COMPARATIVE EVALUATION OF MICROFILTRATION & ULTRAFILTRATION PERFORMANCE AT HOLLYWOOD RESERVOIR

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Background

In an effort to comply with the requirements of the Surface Water Treatment Rule (SWTR), the Los Angeles Department of Water and Power (LADWP) is constructing facilities to bypass its affected open reservoirs and provide partial treatment of the reservoir water by low-pressure membrane filtration. The reservoirs affected by the SWTR are the two Hollywood Reservoirs, Lower Stone Canyon Reservoir and Encino Reservoir. These reservoirs receive treated surface water from the Los Angeles Aqueduct Filtration Plant (LAAFP), occasionally blended with local groundwater in the case of the Hollywood Reservoir. For the treatment needs of the reservoirs, LADWP decided to pilot test four membrane systems including: US Filter/Memcor microfiltration (MF), Pall Corporation microfiltration (MF), Aquasource North America ultrafiltration (UF), and ZENON ultrafiltration (UF). At the time of the evaluation, these membranes were the only ones certified by the California Department of Health Services (DHS). The pilot tests were carried out at the Hollywood Reservoir project site from September 1997 to November 1999.

Objective

The specific objective of the pilot study was to compare the performance of the DHS-approved membrane systems. For this reason, factors such as flux, rate of fouling, frequency and efficiency of chemical cleaning, and rejection of contaminants were evaluated.

Materials & Methods

Feed Water Characteristics

Water stored in the Hollywood Reservoir served as the feed for the pilot test units. This water is made of treated surface water by ozone and conventional direct filtration at the LAAFP. As stated earlier, occasionally, groundwater is blended with the water stored in the reservoir. Overall, the quality of water is stable throughout the year with relatively low levels of turbidity ($\approx$ 1 ntu) and low

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TOC ($\leq$ 2 mg/L). Constituents listed in Table 1 typify the quality of water in the Hollywood Reservoir.

Experimental Setup

Four membrane pilot units from US Filter/Memcor MF, Aquasource UF, Pall Microza MF, and ZENON ZeeWeed® UF were tested during the study. The US Filter/Memcor MF was the first membrane system pilot tested from September 1997 to December 1997. A detailed result of the pilot testing was reported earlier (1). Following the completion of the US Filter/Memcor MF study, pilot testing of the Aquasource UF commenced on October 1998 and was completed by April 1999.

In order to accommodate more DHS-approved membrane systems in the short project schedule, the remaining two systems of Pall Microza MF and ZENON ZeeWeed® UF were pilot tested simultaneously in parallel from May 1999 to November 1999. A brief description of each pilot unit follows:

1. US Filter/Memcor MF

The pilot unit used in this study was consisted of the Memcor hollow fiber MF membrane; Model 3M10C[1]. Table 2 lists the specifications of the Memcor MF membrane. The pilot unit included a feed pump, a feed tank, an air compressor, and a recirculation loop, which contained the membrane modules. Three membrane modules with 290 ft^2 (27 m^2) of surface area each, operated in direct flow mode (i.e., no recirculation) as recommended by the manufacturer. Compressed air at 90 psi (6.2 bar) was used to backwash the membrane modules on an hourly basis. Following each backwash, a rewetting step was performed using the feed water after which the pilot unit was programmed to restart a new operational cycle.

2. Aquasource UF

The Aquasource hollow fiber UF[2]membrane system was used in this study. Table 2 shows the membrane specifications. The pilot unit consisted of a feed pump, a recirculation pump, a backwash pump, and a recirculation loop, which included two membrane modules each with 76 ft^2 (7.1 m^2) of membrane surface area. The UF mode of operation was based on constant flux at variable transmembrane pressure (TMP). Permeate water dosed with 5 to 8 mg/L free chlorine was used for periodical backwashing of the membrane modules. Dislodged debris from the backwash operation was flushed out of the system with a recirculation flow consisting of both the backwash and the feed water. A

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[1] US Filter/Memcor, Timonium, MD.
[2] Aquasource North America, Richmond, VA

programmable logic controller (PLC) implemented the sequence of events associated with the backwashing procedure.

3. Pall Microza MF

The pilot unit (Model XUSV-3003) consisted of the Pall Microza MF hollow fiber membrane system[3]. Table 2 provides the membrane specifications. The MF pilot consisted of a feed pump, a feed tank, an air compressor, and a recirculation loop, which included the membrane modules. Two membrane modules (398 ft^2, 37-m2 ea.) were included in the pilot unit. The flow of water was from the outside of the membrane to the inside of the hollow fiber. During the filtration mode, the feed water was pumped to the bottom of the MF module. Permeate was collected from the top of the module and directed into a permeate storage tank. The pilot unit was also operated under a concentrate recycle flow of about 10 percent of the permeate flow. An automated backwashing was initiated every 60 minutes (i.e., filtration cycle). During the backwash, the feed pump was shut down and a portion of the stored permeate was used to clean the membrane. The backwash cycles typically lasted less than a minute. The backwash preceded by an air scouring of the membrane feed side for about 1.5 minutes.

4. ZENON ZeeWeed® UF

This membrane system consisted of ZeeWeed®-500 OCP ultrafiltration[4]. The ZeeWeed®- process is a proprietary ZENON membrane process that uses ZeeWeed® UF modules immersed in the raw feed water. Table 2 provides the specifications of the ZeeWeed® UF membrane. The pilot unit used in this study had one membrane module (250 ft^2, 23-m^2 ea.) immersed in the process tank. The immersion of the membrane modules in the process tank allowed for the operation of the system under vacuum. An air blower was included in the system to provide a constant supply of air to promote scouring of solids from the outside surface of the membrane modules. The scouring action alleviated solid accumulations on the membrane by moving the solids back into the bulk solution of the process tank. The ZeeWeed® system was operated under a constant flux, by adjusting the vacuum pressure. During the back pulse process (i.e., backwash), solids removed from the membrane surface were transferred back into the bulk solution of the process tank. Concentrated solids were bled continuously from the process tank at a rate of approximately 1.5 percent of the feed water rate.

[3] Pall Corporation, Port Washington, NY.
[4] ZENON Membrane Systems, Ontario, Canada.

Results & Discussion

Membrane Flux and Fouling Rate

1. US Filter/Memcor MF

Pilot testing was carried out for approximately 1,500 hours at flux values of 38 gfd, 45 gfd, 48 gfd, and 56 gfd[5] (Figure 1). The backwash frequency was 30 minutes, resulting in a feed water recovery of 94 to 96 percent. At the beginning of the pilot testing, the TMP was approximately 7 psi. After initial clean in place (CIP) of the membrane, the TMP dropped to below 6 psi. From this point on, a gradual increase in TMP was observed (Figure 1). After about 750 hours of operation, during which time membrane fluxes of 38, 45, and 48 gfd were tested, the TMP increased to 18 psi, after which a second CIP was executed. Prior to this point, due to low TMP readings, no CIP was executed. At a membrane flux of 56 gfd, between the hours of 800 and 1,100 of the pilot testing, TMP increased at a relatively accelerated rate. Lowering the membrane flux from 56 gfd to 38 gfd resulted in a slower buildup of TMP taking into account the drop in water temperature. Addition of 3 mg/L of ferric chloride at 1,348 hours of operation accelerated the buildup of TMP. At this point, due to a high TMP (i.e., 19 psi), another CIP was performed after which the TMP dropped to about 9 psi. Overall, the system demonstrated a stable performance over a flux range 38 – 48 gfd and a backwash frequency of 30 minutes, corresponding to a feed water recovery of 94 to 96 percent.

