MWH
MONTGOMERY WATSON HARZA

Final Report

Assessing the Ability of the Kubota Membrane Bioreactor to Meet Existing Water Reuse Criteria

February 2003

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SECTION 1

Introduction

1.1 INTRODUCTION

As areas around the United States and the world have seen an increased need for the use of reclaimed wastewater this has encouraged the development and implementation of new wastewater reclamation technologies. Membrane bioreactors (MBR) are an example of a wastewater reclamation technology that is currently in use in countries around the world and offers greater promise for increased use in the future.

MBR combines the use of a membrane module and a separate bioreactor. Low pressure membranes, either microfilters (MF) or ultrafilters (UF), are used for the solids separation step. The membrane keeps solids and high-molecular weight compounds in the bioreactor by separating them from the treated water. Sludge concentration in the MBR is controlled by continuous liquid extraction from the bioreactor. As sludge concentration and hydraulic retention time are dissociated in the MBR process, good control of biological processes can be achieved and a high water quality effluent produced. MBR therefore, combines the process elements of secondary, tertiary and advanced wastewater treatment into a single unit operation.

There are two basic configurations of MBR unit processes. They can either be operated "in-series" or "submerged" (Adham, 1998). In the "in-series" configuration, sludge is pumped from the aeration basin to a pressure driven membrane system outside of the bioreactor where the suspended solids are retained and recycled back into the bioreactor. The effluent passes through the membrane. In this configuration, the membranes are regularly backwashed to remove suspended solids build-up and accumulations and are chemically cleaned when operating pressures become too high.

In the "submerged" configuration, a low pressure membrane is submerged in an aeration basin and operated under vacuum. The membrane is agitated by coarse bubble aeration that helps prevent suspended solids accumulation at the membrane surface. Submerged membranes are either regularly backwashed or relaxed and are chemically cleaned when the operating pressures become too high.

1.2 BUREAU OF RECLAMATION STUDY

In October 2001 the City of San Diego and Montgomery Watson Harza were awarded a grant from the Bureau of Reclamation to evaluate Membrane Bioreactor (MBR) technology and its potential application to wastewater reclamation. The project scope includes the evaluation of four leading commercially available MBR systems over a 14-month testing period. The first portion of the study was conducted between April - December 2002 and consisted of pilot testing of two MBR systems. This report includes the results and observations for the study conducted using the Kubota MBR process. An overview of the materials and methods for the pilot-plant study is presented in Section 2 of this report.

During Part 1 of the Kubota MBR testing, the system was operated using raw wastewater from the Point Loma Wastewater treatment plant located in San Diego, CA. During Part 2 testing the feed piping to the pilot was modified for the system to receive advanced primary effluent. During both Part 1 and Part 2 testing the pilot was operated in a nitrification/denitrification mode which utilized a pre-nitrification, nitrification and anoxic zone. The primary objective of the Bureau of Reclamation project was to obtain long-term operational and performance measures for the Kubota MBR process in treating raw wastewater. Secondly, the project was intended to evaluate the feasibility of operating the MBR process using advanced primary treated effluent which contains both ferric chloride and polymer residual. An overview of the results from the Bureau of Reclamation study is provided in Section 3 of this report.

1.3 TITLE 22 APPROVAL

In March 2000, the project team worked with the California Department of Health Services (DHS) to establish criteria of MBR systems for meeting Title 22 approval. Accordingly, a testing protocol was developed which consisted of evaluating long term operational performance and virus rejection. In April 2001 two leading MBR manufactures obtained conditional regulatory approval under specified operating conditions from the DHS (Adham, 2001 a & b). During the current Bureau of Reclamation study, the manufacturer and representatives of the Kubota MBR process expressed interest in obtaining regulatory approval for the use of the their MBR to meet California's Title 22 Water Recycling Criteria. Accordingly, the project team

conducted testing on the Kubota MBR system as established by the California Department of Health Services.

1.4 VIRUS SEEDING EXPERIMENTS

Virus seeding experiments were performed under various fouled conditions (low, medium and high) using both advanced primary effluent and clean water. The results of the virus seeding experiments are presented in Section 4 of this report.

SECTION 2

Materials and Methods

2.1 FEED WATER CHARACTERISTICS

During the main study investigating the performance of the Kubota MBR the system was operated on both raw wastewater and advanced primary effluent from the Point Loma Wastewater Treatment Plant (PLWTP) located in San Diego, CA. Table 2-1 and Table 2-2 show water quality data collected from these two sources during the study, respectively. The primary treatment process of PLWTP includes influent screening, grit removal, coagulation and sedimentation. Prior to the coagulation process, ferric chloride is dosed at a rate of 25 mg/L. In addition, 0.1 mg/L of a heavy anionic polymer is used during the coagulation process to enhance destabilization of colloidal matter. The virus seeding experiments were conducted using advanced primary effluent and clean water. The clean water was obtained on-site and is typically used for industrial purposes throughout the PLWTP. As shown in Table 2-3, representative water quality data for this clean water source meets the primary and secondary drinking water standards.

Table 2-1 Raw Wastewater quality during Bureau of Reclamation pilot study

	No. of Analyses	Units	Median	Maximum	Minimum
Ammonia-N	15	mg/L-N	27.4	30.2	22.4
Nitrite/Nitrate-N	18	mg/L-N	0.552	0.92	0.357
Nitrite-N	17	mg/L-N	0.005	0.05	ND
O-Phosphate-P	19	mg/L-P	0.724	1.53	0.063
BOD_5	15	mg/L	231	264	105
COD	12	mg/L	528	783	308
TOC	12	mg/L	40	56	15
Total Suspended Solids	113	mg/L	250	400	174
Calcium Hardness	6	mg/L-$CaCo_3$	248	270	160
Magnesium Hardness	6	mg/L-$CaCo_3$	292	315	192
Total Hardness	6	mg/L-$CaCo_3$	546.5	578	352

ND = non detect.

Table 2-2 Advanced Primary Effluent quality during Bureau of Reclamation pilot study

	No. of Analyses	Units	Median	Maximum	Minimum
Ammonia-N	7	mg/L-N	26.6	29.4	24.1
Nitrite/Nitrate-N	5	mg/L-N	0.789	1.13	0.594
Nitrite-N	5	mg/L-N	0.026	0.162	ND
O-Phosphate-P	5	mg/L-P	0.455	2.24	0.421
BOD_5	8	mg/L	96.9	110	57.8
COD	6	mg/L	216	245	147
TOC	1	mg/L	44	44	44
Total Suspended Solids	44	mg/L	41	204	28.4
Calcium Hardness	6	mg/L-$CaCo_3$	186	202	181
Magnesium Hardness	6	mg/L-$CaCo_3$	207.5	235	193
Total Hardness	6	mg/L-$CaCo_3$	392.5	437	377

ND = non detect.

Table 2-3 Representative water quality for Clean Water

	Units	MCL	Average	Range
Primary Standards				
Fluoride	ppm	2	0.267	0.241-0.311
Total Trihalomehtanes	ppb	100	58.5	40.5-95.5
Uranium	pCi/L	20	<1.4	ND-1.8
THM4	ppb	100	43.6	25.5-63.9
Disinfectant Residual	ppm	NA	2.6	1.2-3.9
Boron	ppb	1000	107	94-162
Perchlorate	ppb	18	ND	ND
Vanadium	ppb	50	ND	ND
Total Coliform	-	<5% PTT	0.42%P	A-P
Turbidity	NTU	TT	0.11	0.07-0.25
Secondary Standards				
Sodium	ppm	n/a	80	69.8-88.2
Chloride	ppm	500	73.6	65.2-85.9
Sulfate	ppm	500	150	120-176
Total Hardness	ppm	NA	228	204-251
Color	CU	15	<2	ND-3
Odour-Threshold	OU	3	<1	ND-1
Corrositivity	-	-	0.590	0.16-1.08
Total Dissolved Solids	ppm	1000	487	434-540
Specific Conductance	umhos	1600	847	782-909

Data provided by the Alvarado Water Treatment Plant, San Diego CA. Samples taken in 2001.
A = absent; P = present; TT = treatment process intended to reduce the level of a contaminant in drinking water; ND = non detect; NA = not applicable.

2.2 DESCRIPTION OF PILOT PLANT

The Kubota MBR Pilot system is comprised of a feed holding tank, auxiliary equipment skid, control panel, and a process tank. The process tank is the main component of the system and contains three distinct zones: denitrification/anoxic, pre-nitrification, and nitrification. The footprint of the process tank is 96 inches (244 cm) long by 84 inches (213 cm) wide by 185 inches (470 cm) high. A photograph of the process tank is provided in Figure 2-1.

