Performance of Full Scale and Demonstration-Scale Primary Filtration Projects

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KEYWORDS

Carbon Diversion, Primary Filtration, Cloth Depth Filtration, Advanced Primary Treatment, Energy Savings, Capacity Increase

ABSTRACT

Primary filtration (PF) is an advanced primary treatment (APT) technology that can be used to replace conventional primary sedimentation process to provide significant benefits at water resource recovery facilities (WRRFs). The use of a primary filter with relatively small pore media size [e.g., 5 to 10 micrometer (µm)] yields high total suspended solids (TSS) and biochemical oxygen demand (BOD) removal efficiencies. TSS removal efficiency by PF is between 75 and 85%, significantly higher than the typical TSS removals (50-60%) obtained with conventional primary sedimentation. PF achieves an overall 45-60% BOD reduction depending on the influent characteristics.

INTRODUCTION

Advanced primary treatment (APT) is used at water resource recovery facilities (WRRFs) to enhance total suspended solids (TSS) and organic removal efficiencies in primary treatment process. Primary filtration (PF) is an APT technology which achieves high primary TSS and organic removal via filtering using a filter media with a relatively small pore size [e.g., 5 to 10 micrometer (µm)]. TSS removal efficiency is significantly higher than the typical TSS removals (50-60%) obtained with conventional primary sedimentation (Metcalf and Eddy, 2013). PF achieves an overall 75-85% TSS and 45-60% biochemical oxygen demand (BOD) reduction depending on influent characteristics (Caliskaner et.al., 2017; Caliskaner et.al., 2016).

PF system is used in place of conventional primary sedimentation to offer significant energy and capital cost savings via carbon diversion, including:

1. Decreased electrical energy required for aeration (by approximately 20 to 30%) in secondary treatment because of reduced organic loading,

2. Increased gas energy production in the anaerobic digestion process (by up to 30 to 40%) resulting from the high organic energy content of the volatile suspended solids (VSS) removed by PF,

3. Expanded secondary treatment capacity by reducing the organic loading upstream of the secondary process,

4. Reduction of footprint required for primary treatment by approximately 75%, and

5. Enhanced particle size characteristics of the wastewater to be treated biologically, increasing the effectiveness of secondary treatment.

A full-scale PF system, the first to be implemented for carbon diversion objectives, was installed at Linda County Water District (Linda) WRRF and has been in operation since July 2017. The system uses pile cloth depth filtration (PCDF) media with 5 micrometer (µm) nominal pore size, which removes finer size particles compared to conventional primary sedimentation. Multiple other demonstration-scale PF projects have been conducted or are currently underway. The treatment and operational performance of the full and demonstration-scale PF projects is presented and discussed in this paper.

FIRST FULL-SCALE PRIMARY FILTER INSTALLATION

The Linda WRRF is in Olivehurst, California, approximately 40 miles north of Sacramento, California, as shown in Figure 1. The Linda WWRF is a tertiary wastewater treatment facility (see Figure 2). The WRRF's treatment train consists of screening, primary clarification, nitrification and denitrification, secondary clarification, tertiary filtration, and chlorination. Primary sludge and thickened secondary sludge are processed by anaerobic digestion. The WRRF discharges to percolation ponds or directly to Feather River in accordance with National Pollution Discharge Elimination System (NPDES) No. CA0079651, Order R5-2012-0034 (Permit). The Permit effluent quality requirements are summarized in Table 1.