2. Aquasource UF

Pilot testing was carried out for approximately 4,000 hours at flux values of 60 gfd, 70 gfd, 80 gfd, and 100gfd (Figure 2). The backwash frequency was initially set at 30 minutes and later on changed to 60 minutes towards the end of the pilot testing, resulting in a feed water recovery of 86 to 92 percent. At the beginning of the testing, the pilot unit was operated at 60 gfd and a TMP of approximately 7-psi. A minimal rate of fouling was noticed during the first 500 hours of operation, as evident from the slow increase in TMP. At the end of the first 500 hours of operation, the membrane was chemically cleaned and the flux was increased to 80 gfd, which resulted in higher a rate of fouling as expected. At approximately 1,100 hours of operation, the membrane was chemically cleaned and the flux was increased to 100 gfd. Due to ineffective chemical cleaning, the higher flow rate through the membrane, and decline of water temperature, the initial TMP at this flux was close to the maximum operating limit of 21 psi. During this period, the pilot unit experienced several shut downs.

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[5] It should be noted that the flux values for the Memcor system are calculated based on the membrane surface area using the external diameter of hollow fibers. The same data were published earlier (1) but with flux values calculated using the internal diameter of hollow fibers.

In an effort to evaluate the effect of powder activated carbon (PAC) on organic removal and on the system performance, the UF membrane was chemically cleaned and then operated at 60 gfd with 15 mg/L of PAC addition to the feed water. Stable performance was noticed during this period ($\approx$ 500 hours) with minimal fouling of the membrane. Due to problems experienced with the PAC dosing system, PAC was not utilized during the subsequent filtration cycles. At the end of the PAC experiment, the membrane was chemically cleaned and operated at 80 gfd. Results confirmed the accelerated fouling rate, as experienced earlier. Following this flux experiment, the membrane was cleaned more rigorously using warm cleaning solutions, resulting in improved recovery of TMP. The last two experiments were performed at flux values of 60 and 70 gfd and the backwash frequency was increased from 30-minutes to 60-minutes. Overall, it appeared that the optimal condition of the membrane operation occurred at a flux of 70 gfd and a backwash frequency of 60 minutes, corresponding to a feed water recovery of about 88 percent.

3. Pall MF

Pilot testing was carried out for approximately 3,000 hours at flux values of 50 gfd, 70 gfd, 80 gfd, and 86 gfd and a backwash frequency of 60 minutes (Figure 3). The water recovery of the membrane system under this condition ranged from 96 to 97 percent. One unique advantage of this system was its ability to operate at feed pressures as high as 60 psi. In areas with available hydraulic heads, this feature may eliminate the need for feed water pump stations.
At the beginning of the pilot testing, the system was operated at 50 gfd with and a TMP of about 5-psi. A minimal rate of fouling was noticed during the first 500 hours of operation, as evident from the TMP profile (Figure 3). Towards the end of this period, the membrane was chemically cleaned and the flux was increased to 70 gfd. As expected, a higher rate of fouling was experienced first, after which, the TMP stabilized reached a steady state. After approximately 1,000 hours of operation, the membrane was chemically cleaned and the flux was increased to 86 gfd. At this flux, a rapid rate of fouling was experienced in less than 200 hours into the pilot testing. After chemical cleaning, the flux was reduced to 80 gfd after which, a relatively lower rate of fouling was experienced. During this period, the length of the filtration cycle was improved to approximately 600 hours.

Following this experiment, the membrane was chemically cleaned and operated at lower flux values of 70 gfd and 52 gfd. However, higher rate of fouling was experienced during these experiments, requiring additional chemical cleanings after only 200 to 400 hours of operation. The manufacturer attributed the quick fouling of the membrane to the precipitation of iron and other metal oxides on the membrane. Towards the end of this experiment, a citric acid wash was performed on the membrane, which recovered TMP to its original value. Overall, it appeared that the system was able to operate reliably at flux ranges of 50–70 gfd feed pressure of as high as 60 psi. The recovery of water under this range of membrane flux was 96 to 97 percent, provided if citric acid is periodically used to clean the membrane through typical backwash process and/or chemical cleaning events.

4. ZENON UF

Pilot testing of the ZENON UF system was carried out simultaneously with the Pall MF system for approximately 3,000 hours at flux values of 50 gfd, 60 gfd, 82 gfd, and 90 gfd (Figure 4). The system was backwashed at 15-minute intervals, which resulted in feed water recovery of 94 to 96 percent depending on the flux examined. At the beginning of the experiment, the pilot unit was operated at 60 gfd and a vacuum pressure of 3 to 4 psi. A minimal rate of fouling was noticed during the first 500 hours of operation as evident from the TMP (i.e., vacuum pressure) profile (Figure 4). At the end of this experiment, the membrane was chemically cleaned and the flux was increased to 82 gfd, which resulted in higher rate of fouling as expected. After about 1,100 hours into the operation, the membrane was chemically cleaned and the flux was increased to 90 gfd. Due to ineffective previous chemical cleaning and increase in the flow throughput, the initial vacuum pressure at this flux reached the maximum operating limit of the membrane (9-psi). Hence, the system did not operate reliably during this period and several shut downs were experienced.

During the remaining duration of the study, the pilot unit was operated at a reduced flux of 50 gfd. The first filtration cycle lasted about 500 hours (Figure 4). During the second cycle, the aeration of the system (via the air blower) was switched from continuous to intermittent. This change resulted in a higher rate of fouling. Hence, during the last two cycles, the aeration was switched back to continuous mode. Results showed that at 50-gfd flux, the system might require chemical cleaning every 400 to 500 hours.

Removal of Contaminants

1. Particulate Removal

The product water turbidity of all membrane systems was < 0.1 ntu, regardless of the membrane flux. The feed water turbidity throughout the testing period ranged from 0.3 – 3.5 ntu (Figures 5, 6, 7, and 8).

Significant rejection of all particles, including those in the size range of *Giardia* (5-15 µm) and *Cryptosporidium* (2-5 µm) was noticed for all membrane systems. As an example, the log removal of particles in the size range of 2-5 µm and 5-15 µm versus membrane flux are presented in Figures 9 and 10 for the Pall MF system. As is clear from these figures, 3 to 4 log removals of the particles can be achieved under all flux values tested, which was more or less typical of other membranes tested in this study. Higher log removal of particles could be expected from waters with high concentrations of particles in the feed water. Overall, it can be stated that the rejection of particulates by the membranes was independent of the flux as reported elsewhere (1).