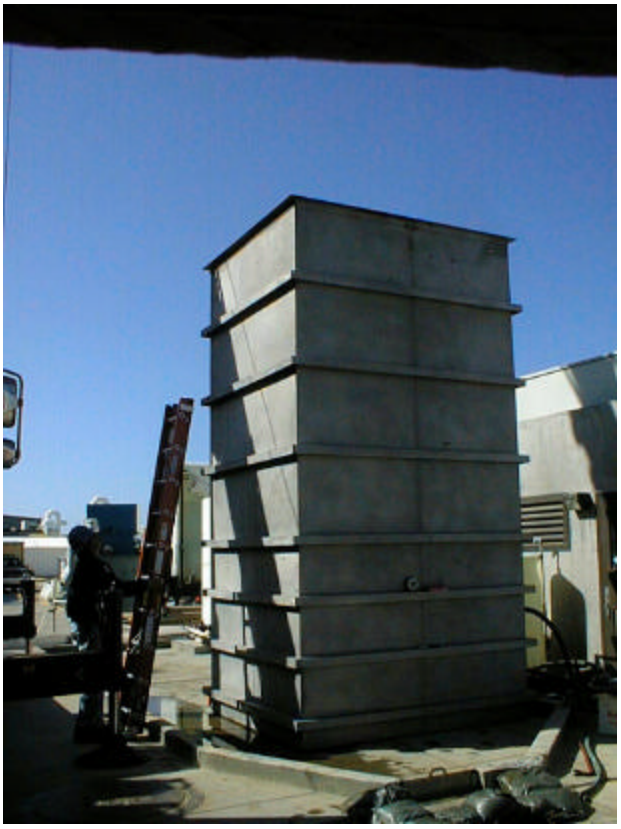


Figure 2-1 Photograph of the Kubota MBR Pilot Process Tank

A general process flow schematic of the Kubota MBR pilot system is provided in Figure 2-2. As shown, the operating volume of each zone within the process tank is as follows: denitrification/anoxic zone = 1,695-gal (6.42 m^3); pre-nitrification zone = 638-gal (2.41 m^3); nitrification zone = 2,664-gal (10.09 m^3). Feed water passes through a 3.2 mm pre-screen before entering the feed holding tank. Next, the feed water is pumped from the feed holding tank to the denitrification zone of the process tank using a submerged pump with a programmable logic controller (PLC). Water is then pumped to the pre-nitrification zone where it is aerated using a fine bubble air diffuser. Mixed liquor then flows by gravity to the nitrification zone where filtration occurs. As shown in Figure 2-2, constant coarse bubble aeration is provided in the nitrification zone to minimize fouling. The aeration generates a upward sludge crossflow over the membrane surface of approximately 0.5 m/s. Lastly, mixed liquor overflows back to the denitrification zone at a rate which is approximately 4 times the permeate flow rate.

As shown in Figure 2-2, the nitrification zone contains an upper and lower membrane cassette. A photograph of the membrane cassette being lowered into the process tank is provided in Figure 2-3. Each cassette contains 100 individual Type 510 membrane sheets to provide a total membrane area of 1,721 ft^2 (160 m^2). The use of flat sheet membranes to separate activated sludge into solid and liquid is a unique feature of the Kubota MBR system. Specifications of the Kubota Type 510 flat sheet membrane are provided in Table 2-4. The system is also designed to use hydrostatic pressure during filtration, which reduces the power consumption.

During pilot testing, the Kubota membrane was operated at a flux = 15 gfd (25 L/h-m^2) and a constant coarse bubble airflow = 55 scfm (1.6 m^3/min). The membrane was operated using a filtration cycle of 9 minutes followed by a 1 minute relaxation period. During relaxation filtration stopped but the coarse bubble aeration continued. Nitrified mixed liquor was circulated at approximately 80 gpm.

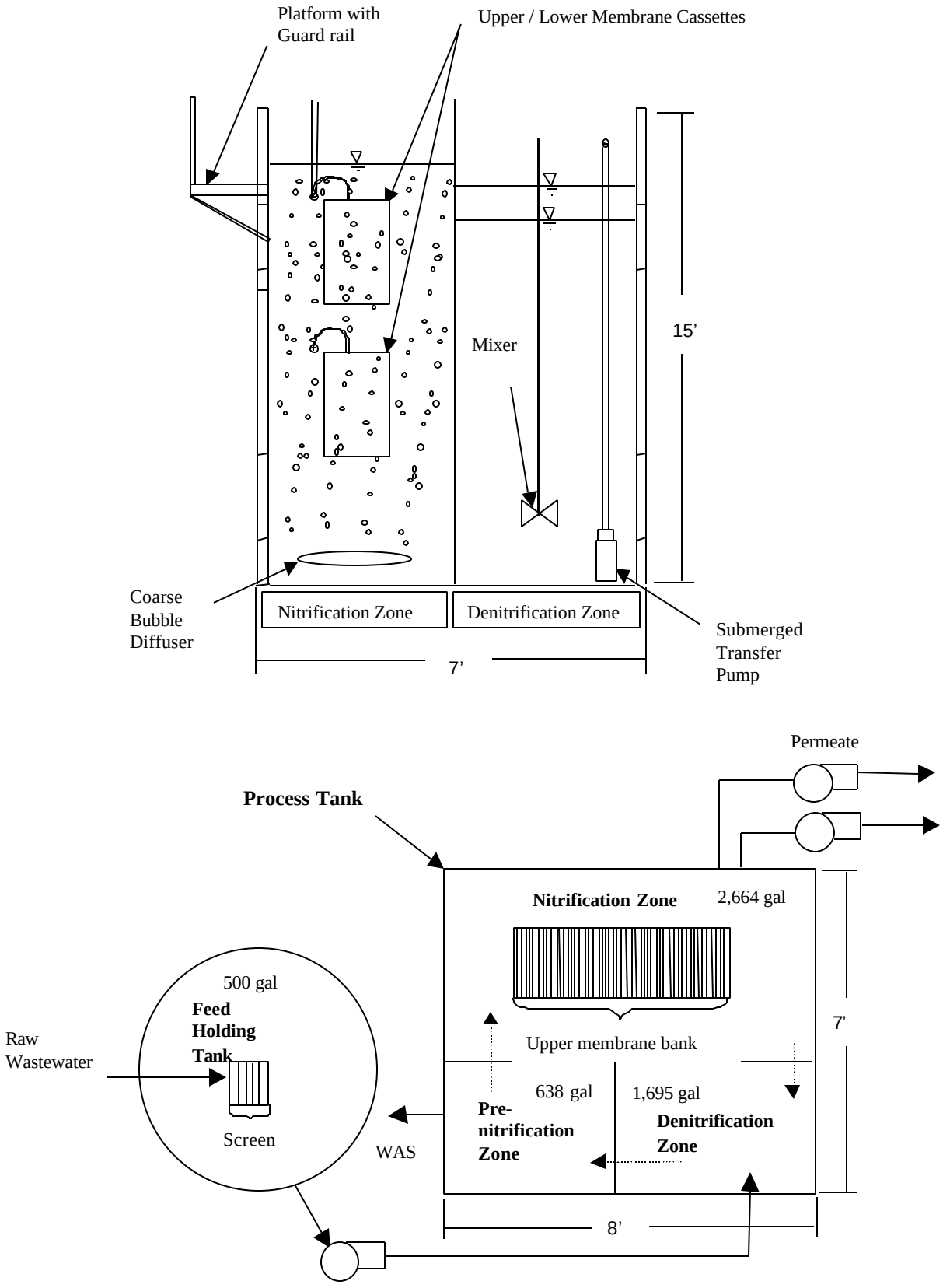


Figure 2-2 Kubota MBR side view (top) and plan view (bottom)

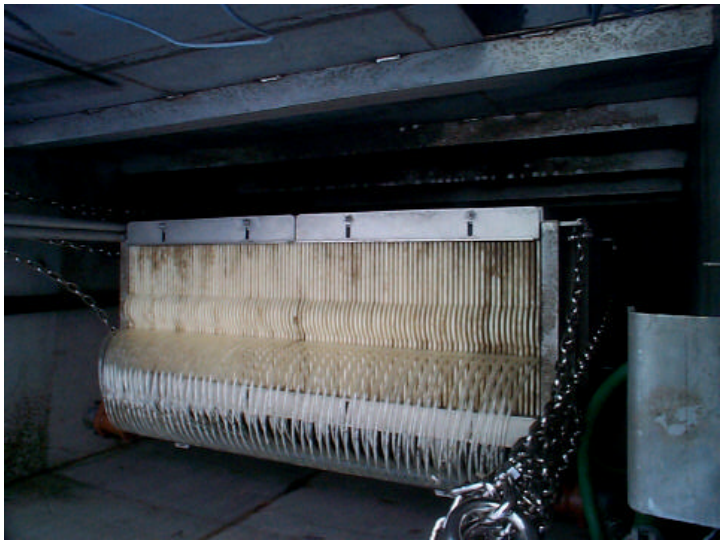


Figure 2-3 Photograph of the Kubota Type 510 Membrane Cassette

Table 2-4 Specifications for the Kubota Type 510 Membrane

	Units	Value
Membrane Sheet Size (LxWxH)	mm	490X6X1000
Number of Sheets per membrane cassette	---	100
*Active Membrane Area	ft^2 (m^2)	1721 (160)
Flow Direction	---	outside - in
Nominal Membrane Pore Size	micron	0.4
Membrane Material / Construction	---	chlorinated polyethylene, flat sheet
Recommended Design Flux	gfd (L/h-m^2)	14.7 (24.9)
Approval Study Test Flux	gfd (L/h-m^2)	20 (33.9)
Standard Testing pH range	---	5.8 - 8.6
Standard Testing Temperature range	degC	>17
Vacuum Pressure for System	psi (bar)	<3 (<0.2)

*Based on model EK200 unit which contains two membrane cassettes (200 membranes sheets).

2.3 CALCULATION OF OPERATING PARAMETERS

2.2.1 Flux Calculation

The flux of the MBR membranes can be calculated as follows:

$$J = \frac{Q_p \times 1440}{A} \qquad (1)$$

Where,

J = Membrane flux (gfd)
A = Total membrane surface area (ft^2)

2.2.2 Temperature Correction

Low-pressure membrane fluxes are normally adjusted to a temperature of 20°C using:

$$J\,@\,20°C = J \times e^{-0.0239(T-20)} \quad (2)$$

Where,

T = Feed water temperature (°C)

2.2.3 Specific Flux

The specific flux is the relationship between flux and the net operating pressure as follows:

$$J_{SP} = \frac{J}{P_{Net}} \quad (3)$$

Where,

J_{SP} = Specific flux (gfd/psi)

P_{Net} = net applied operating pressure (psi)

The temperature-corrected specific flux can be calculated using the temperature corrected flux (equation 2).

