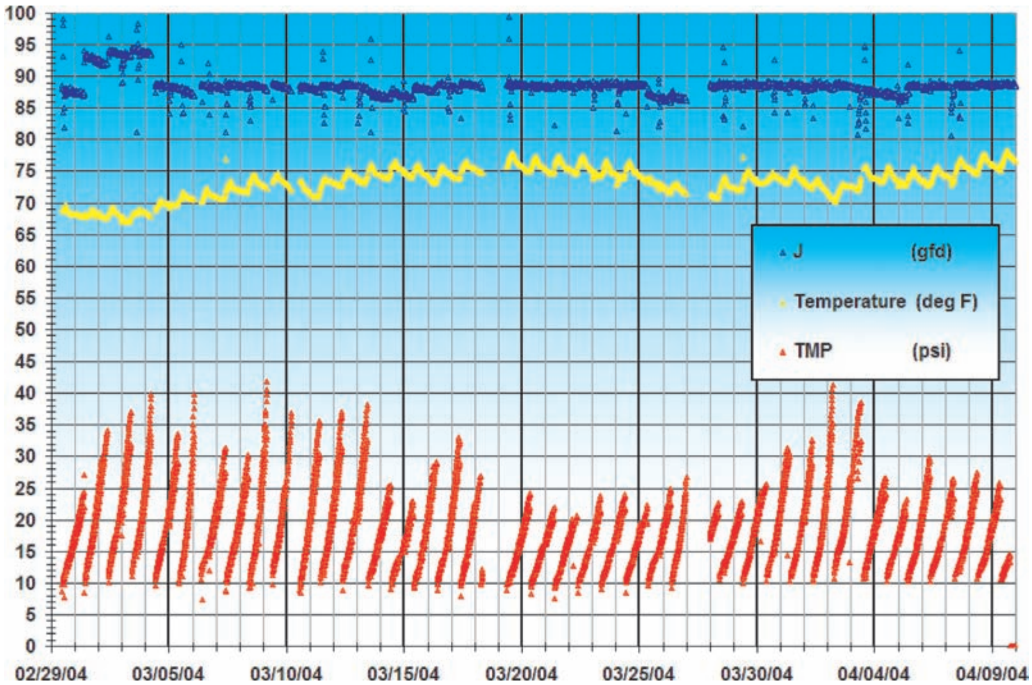

Fig. 12. Pilot condition 3.

the Day 4 Challenge test TMP projections made in the previous section.

5.2. Condition 2: 51 gfd (86.7 lmh), 96.1% recovery—pre filtration bypassed, EFM enabled

In this run, the pilot system operated for over 21 days at 51 gfd (86.7 lmh) without prefiltration. The effect of the EFM process is evident in Figure 11 as the TMP generally increased 5 psi (34.5 kPa) per day and is reduced by daily EFM to a baseline value of approximately 5 psi (34.5 kPa), thus net daily increase in zero. This run demonstrates the enhanced capacity of the MF system when process variables are optimized.

5.3. Condition 3: 89 gfd (151.3 lmh), 97.7% recovery—pre filtration enabled, EFM enabled

Figure 12 demonstrates MF operation at a flux rate of 89 gfd (151.3 lmh) using prefiltration and EFM. Daily TMP increases were more pronounced than the other conditions and occasionally approached the operating limit of 43.5 psi (300 kPa). Daily use of EFM was effective in reducing TMP to a baseline value of approximately 10 psi (68.9 kPa) allowing this run to continue for over 40 days without the need of a CIP. This run demonstrates the high end of the membrane's operating flux range on secondary effluent.

6. Conclusions

- The Hobart MF system's capability to handle peak flows with the sand filters out of service was verified.
  - The MF system was effectively operated at flux rates up to 32 gfd (54.4 lmh) with minimal fouling. At this sustained flux rate, either of the two membrane racks could process 325,000 gpd (1,230,000 lpd).
  - Extrapolation of the full-scale test data suggest that operation at 32 gfd (54.4 lmh) is sustainable for at least 12 days under the test conditions using 28 minute backwash intervals. This duration can be further extended with optimized backwash frequencies.
- Plant effluent quality and SPDES permit compliance during challenge conditions has been verified by analyses from two independent labs.
- Hobart's Operations personnel gained valuable firsthand experience in operating the membrane system through extreme conditions. Through this test, the staff obtained further insight into the extent of their membrane system's capabilities.
- The plant data obtained under the challenge conditions demonstrates the conservatism inherent to the current technical specifications for membrane systems under SPDES upgraded WWTPs in the NYC Watershed.

- The results of the challenge test along with the supplementary data support revised MF design specifications for SPDES upgraded WWTPs.
  - The Challenge test results demonstrate that the Hobart microfilters can reliably operate without pre-filtration and at augmented flux rates.
  - Supplementary pilot data from a similar extended aeration plant demonstrates stable long term operation of the microfilters at flux rates of 51 gfd (86.7 lmh) when operated on secondary effluent directly, and 89 gfd (151.3 lmh) when pre-filtration is employed.

Acknowledgements

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