2. Organic Removal

Minimal rejection (i.e., 5 – 15 percent) of TOC, UV 254, and disinfection by-product (DBP) precursors were observed by all MF and UF systems tested in this study. Addition of 3 mg/L of Ferric chloride and 15 mg/L of PAC as pretreatment to the Memcor MF and the Aquasource UF systems, respectively, slightly (i.e., 5 – 10 percent) enhanced the organic removal. Removal of instantaneous DBPs such as trihalomethanes (THMs) was essentially negligible, even with the addition of PAC. Approximately 50–90 percent of the THM precursors were already converted to THMs in the feed due to heavy chlorination of the water and the long contact time provided within the Hollywood Reservoir.

3. Inorganic Removal

As expected, no removal of inorganic constituents (i.e., hardness, alkalinity, silica, and total dissolved solids) was noticed by any of the membrane systems tested. Approximately 80-90 percent removal of iron was observed by the membrane units, possibly due to the aeration of the water by the membrane feed system.

4. Algae Removal

Removal of algae from the feed water was considered important by LADWP due to their presence in the reservoirs and concern over their impact on taste and odor. Monitoring for algae, which predominantly consisted of Hypnomonas sp., showed counts from 275 to 700 ASU during the course of the pilot testing. Results showed the permeate counts of algae and its associate chlorophyll-a below the detection limits (25 ASU and 0.5 ug/L respectively), confirming their complete removal by the membrane systems.

Summary and Conclusions

Four membrane pilot units, currently certified by the California DHS were pilot tested at the Hollywood Reservoir. The objective of the pilot testing was to define the optimum range of operation and to determine their suitability for full-scale applications. The membrane units included US Filter/Memcor MF, Aquasource UF, Pall Microza MF, and ZENON ZeeWeed® UF. The water quality of the Hollywood Reservoir is typically stable throughout the year with relatively low levels of turbidity (≈ 1 ntu) and TOC (< 2 mg/L).

Based on the pilot test results, the US Filter/Memcor MF system demonstrated a stable performance over a flux range of 38 – 48 gfd and the feed water recovery of 94 to 96 percent. For the Aquasource UF system, it appeared that the optimal operating condition occurred at a flux of 70 gfd and a feed water recovery of 88 percent. For the Pall MF, the system demonstrated reliable performance at a flux range of 50 – 70 gfd and a feed water recovery of about 96 percent, provided if citric acid is periodically used for membrane cleaning. For the ZENON ZeeWeed® UF, the system appeared to perform reliability at the beginning of the pilot experiment at 60-gfd flux, feed water recovery of 94 percent, and continuous aeration of the process tank. However, during the latter part of the testing, variable performance of the membrane was noticed. Because of this observation, a firm conclusion can not be made.

The permeate turbidity of all membrane systems was consistently below 0.1 ntu regardless of the operating flux. Significant log removal (i.e., 3 -5 logs) of particles, including those in the size range of *Giardia* and *Cryptosporidium* was achieved by all membrane systems. Minimal removal of TOC, DBPs (i.e., THMs, HAAs) and DBP precursors was observed for both MF and UF systems. Addition of 3 mg/L of ferric chloride and 15 mg/L of powdered activated carbon as a pretreatment to the US Filter/Memcor MF and Aquasource UF, respectively, slightly enhanced the removal of organics.

References

1. Karimi, Ali. A., Vickers, J.C., and Harasick, R.F. (1999). Microfiltration Goes Hollywood: the Los Angeles Experience, Journal AWWA, 91(6) 90-103.

Acknowledgement

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TABLE 1. TYPICAL WATER QUALITY PARAMETERS OF THE HOLLYWOOD RESERVOIR

Parameter	Unit	Average	Minimum	Maximum
Inorganics				
pH		7.9	7.0	8.7
Temperature	°C	17.6	8.8	25.9
Silica	mg/L	18.3	16.0	21.0
Alkalinity- $CaCO_3$	mg/L	92	83	105
Hardness	mg/L	135	61.0	269
Conductivity	µmhos/cm	477	262	815
Phosphate-P	mg/L	0.03	0.02	0.05
Turbidity	NTU	1.4	0.17	3.3
Iron	µg/L	60	36	102
Manganese	µg/L	30	21	47
Copper	µg/L	11	3	23
Free Chlorine Residual	mg/L	0.22	0	3.6
Total Chlorine Residual	mg/L	0.33	0	3.8
Algae	ASU	442	0	8,650
Nitrogen				
Nitrate-N	mg/L	0.9	0.8	1
Organics				
Total Organic Carbon	mg/L	1.7	1.3	2.0

TABLE 2. TYPICAL CHARACTERISTICS OF TESTED MEMBRANES

CHARACTERISITIC	UNITS	MEMCOR MF	PALL	AQUASOURCE	ZENON
Membrane Commercial Designation		Memcor	Microza	Aquasource	ZW-500
Active Membrane Area per Module	ft^2	290	398	76	250
Number of Fibers/Module		11,000	4,800	2,060	~4700
Nominal Membrane Pore size	μm	0.2	0.1	0.01	0.035
Membrane Material/Construction		Polypropylene	PVDF	Cellulose Acetate Derivative	Proprietary Polymer
Membrane Surface Characteristics			Hydrophobic	Slightly Hydrophilic	Hydrophilic
Acceptable Range of Operating Pressures	psi	3 - 18	50 (Max.)	2 - 21	-1 to -12
Acceptable Range of Operating pH		0.5 - 13.5	2-10 (long term) 1-14 (short term)	4 - 8.5	5-9 (cleaning range 2-10.5)
Chlorine/Oxidant Tolerance	ppm	0	5,000 (during cleaning)	1-2 ppm constant or 2000 ppm/year	>1000