2.2.4 Log Removal

The log removal of virus was calculated as follows:

$$Log\ Removal = Log\ (c_f) - Log\ (c_p) \quad (4)$$

Where,

c_f = virus concentration in the feed (PFU/100 mL)
c_p = virus concentration in the permeate (PFU/100 mL)

SECTION 3

Summary of Results from the Bureau of Reclamation Project "Optimization of Various Membrane Bioreactors (MBR) for Water Reclamation"

3.1 BACKGROUND

During Part 1 of the testing, the pilot plant was operated in a nitrification/denitrification mode using raw wastewater. During Part 2, the pilot plant was also operated in a nitrification/denitrification mode; however, the feed water was changed to advanced primary effluent. Overall the Kubota MBR demonstrated minimal fouling throughout both testing periods, producing consistent effluent turbidity values less than 0.1 NTU, BOD_5 <2 mg/L, and up to 6-log removal of total coliforms.

3.2 SUMMARY OF RESULTS

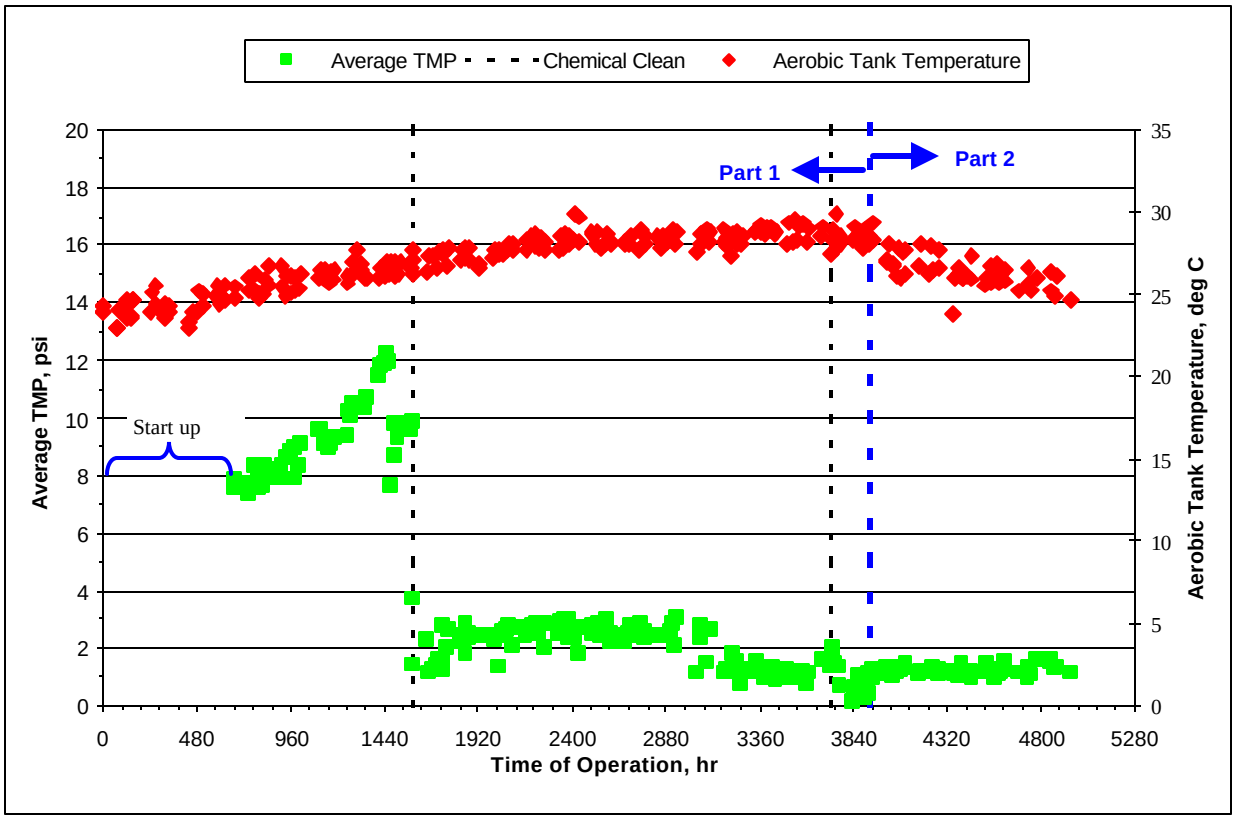
3.2.1 Membrane Performance

Figures 3-1 presents the (a) average transmembrane pressure (TMP) and (b) flux data of the Kubota MBR system during Part 1 and Part 2 testing. The target average membrane flux during both testing periods was 15 gfd (25 L/m^2h). Note the average TMP described in this report is the average driving pressure required to filter water through the upper and lower membrane banks at the given flow rate plus piping resistance. The TMP of each membrane bank was calculated by subtracting the dynamic pressure measured during filtration from the static head in the membrane tank.

As shown in Figure 3-1, the start up period of the Kubota MBR system was performed during the initial 676 hours of operation. Proceeding this period, the Kubota Type 510 membrane fouled over the next 785 hours of operation during which time the TMP increased from 7.3 psi (0.51 bar) to 12.3 psi (0.85 bar). The membranes were then cleaned using sodium hypochlorite and oxalic acid. The chemical cleaning reduced the average TMP from 12.3 psi (0.85 bar) to 1.4 psi (0.10 bar). Observation of the membrane sheets during the cleaning indicated the fouling might

have resulted from ferric hydroxide precipitation. As previously mentioned, ferric chloride is added as part of the grit removal process of the PLWTP at a dose of 25 mg/L. In addition, the manufacturer suggested a potential cause for the high TMP was that the pilot unit was originally piped with 20 mm diameter permeate hose which may have constricted the permeate flow and increased piping resistance. Accordingly, the manufacturer modified the pilot with standard 40 mm diameter permeate piping after the fouling occurrence. As shown in Figure 3-1, the average TMP remained constant at an approximate value of 2.5 psi (0.17 bar) for the remainder of Part 1 testing. The TMP was reduced to 1.5 psi (0.10 bar) towards the end of Part 1, apparently due to the increase of the water temperature. Overall, the Type 510 Kubota membrane demonstrated stable performance at 15 gfd for more than 2,000 (83 days) hours of operation during Part 1 testing without chemical cleaning.

As indicated in Figure 3-1, the membranes were cleaned again at time of operation = 3,724 hours in order to prepare for Part 2 testing. Accordingly, the system was then operated for a short time on raw wastewater during which time hydraulic connections were made to allow the system to operate on advanced primary effluent. As shown during Part 2 testing, the system operated for over 1,000 hours (42 days) with a steady TMP of approximately 1.5 psi (0.10 bar) during which time no chemical cleaning was performed.



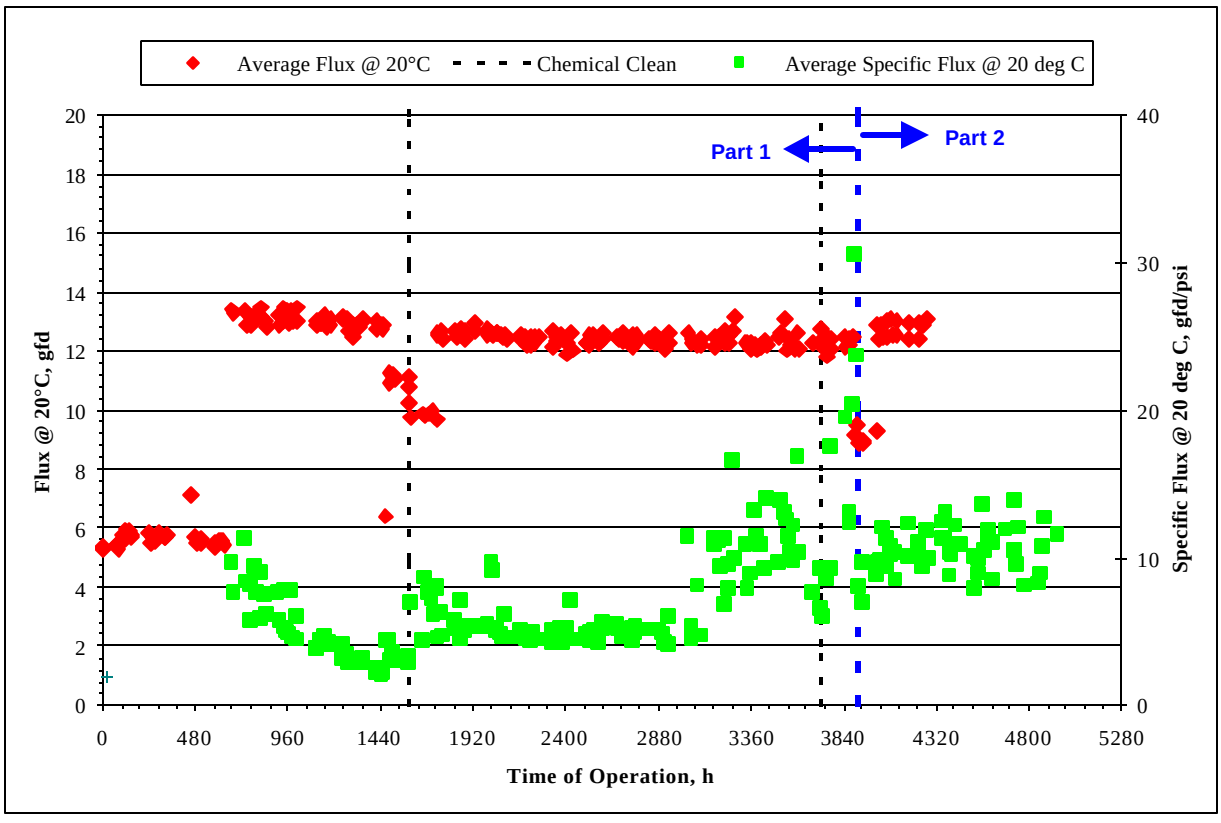


Figure 3-1 Membrane Performance by the Kubota MBR

3.2.2 Dissolved Oxygen

Concentrations of dissolved oxygen (DO) measured during testing of the Kubota MBR are presented in Figure 3-2. As shown, following the start up period the DO was consistently 2 mg/L. As indicated the aerobic tank was dumped at time of operation = 1679, which resulted in an increase in DO. Once the mixed liquor increased to the operating level the DO returned to approximately 2 mg/L for the remainder of Part 1 testing. As shown, during Part 2 testing the DO was consistently higher and ranged between 3-6 mg/L. The increased DO during this part of testing is due to the decreased solid and organic content of the primary effluent as compared to raw wastewater. For example the median BOD_5 value measured during Part 1 testing was 231 mg/L compared to 97 mg/L during Part 2 testing. In addition the median total suspended solids content during Part 1 was 250 mg/L compared to 41 mg/L during Part 2 testing.