Figure 1. TMP and Temperature Profile of Memcor System

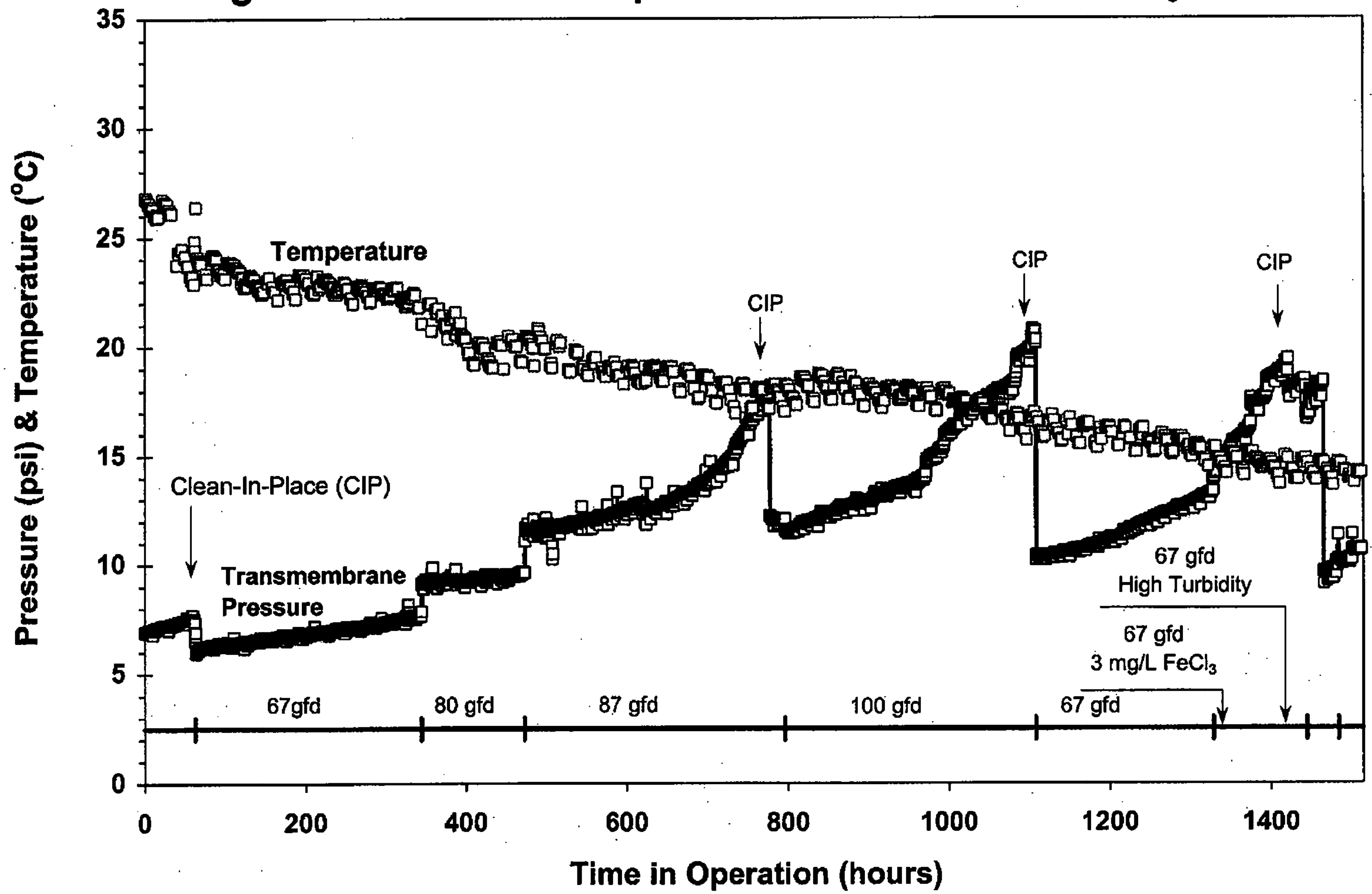


Figure 2. TMP and Temperature Profile of Aquasource System

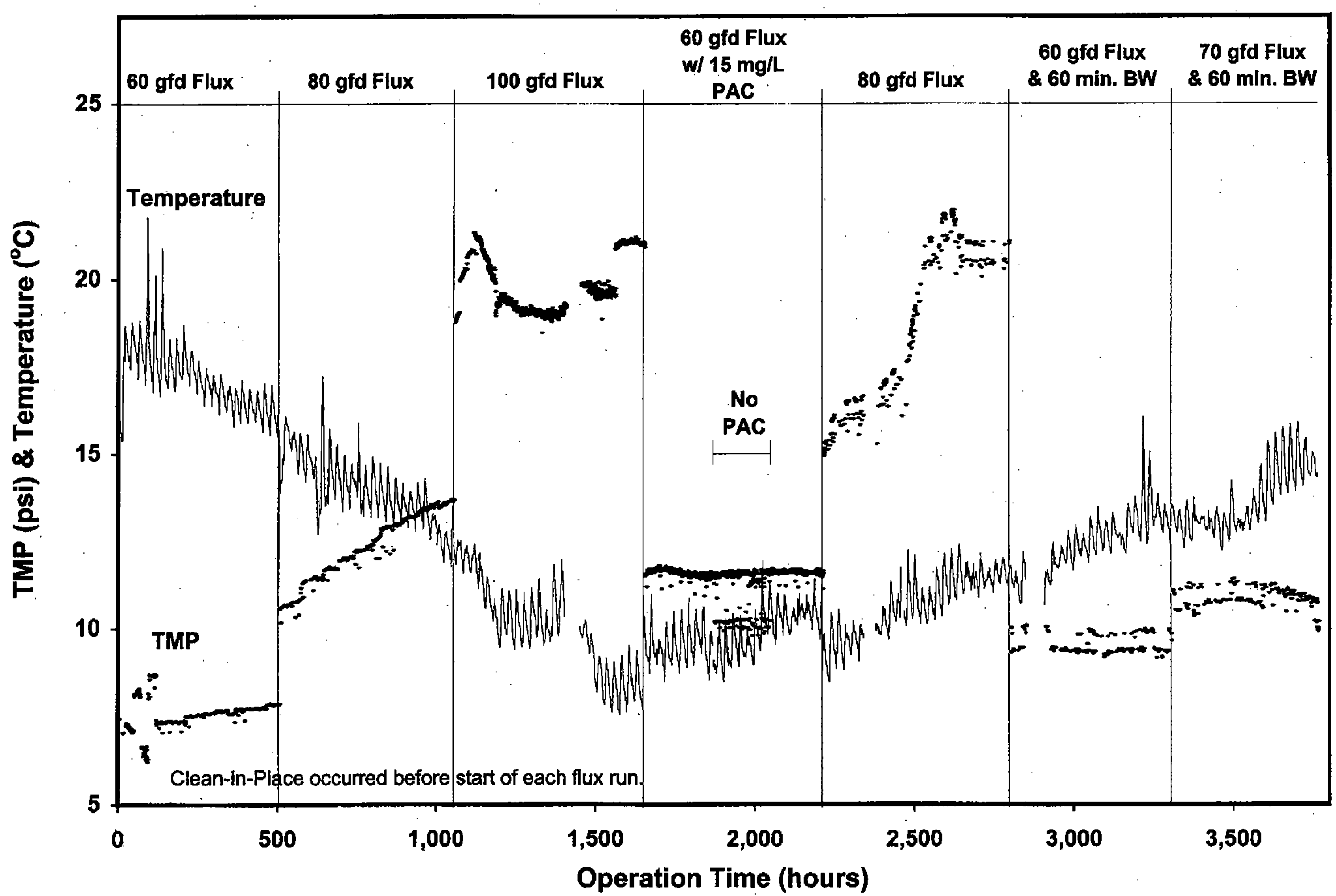
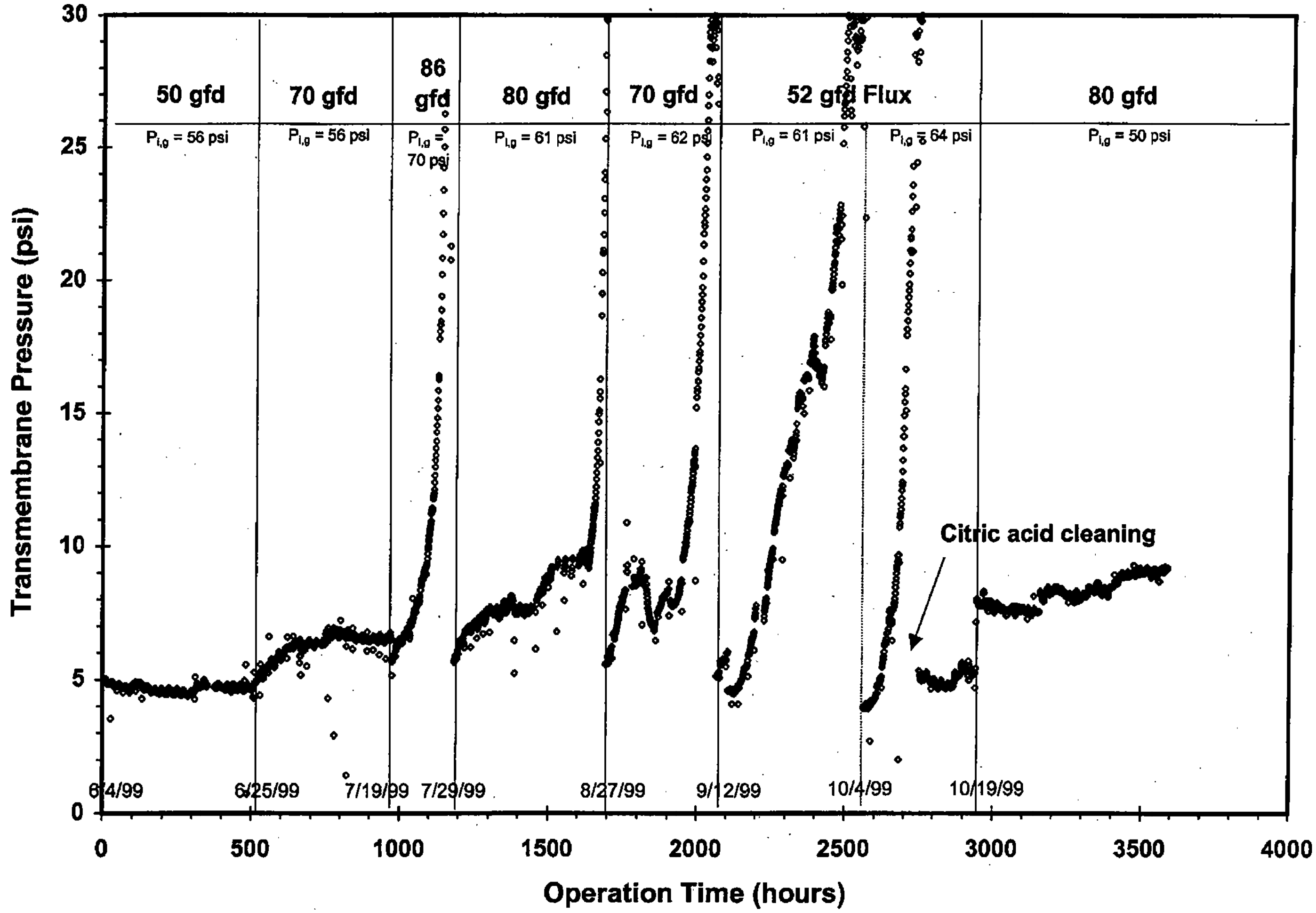
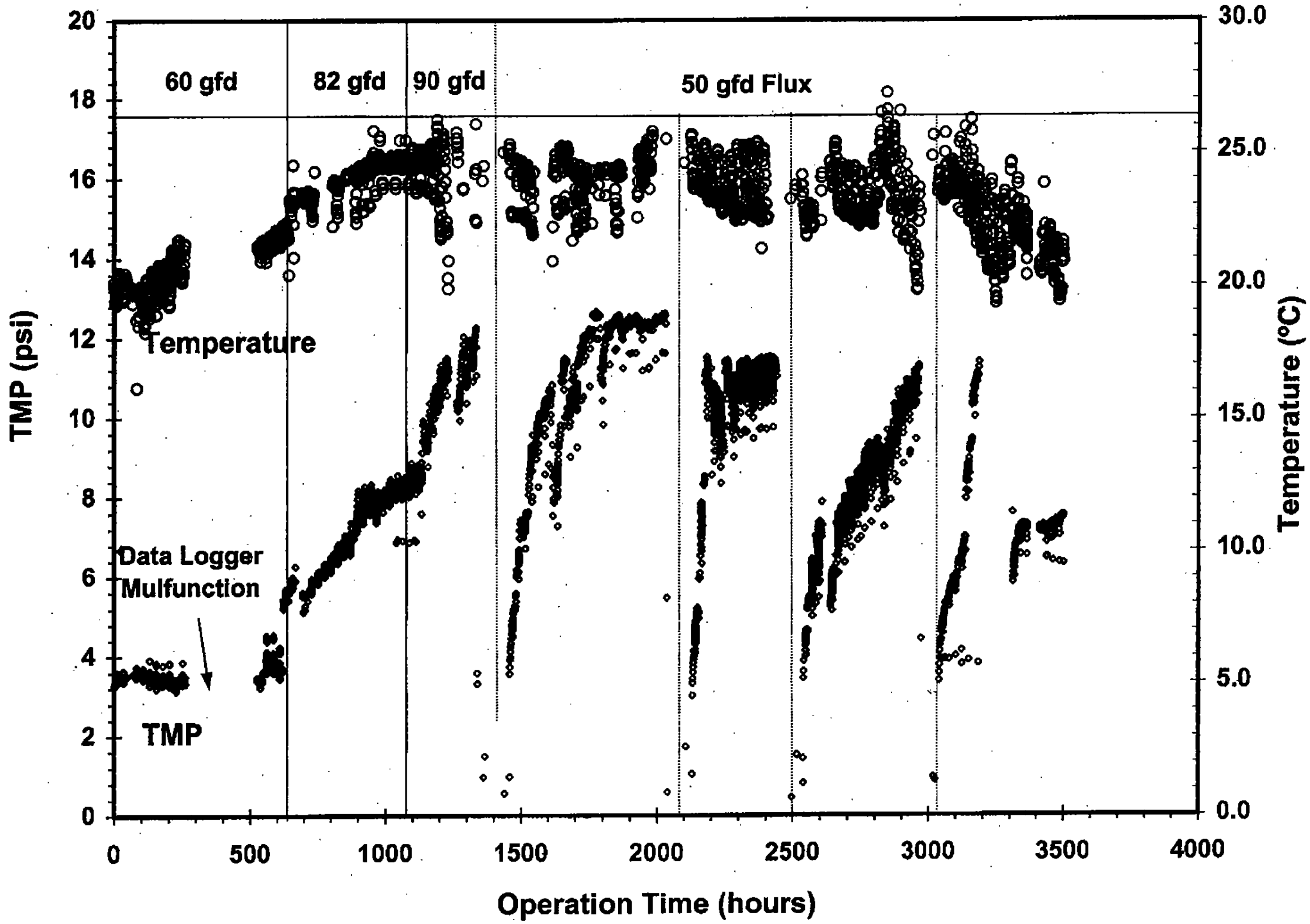