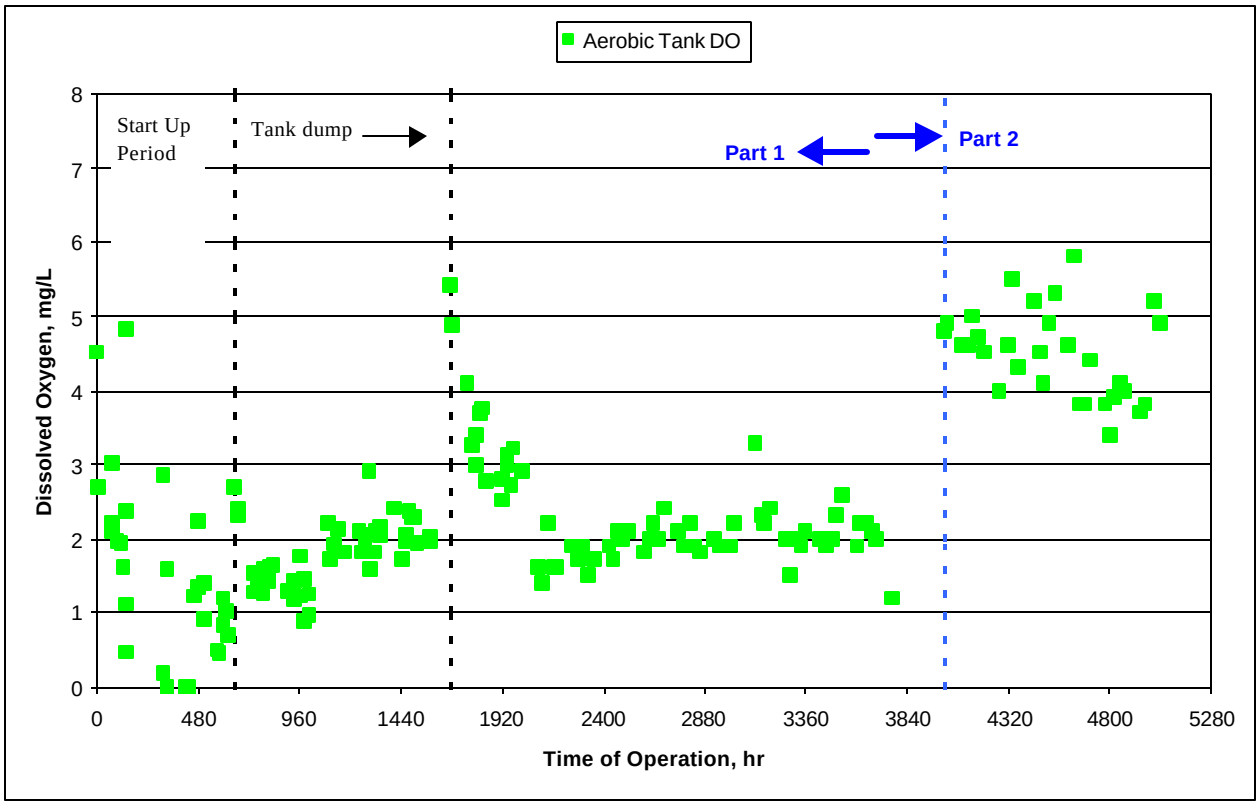


Figure 3-2 Dissolved Oxygen in the Kubota MBR

3.2.3 Organic Removal

The Kubota MBR achieved BOD_5 permeate values below the detection limit of 2 mg/L in 100% of the samples measured throughout the entire pilot testing period. Figure 3-3 shows BOD_5 values measured in the feed wastewater and the Kubota MBR permeate measured during pilot testing. Note the hollow symbols used to represent the BOD_5 of the Kubota MBR permeate indicate the values were below the detection limit of 2 mg/L. As shown, BOD_5 in the feed wastewater ranged from 58 mg/L to 264 mg/L.

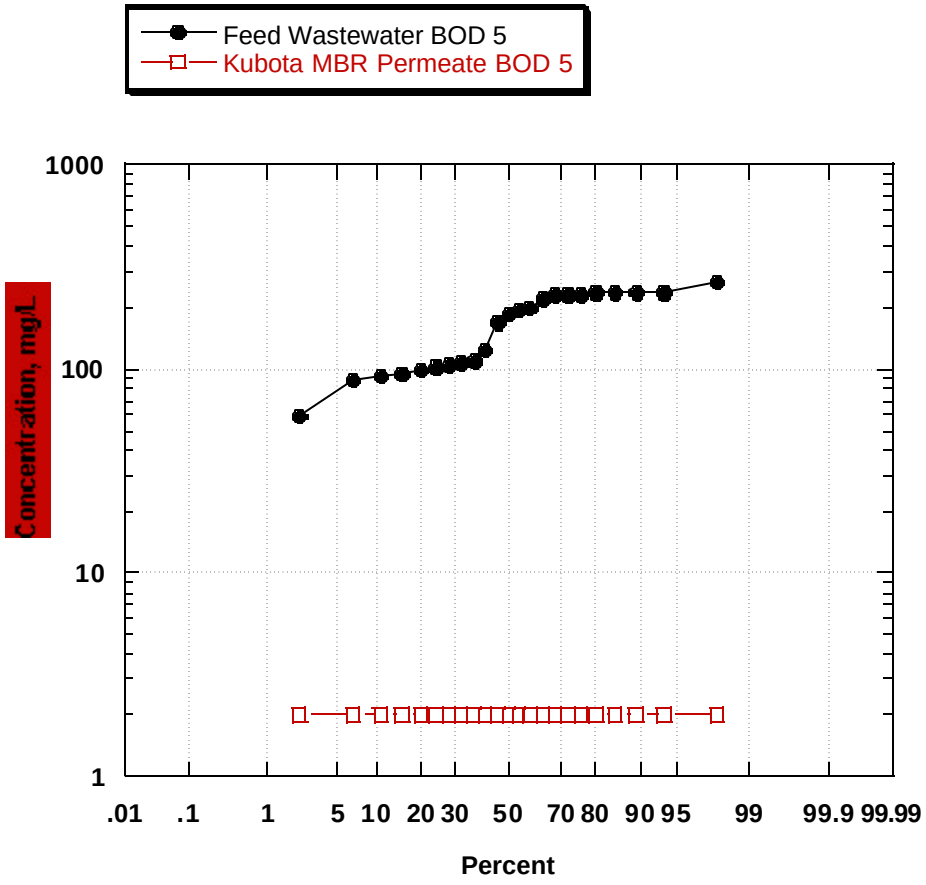


Figure 3-3 Probability plot of BOD_5 removal by the Kubota MBR

3.2.4 Particulate Removal

The Kubota MBR pilot plant produced permeate turbidity values of <0.2 NTU in all of the samples, as shown in Figure 3-4. As shown the feed wastewater turbidity ranged from 36 NTU to 210 NTU.

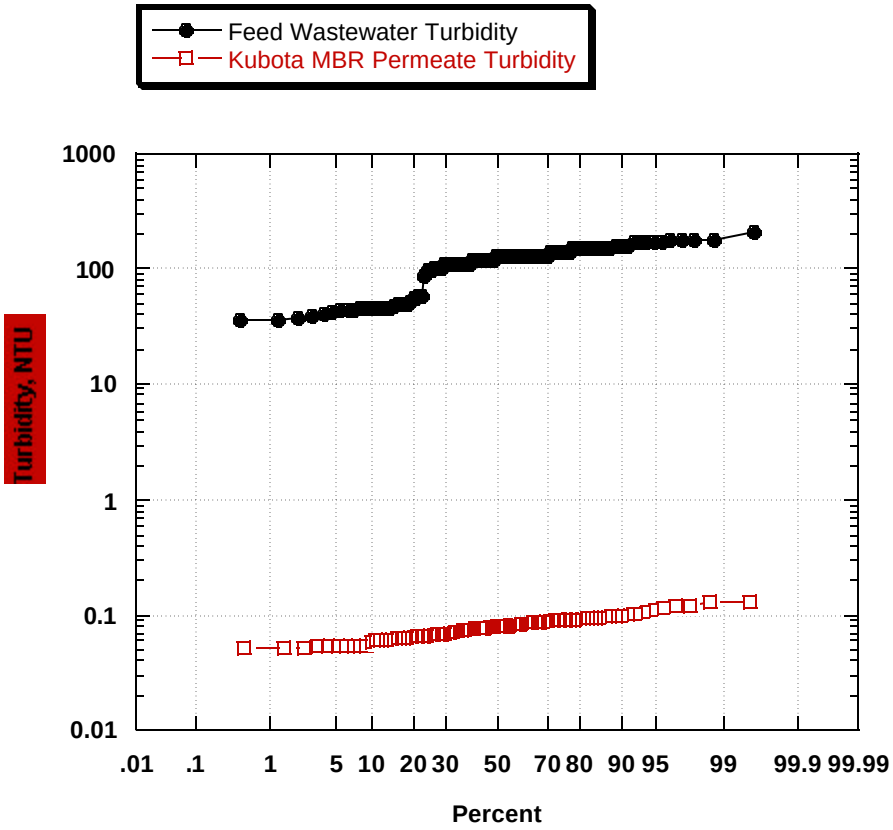


Figure 3-4 Probability plot of turbidity removal by the Kubota MBR

3.2.5 Biological Nutrient Removal

Figure 3-5 shows the Kubota MBR produced permeate with total inorganic nitrogen values of ≤ 4 mg-N/L in 90% of all samples measured during the pilot testing. The ammonia in the feed wastewater ranged from 22.4 mg-N/L to 30.2 mg-N/L. Such results indicate that the Kubota MBR consistently achieved nitrification/denitrification throughout the testing period.