Figure 3. TMP Profile of Pall MF System



*CIP was performed after each tested flux

Figure 4. TMP (Vacuum Pressure) Profile of Zenon UF System



*CIP was performed after each tested flux

Figure 5. Turbidity Profile of Memcor System

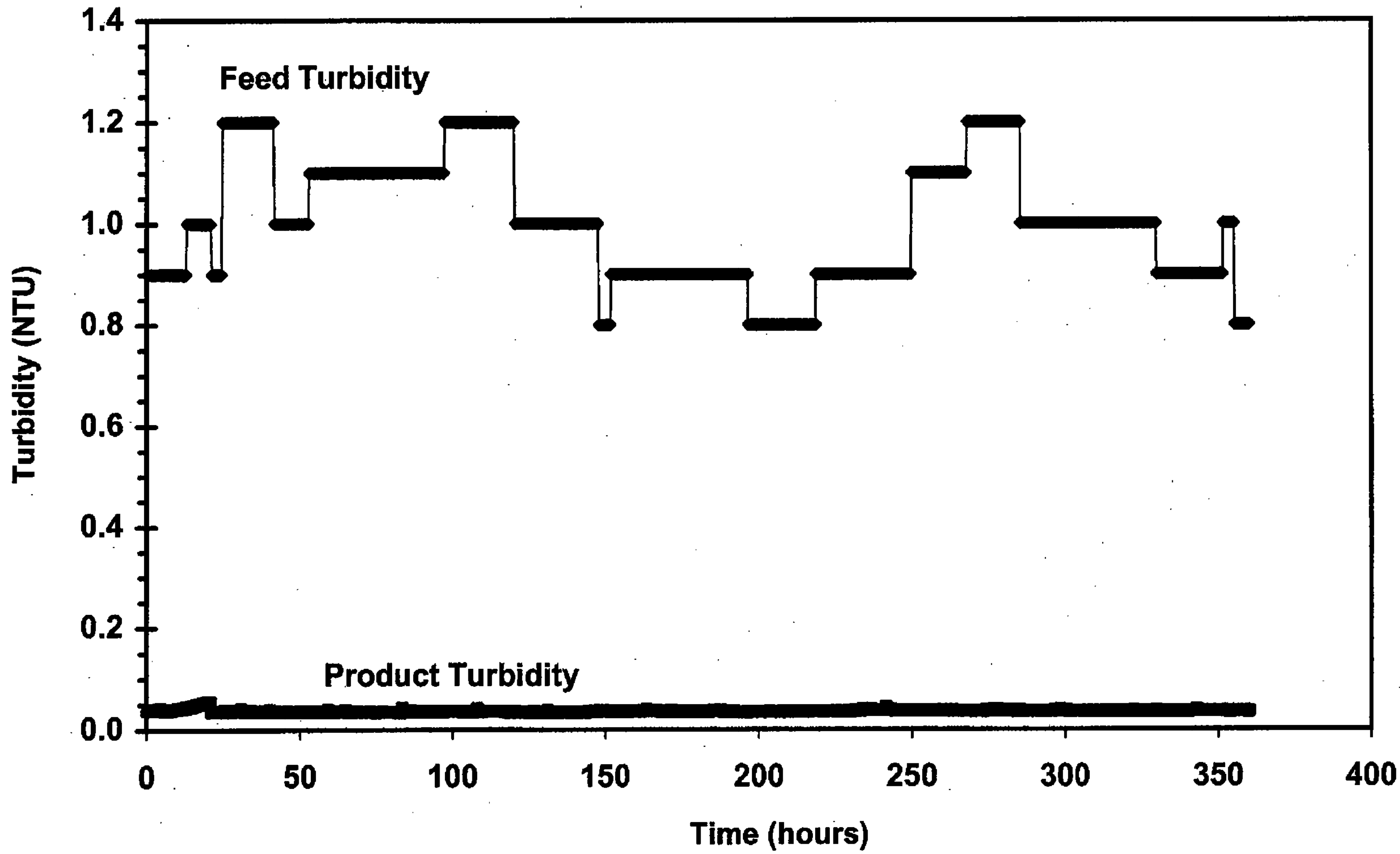


Figure 6. Turbidity Profile of Aquasource System

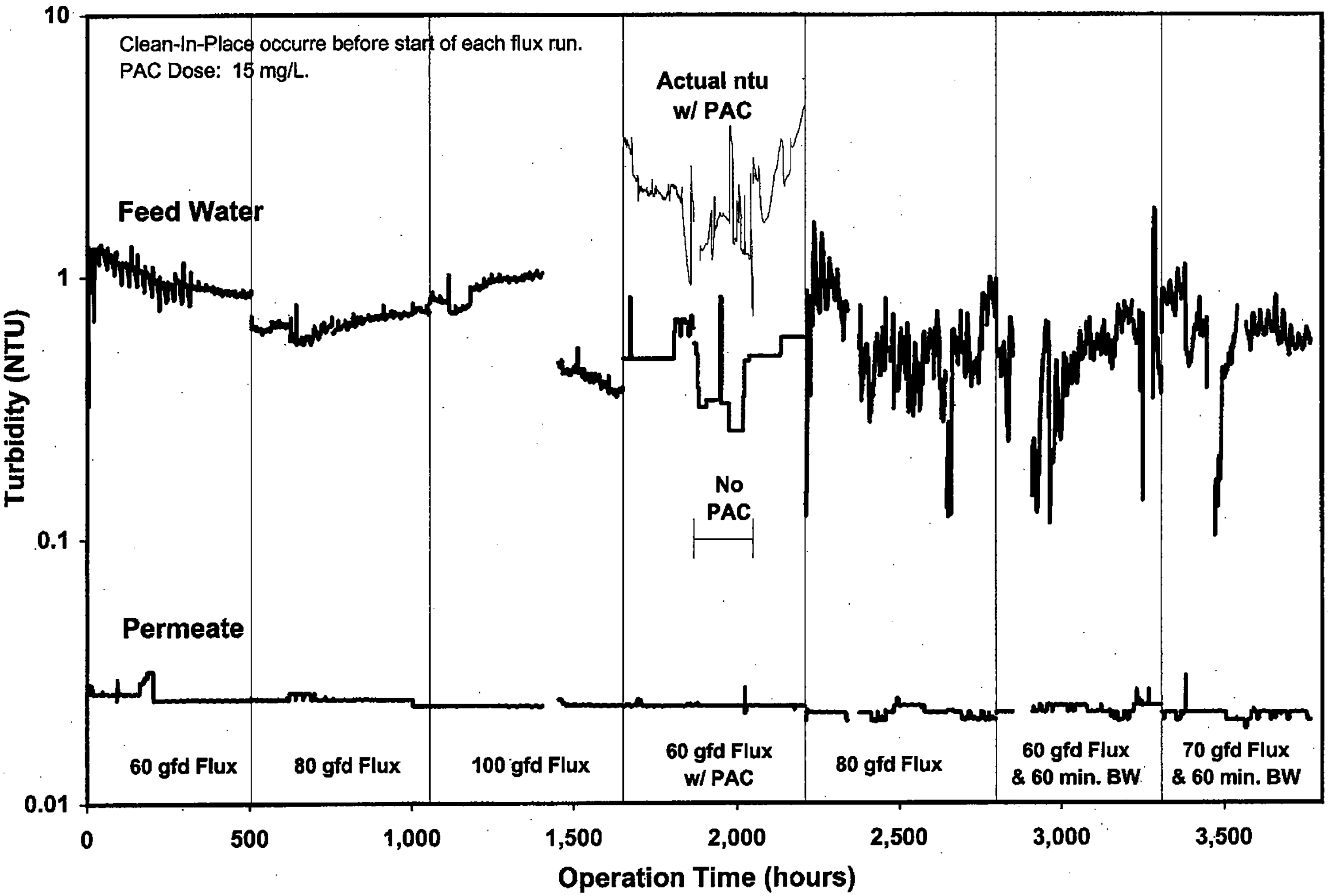
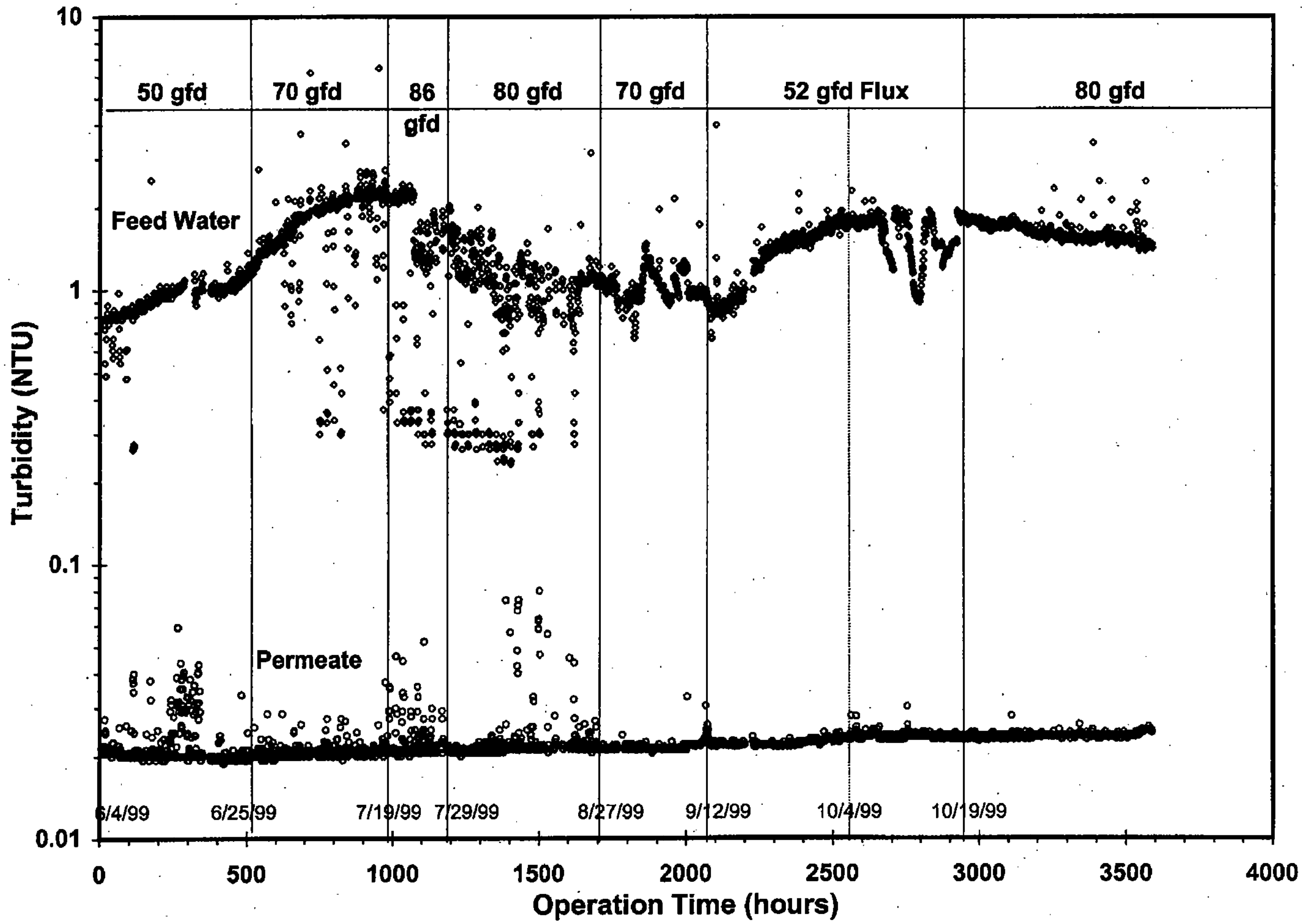
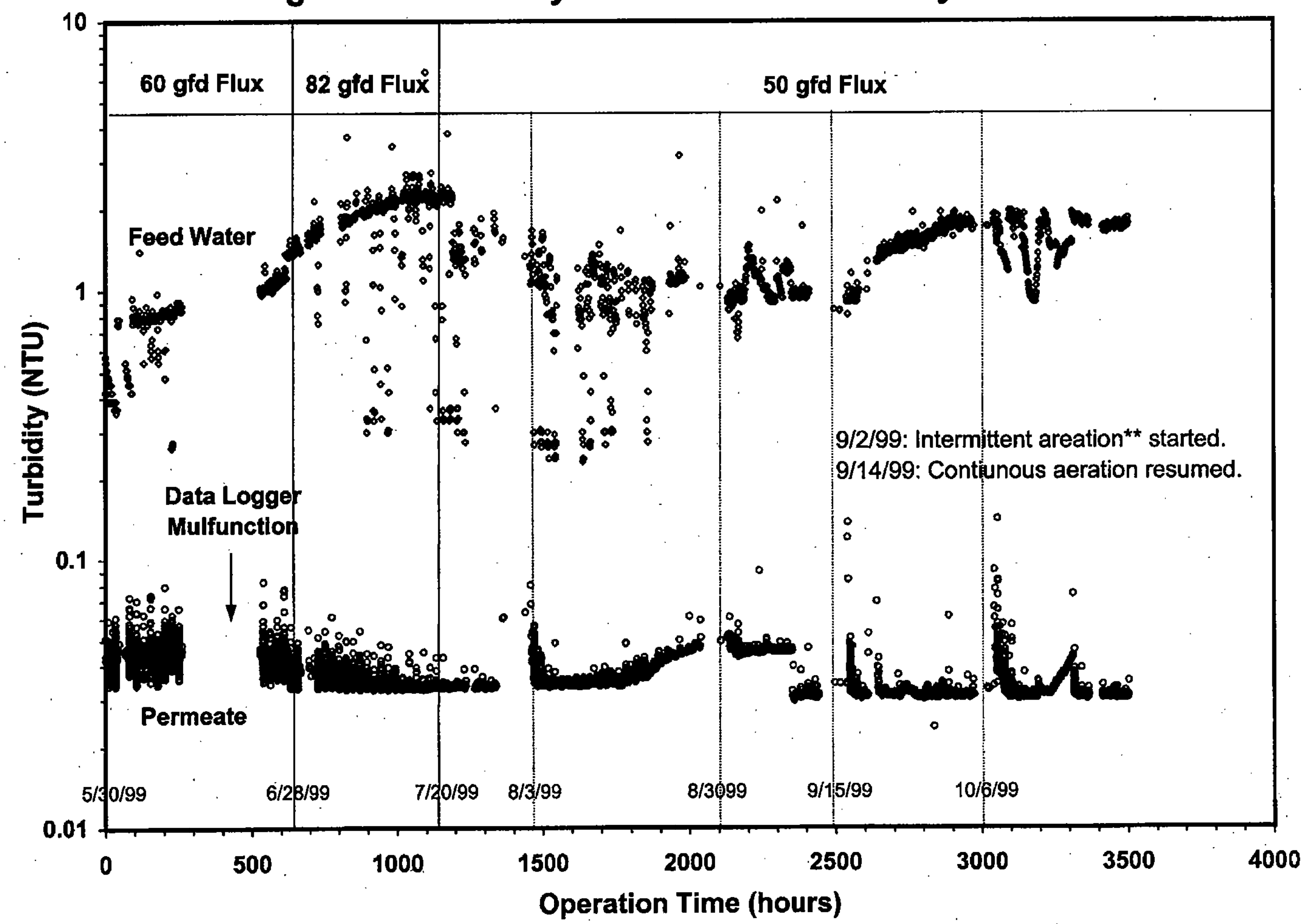