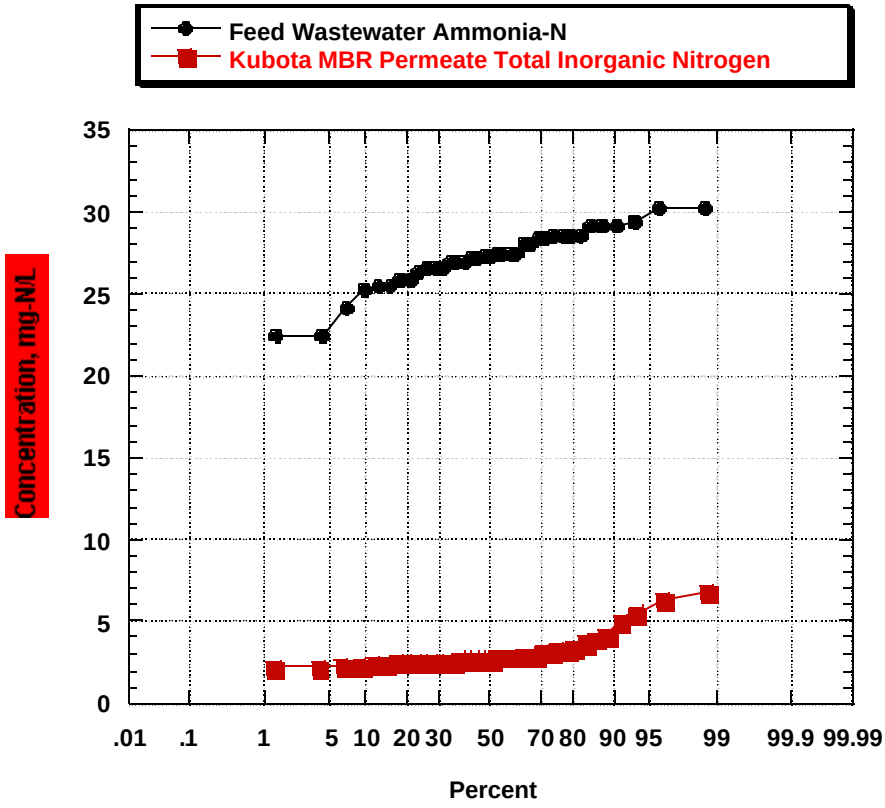


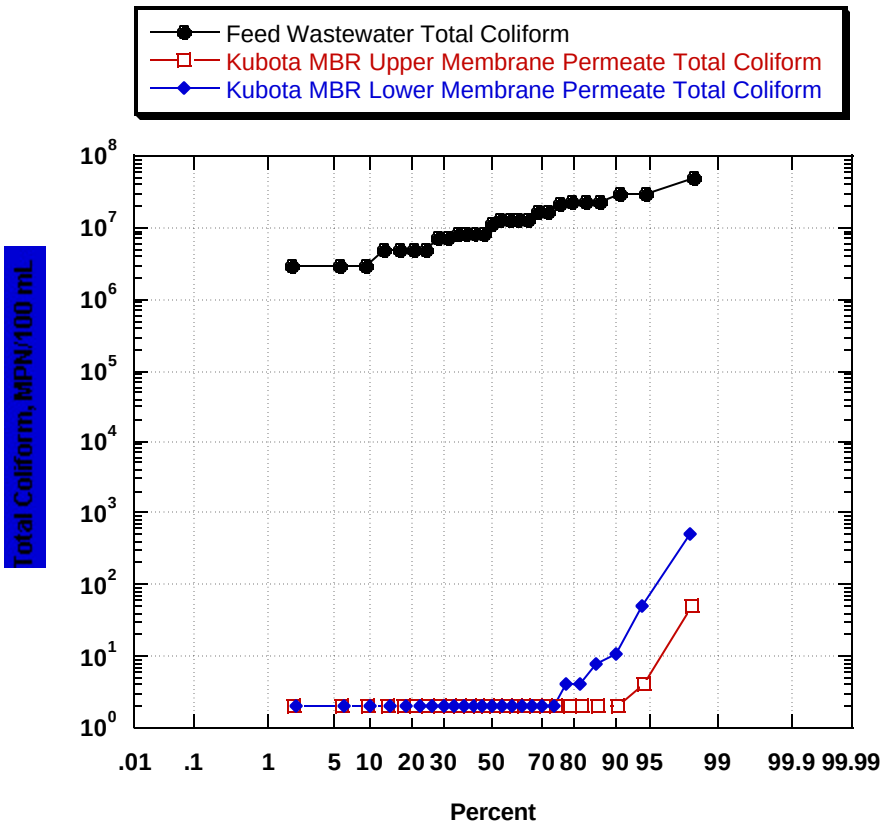
Figure 3-5 Probability plot of the biological nutrient removal by the Kubota MBR

3.2.6 Total Coliform, Fecal Coliform, Total Coliphage

The microbial concentration and log removal of the Kubota MBR system is presented in Figures 3-6, 3-7, and 3-8. As indicated data is shown for both the upper and lower membrane cassettes of the MBR system. The Kubota permeate total coliform was ≤2 MPN/100 mL in 90% of all samples measured from the upper membrane bank and ≤2 MPN/100 mL in 75% of the samples measured from the lower membrane cassette. Total coliform in the feed wastewater ranged from 3×10^6 MPN/100mL to 5×10^7 MPN/100mL. As presented in Figure 3-6, this results in ≥ 6-log removal of total coliform in 95% of all samples collected from the upper membrane cassette and ≥ 5 log removal in 95% of all samples measured from the lower membrane cassette.

The fecal coliform concentration of the Kubota permeate samples were ≤2 MPN/100 mL in all samples measured from the upper membrane bank and ≤2 MPN/100 mL in 85% of the samples measured from the lower membrane bank. Fecal coliform concentrations in the feed wastewater ranged from 8×10^5 MPN/100mL to 1×10^7 MPN/100mL, giving >5-log removal of fecal coliform in all samples as shown in Figure 3-7.

The total coliphage concentration in the Kubota permeate were <3 PFU/100 mL in 50% of all samples while feed wastewater concentrations ranged from 2×10^3 PFU/100mL to 3×10^5 PFU/100mL. As presented in Figure 3-8, >3-log removal of total coliphage was achieved in 80% of all samples measured during the pilot testing.



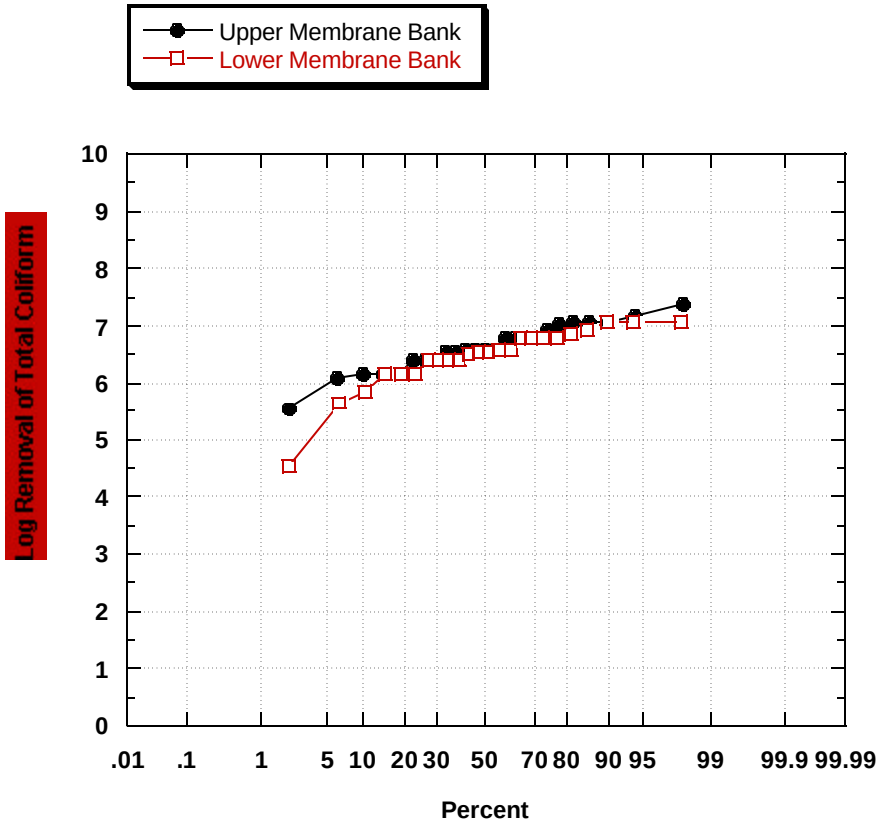
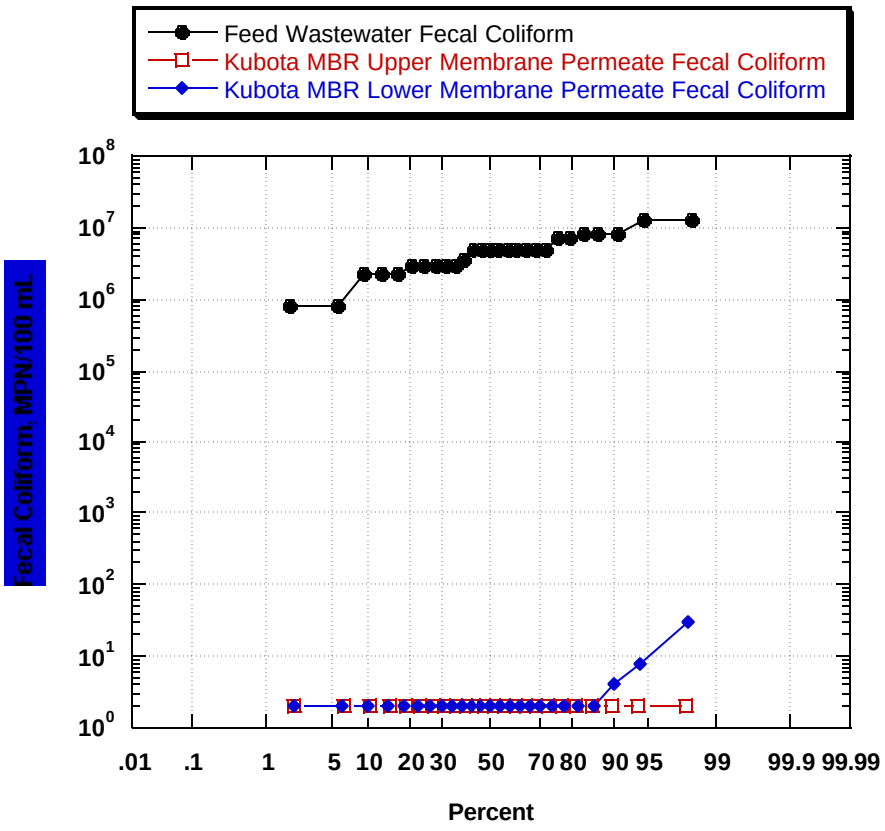


Figure 3-6 Probability plot of Total Coliform removal for Kubota MBR



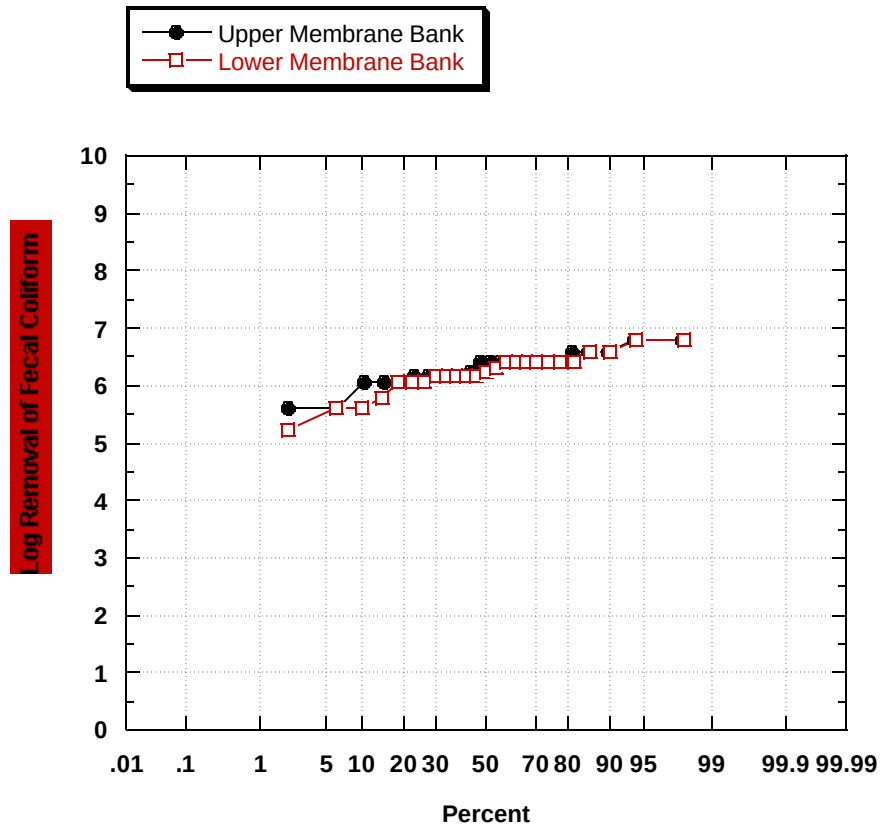


Figure 3-7 Probability plot of Fecal Coliform removal for Kubota MBR

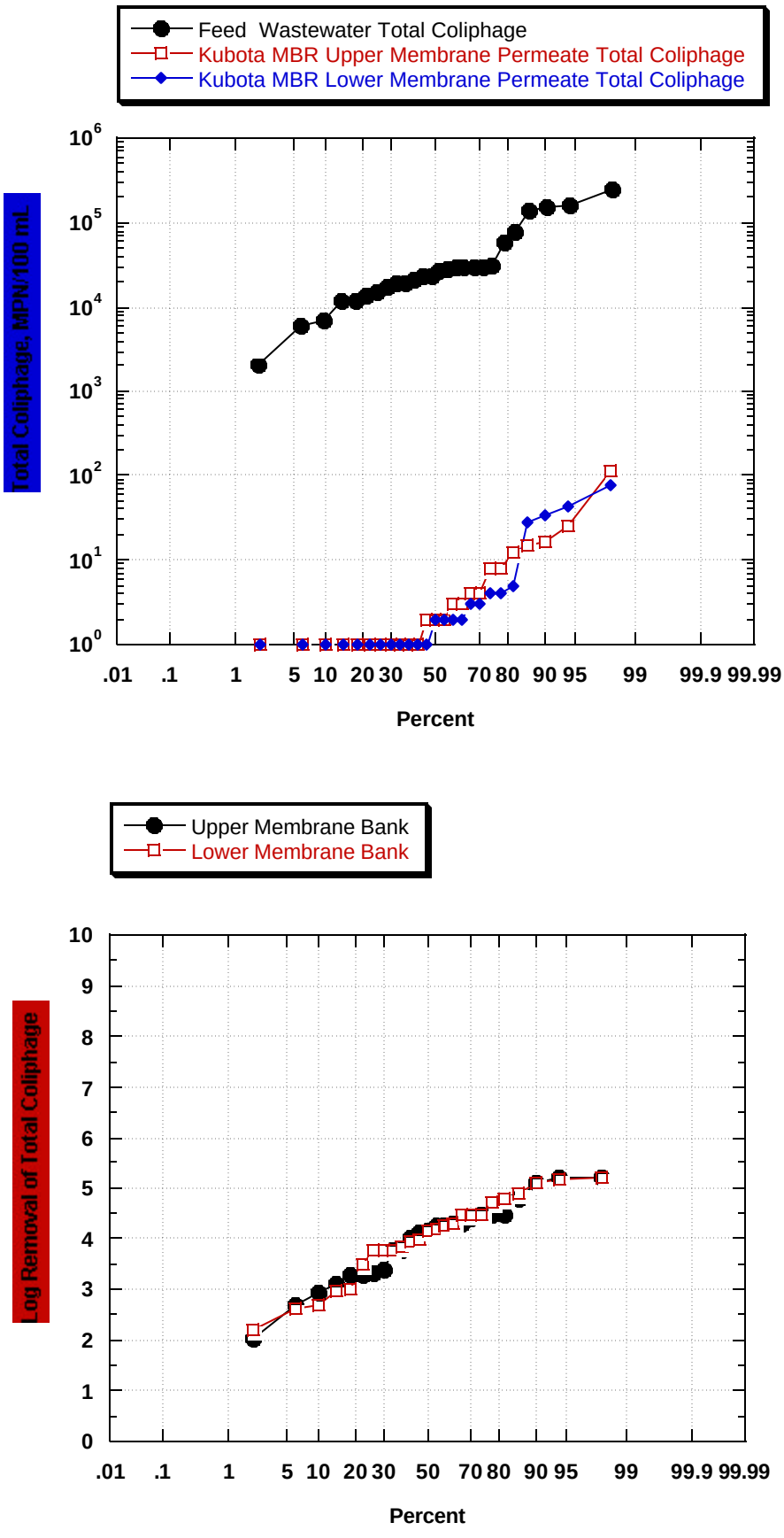


Figure 3-8 Probability plot of Total Coliphage removal for Kubota MBR

SECTION 4

Summary and Results of MBR Virus Seedings

4.1 VIRUS SEEDING PROTOCOL

4.1.1 Introduction

As indicated previously, MWH conducted virus seeding experiments with the intent to further evaluate the Kubota MBR for California DHS regulatory approval. Table 4-1 summarizes the protocol that was followed during the virus seeding experiments. The virus seeding experiments were conducted using primary effluent as well as clean water. The organism selected for seeding experiments was MS2 virus. MS2 virus is not a human pathogen; however, this organism is similar in size (0.025 microns), shape (icosahedron) to polio virus and hepatitis virus. Because MS2 is not a human pathogen, live MS2 virus was used in the seeding experiments. This section presents a description of the protocol used for the virus seeding experiments and the results that were observed.

Table 4-1 Virus Seeding Test Sampling Protocols

Experiment	Number of Seed Stock Samples	Number of Samples	Replicates	Total Number of Samples per Experiment
1	1	3 feed/3 filtrate	2 service cycles	13
2	1	3 feed/3 filtrate	2 service cycles	13
3	1	3 feed/3filtrate	2 service cycles	13

4.1.2 Seedings Using Activated Sludge

Three virus seedings were performed on the Kubota MBR pilot plant while operating on primary effluent. These included seedings at a low, medium and high fouled condition. The low-fouled virus seeding was performed after a chemical cleaning of the membrane using both sodium hypochlorite and oxalic acid. The cleaning was performed in accordance to the manufacturer's recommended protocol. A copy of this protocol is given in Appendix A. The membrane continued to foul as the system was operated, and a virus seeding was performed at medium and high-fouled condition.