Figure 7. Turbidity Profile of Pall MF System



*CIP was performed after each tested flux

Figure 8. Turbidity Profile of Zenon UF System



*CIP was performed after each tested flux

**Twice during the 15-min filtration cycle (one in the middle of filtration for 15 sec and one during back pulse)

Figure 9. Log Removal of 2-5 Micron Particles vs. Flux (Pall Microza MF)

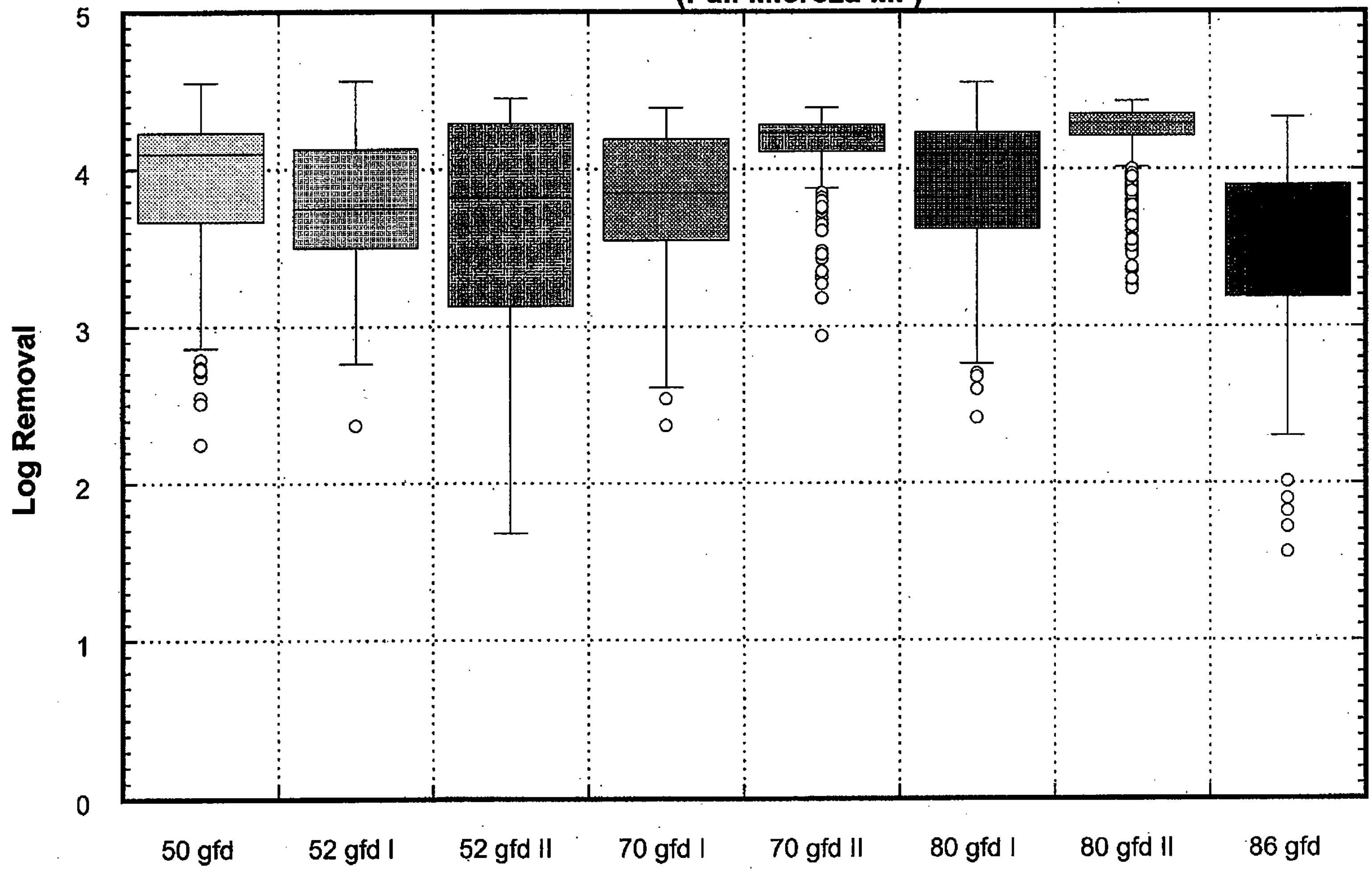


Figure 10. Log Removal of 5-15 Micron Particles vs. Flux
(Pall Microza MF)