MS-2 bacteriophage was directly seeded into the reactor 9 minutes before the seeding experiment began to allow adequate mixing and distribution. The reactor concentration was

sampled at the beginning, middle and end of two consecutive filtration cycles. As shown in Table 4-2, the reactor concentration at the beginning and end of each seeding showed no significant change in concentration. Lastly Kubota MBR permeate samples were collected from a stainless steal sample port installed on the permeate piping of the lower membrane cassette. These samples were also collected at the beginning, mid and end of two consecutive filtration cycles.

Table 4-2 Reactor concentration at the beginning and end of each seeding using activated sludge

Fouling Condition	Reactor Concentration, Initial (PFU/100 ml)	Reactor Concentration, Final (PFU/100 ml)	Concentration Change, Logarithmic
Low	3.30E+06	5.90E+06	0.25
Medium	9.70E+05	9.70E+05	0.00
High	2.20E+06	1.60E+06	-0.14

4.1.3 Seedings Using Clean Water

Like the testing conducted using activated sludge, three virus seedings were also performed on the Kubota MBR using clean water. Similarly, seedings were performed at a low, medium and high fouled condition. Upon completion of the high fouled seeding using activated sludge, the system was completely drained and flushed with clean water. The MBR was then operated using the clean water as a feed source. Next, the medium fouled seeding was completed. The system was then operated for nearly one week on clean water resulting in an increase of TMP. At this time, the high fouled seeding was completed. Lastly the system was chemically cleaned and the low fouled seeding was completed.

As with the seedings using activated sludge, MS-2 bacteriophage was seeded directly into the reactor 9 minutes before the seeding experiments began. It should be noted the chloramine residual present in the clean water was neutralized prior to entering the MBR system using sodium metabisulfite. This was necessary to prevent disinfection of the seeded MS2 virus. Total chlorine samples were taken from the feed water at the beginning, mid and end of the seeding experiment to ensure complete neutralization was maintained. The reactor concentration of MS2 and permeate were also sampled at the beginning, middle and end of two consecutive filtration

cycles. As shown in Table 4-3, no significant change in the MS2 reactor concentration was observed.

Table 4-3 Reactor concentration at the beginning and end of each seeding using clean water

Fouling Condition	Reactor Concentration, Initial (PFU/100 ml)	Reactor Concentration, Final (PFU/100 ml)	Concentration Change, Logarithmic
Low	2.80E+06	6.20E+06	0.35
Medium	5.30E+06	4.60E+06	-0.06
High	4.20E+06	5.20E+06	0.09

4.2 RESULTS OF VIRUS SEEDINGS USING ACTIVATED SLUDGE

4.2.1 Operating Parameters

The Kubota MBR pilot plant was operated in a nitrification/denitrification mode during the virus seeding experiments. The operating conditions during the seeding included a flux of 20 gfd, HRT of 3.7 hours and an average SRT of approximately 12 days. The MLSS concentration was maintained at approximately 11,000 mg/L. The membrane was agitated with continuous aeration using coarse air diffusers at a flowrate of 55 scfm. Table 4-4 shows the membrane operating conditions measured during the virus seeding of the MBR pilot plant using activated sludge.

Table 4-4 Operating conditons during virus seedings using activated sludge

Fouling Condition	Target Flux (gfd)	Vacuum Pressure (psi)	Specific Flux (gfd/psi)
Low	20	1.4	14.3
Medium	20	1.6	12.5
High	20	2.7	7.4

4.2.2 Seeding Results

Table 4-5 shows the results of the virus seedings performed on the Kubota MBR pilot plant using primary effluent. A probability plot of the results of the virus seedings using activated sludge

can be seen in Figure 4-1**.** The Kubota MBR achieved ≥1.1-log removal of viruses in 50% of samples from the aeration basin to the permeate of the system.

Table 4-5 Kubota MBR virus seeding results using activated sludge

Time (min)	Fouling Condition	Reactor Concentration (PFU/100 mL)	Permeate Concentration (PFU/100 mL)	Log Removal
1	Low	3.30E+06	4.50E+06	-0.13
3	Low	3.50E+06	3.60E+06	-0.01
8	Low	1.80E+06	3.40E+06	-0.28
1	Low	2.00E+06	2.10E+06	-0.02
3	Low	1.50E+06	2.60E+06	-0.24
8	Low	5.90E+06	1.60E+06	0.57
1	Medium	9.70E+05	5.10E+04	1.28
3	Medium	8.80E+05	4.00E+04	1.34
8	Medium	9.00E+05	3.90E+04	1.36
1	Medium	1.00E+06	2.10E+04	1.68
3	Medium	9.80E+05	1.30E+04	1.88
8	Medium	9.70E+05	1.70E+04	1.76
1	High	2.20E+06	1.90E+05	1.06
3	High	1.50E+06	1.40E+05	1.03
8	High	2.30E+06	1.10E+05	1.32
1	High	2.00E+06	1.50E+05	1.12
3	High	1.90E+06	1.40E+05	1.13
8	High	1.60E+06	1.20E+05	1.12

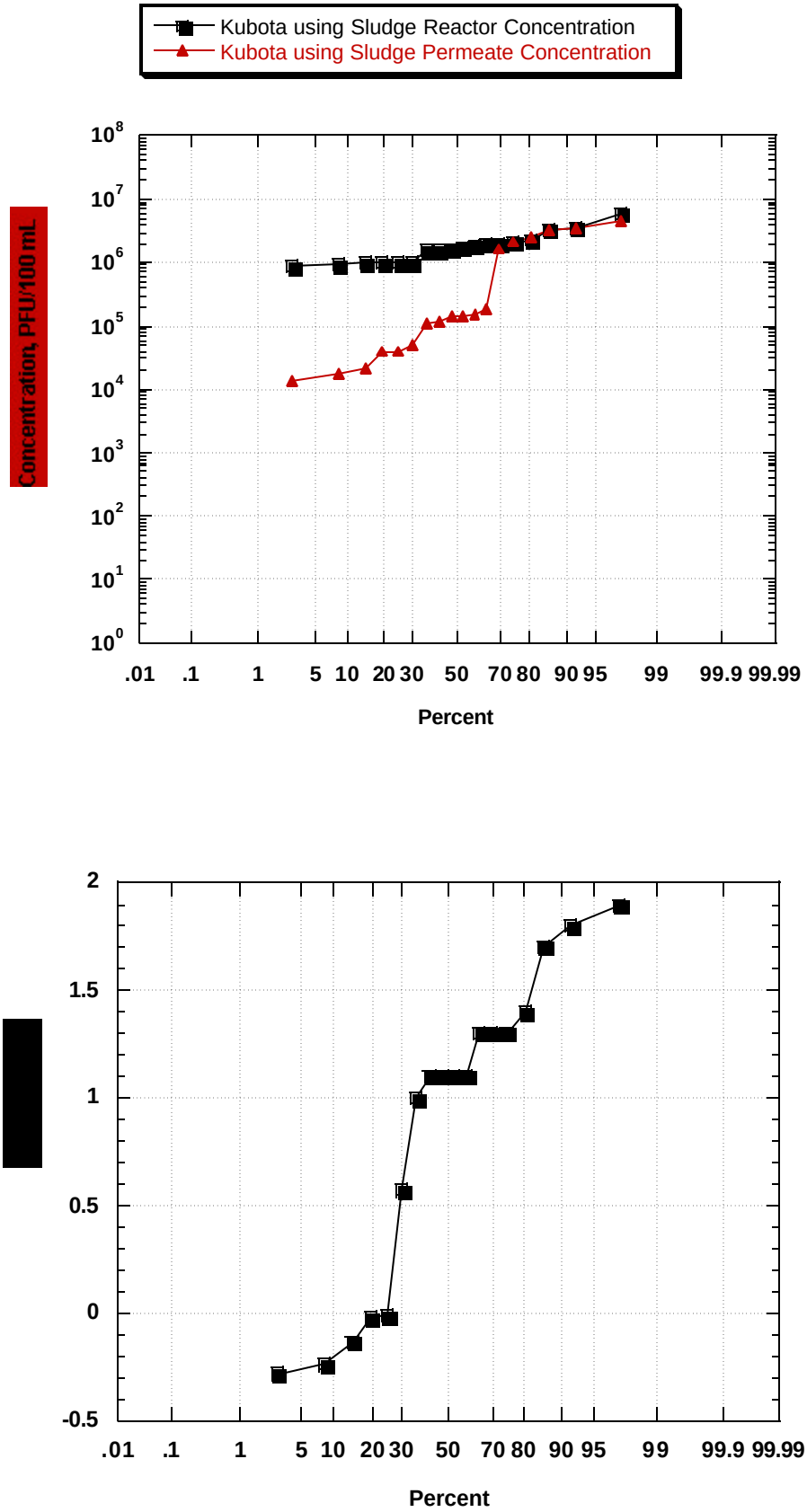


Figure 4-1 Probability plots of virus seedings of Kubota MBR using activated sludge

4.3 VIRUS SEEDINGS USING CLEAN WATER

4.3.1 Operating Parameters

The Kubota MBR pilot plant was retrofitted to operate using a potable water quality source located onsite at the PLWTP. The membrane was operated in the same manner as during the seedings conducted using activated sludge. The membrane was agitated with continuous aeration using coarse air diffusers at a flowrate of 55 scfm. Table 4-6 shows the membrane operating conditions measured during the virus seedings conducted using clean water.

Table 4-6 Operating Conditions during virus seedings using Clean Water

Fouling Condition	Target Flux (gfd)	Vacuum Pressure (psi)	Specific Flux (gfd/psi)
Low	20	1.9	10.5
Medium	20	2.4	8.3
High	20	5.2	3.8

4.3.2 Seeding Results

Table 4-7 shows the results of the virus seedings performed on the Kubota MBR pilot plant using clean water. A probability plot of the results of the virus seedings using clean water can be seen in Figure 4-2**.** The Kubota MBR achieved ≥0.4-log removal in 50% of samples from the reactor to the permeate of the system.

Table 4-7 Kubota MBR virus seeding results using clean water

Time (min)	Fouling Condition	Reactor Concentration (PFU/100 mL)	Permeate Concentration (PFU/100 mL)	Log Removal
1	Low	2.80E+06	7.10E+05	0.60
3	Low	8.00E+05	4.50E+05	0.25
8	Low	4.70E+05	2.60E+05	0.26
1	Low	1.90E+06	2.60E+05	0.86
3	Low	7.50E+06	1.20E+05	1.80
8	Low	6.20E+06	1.00E+05	1.79
1	Medium	5.30E+06	3.60E+06	0.17
3	Medium	6.10E+06	3.00E+06	0.31
8	Medium	3.50E+06	2.30E+06	0.18
1	Medium	4.80E+06	2.80E+06	0.23
3	Medium	5.90E+06	1.60E+06	0.57
8	Medium	4.60E+06	1.50E+06	0.49
1	High	NA	NA	NA
3	High	4.80E+06	1.80E+06	0.43
8	High	4.30E+06	1.70E+06	0.40
1	High	4.30E+06	2.90E+06	0.17
3	High	4.70E+06	2.00E+05	1.37
8	High	5.20E+06	1.60E+06	0.51

NA = not avaialble due to lab error.

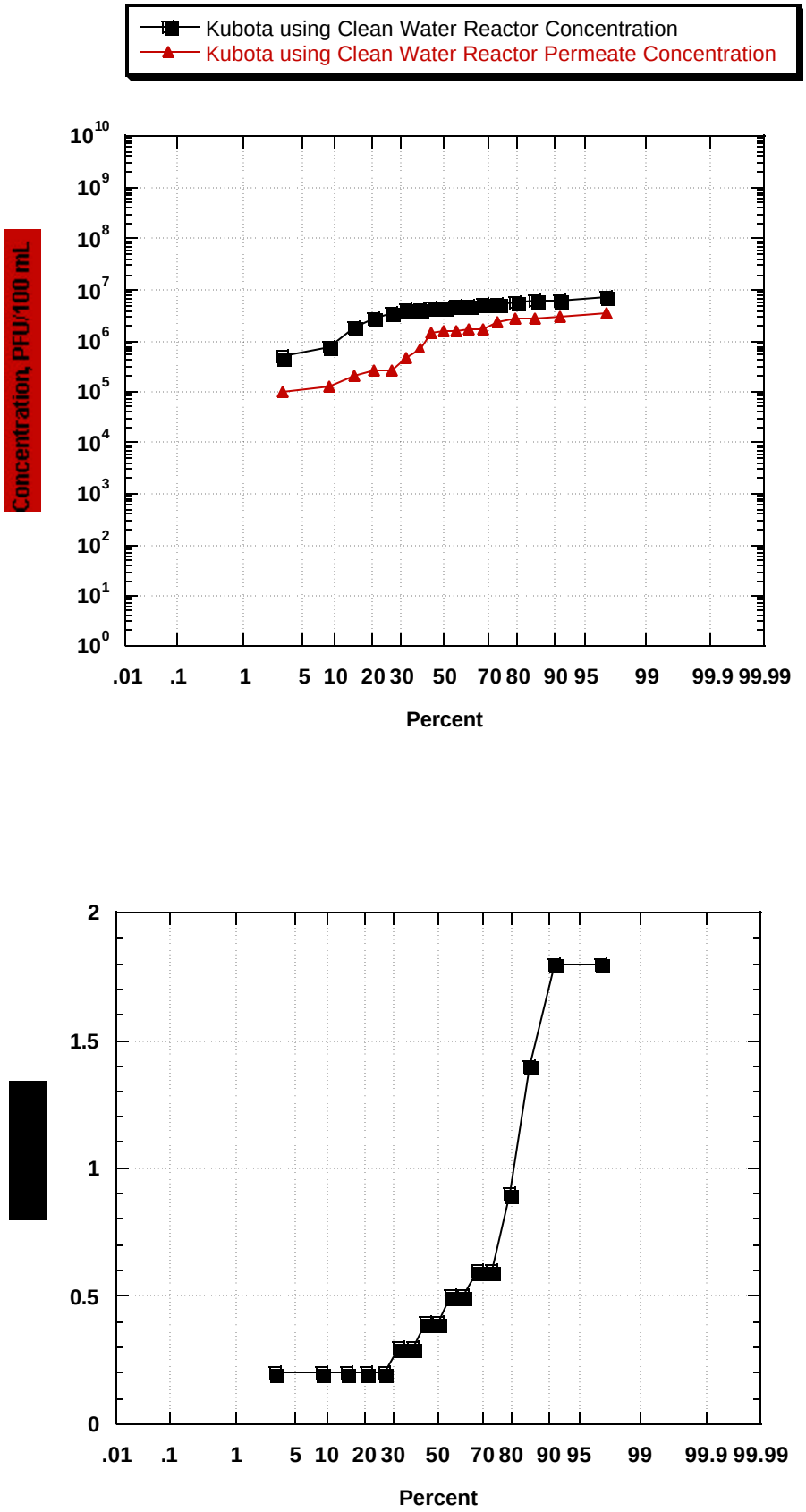


Figure 4-2 Probability Plots of Kubota MBR using Clean Water

SECTION 5

Summary and Conclusions

5.1 BUREAU OF RECLAMATION STUDY

In October 2001 the City of San Diego and Montgomery Watson Harza were awarded a grant from the Bureau of Reclamation to evaluate Membrane Bioreactor (MBR) technology and its potential application to wastewater reclamation. The project scope includes the evaluation of four leading commercially available MBR systems over a 14-month testing period. The first portion of the study was conducted from April to December 2002 and consisted of pilot testing of the Kubota MBR system. During Part 1 of the Kubota testing the system was operated in a nitrification/denitrification mode using raw wastewater as the feed source. During Part 2, the system was operated in the same operational mode but was retrofitted to receive primary effluent as the feed source. The primary objectives of the Bureau of Reclamation project were to obtain long-term operational and performance data for the MBR process and assess the feasbilty of operating the sytem on advanced primary treated effluent.

The Bureau of Reclamation study demonstrated the following:

- The Kubota MBR pilot system produced effluent with turbidity ≤0.1 NTU in 95% of all samples and <0.2 NTU throughout the pilot testing.
- The Kubota MBR pilot system was capable of producing excellent quality effluent water suitable for use by an RO system.
- Run times between chemical cleanings were reasonable.
- Very high removal of total and fecal coliforms and total coliphage was achieved.
- Excellent organic removal was achieved.
- The Kubota MBR pilot system achieved complete nitrification and denitrification during Part 1 and Part 2 testing.

To further demonstrate the performance of the Kubota MBR system the project team conducted virus seedings. The seedings were conducted in accordance to the criteria established by the California DHS in 2000 to approve MBR systems for water reclamation.

5.2 VIRUS SEEDING STUDY

The virus seeding studies were conducted using both primary effluent wastewater and clean water as the feed to the MBR. Three seedings were conducted using each feed water source. Virus seedings were conducted at low, medium and high fouled conditions. During the seedings using primary effluent, samples were taken from the MBR permeate and the activated sludge of the MBR. During the clean water seedings, samples were taken from the membrane reactor tank and the MBR permeate. The 50^{th} percentile log removal of MS-2 was ≥1.1 log during the studies conducted on activated sludge and ≥0.4 log for seedings conducted on clean water.

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SECTION 6

6.1 REFERENCES

Adham S. and Gagliardo P. Membrane Bioreactors for Water Repurification – Phase I. Final Technical Report. Desalination Research and Development Program Report No. 34. Bureau of Reclamation. Denver, CO November, 1998.

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APPENDIX A

CHEMICAL CLEANING PROCEDURE

Kubota Chlorine Cleaning Protocol

1. Prepare 160 gallons of 0.5 % (w/w) of sodium hypochlorite.
2. Stop the feed to system.
3. Stop filtration.
4. Stop MBR blower.
5. Stop recycle pump
6. Open caps on the 2" permeate lines (upper and lower membrane banks) at the top of the nitrification tank.
7. Insert the chemical feed pump discharge into the upper permeate line.
8. Pump 80 gallons of the sodium hypochlorite solution prepared in Step 1.
9. Insert the chemical feed pump discharge into the lower permeate line.
10. Pump 80 gallons of the sodium hypochlorite solution prepared in Step 1.
11. Close caps on the permeate lines.
12. Soak membranes for 2 hours.
13. Turn all equipment back on and put the system in auto.

Kubota Oxalic Acid Cleaning Protocol

2 Prepare 160 gallons of 1% (w/w) Oxalic Acid.
3 Stop the feed to system.
4 Stop filtration.
5 Stop MBR blower.
6 Stop recycle pump
7 Open caps on the 2" permeate lines (upper and lower membrane banks) at the top of the nitrification tank.
8 Insert the chemical feed pump discharge into the upper permeate line.
9 Pump 80 gallons of the sodium hypochlorite solution prepared in Step 1.
10 Insert the chemical feed pump discharge into the lower permeate line.
11 Pump 80 gallons of the sodium hypochlorite solution prepared in Step 1.
12 Close caps on the permeate lines.
13 Soak membranes for 1 hour.
14 Turn all equipment back on and put the system in auto.