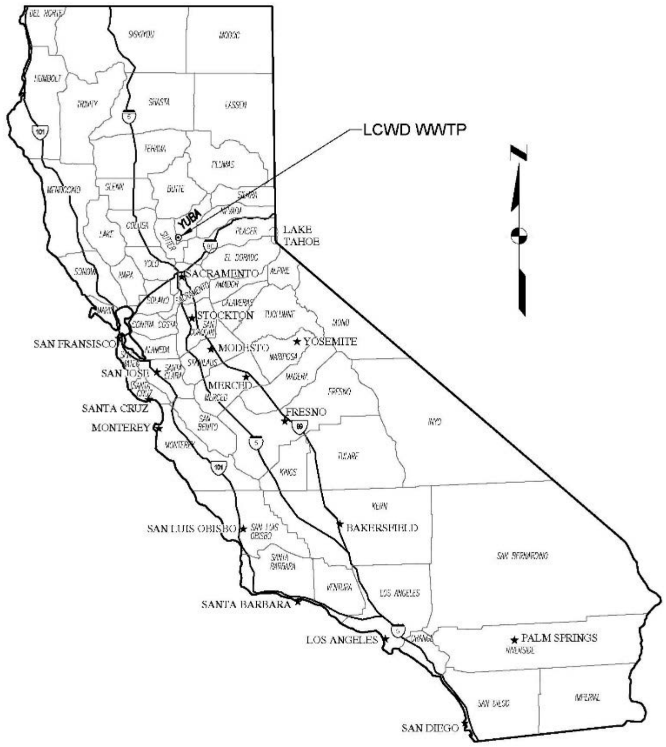

Figure 1. Map of Location of Linda WRRF

Table 1. Linda County Water District Wastewater Treatment Plant Effluent Quality Requirements

Parameter	Criteria
BOD (5 days @ 20°C), mg/L	10, monthly average 15, weekly average 20, daily maximum
Total Suspended Solids, mg/L	10, monthly average 15, weekly average 20, daily maximum
Ammonia Nitrogen, Total (as N), mg/L	2.4, monthly average 3.5, daily maximum
Nitrate Plus Nitrite (as N), mg/L	10, monthly average
Turbidity (NTU)	2, daily average 5, not to exceed more than 5% of the time 10, at any time
Total Coliform, MPN/100 mL	2.2, as a 7-day median 23, more than once in 30-day period 240, at any time
Total Chlorine Residual, mg/L	0.01, as a 4-day average 0.019, as a 1-hour average

Figure 2. Linda County Water District Water Resource Recovery Facility (Olivehurst, California; view from the back of secondary clarifiers looking towards the headworks)

The Linda WRRF has an average treatment capacity of 5 million gallons per day (mgd) and currently operates at an average daily flow of approximately 1.3 mgd. Construction of a full-scale PF system (Aqua-Aerobic Systems, Inc., AquaPrime filtration system) was completed at the Linda WRRF in June 2017, and the system has been operational since July 2017 (see Figures 3a). The PF unit at Linda WRRF uses PCDF to treat average and peak flow capacities of 1.5 and 2.5 mgd, respectively. Eight pile cloth filter disks provide a total filtration area of 432 square feet (see Figure 3b). Influent wastewater is filtered outside-in through the pile cloth filter disks. Filter influent versus effluent water quality is visibly distinguishable, as shown in Figure 4. The PF unit at Linda WRRF has a footprint of 150 square feet, which is approximately 15 to 20% of the footprint of a primary sedimentation tank with similar capacity.

A flow diagram of the treatment plant with the PF system is presented in Figure 5. Following the removal of coarse solids by screening, the raw wastewater is filtered before secondary treatment. PF effluent is then conveyed to the activated sludge basin for secondary treatment. In addition to the filtered effluent, the PF unit discharges reject streams in the form of filter sludge (FS), backwash reject water (BRW), and scum. FS and BRW combined typically contain less than 0.5% solids. The mixture of BRW and FS is equalized and thickened by a dewatering drum thickener (Process Wastewater Technologies, LLC, Volute Thickener VT302) to produce thickened PF sludge with solids content of 2 to 10%. Photograph of the thickening device is shown in Figure 6. Thickened PF sludge is combined with filter scum and pumped to the plant's digester for solids processing. The combined filter reject flows total to less than 10% of the applied filter flow.

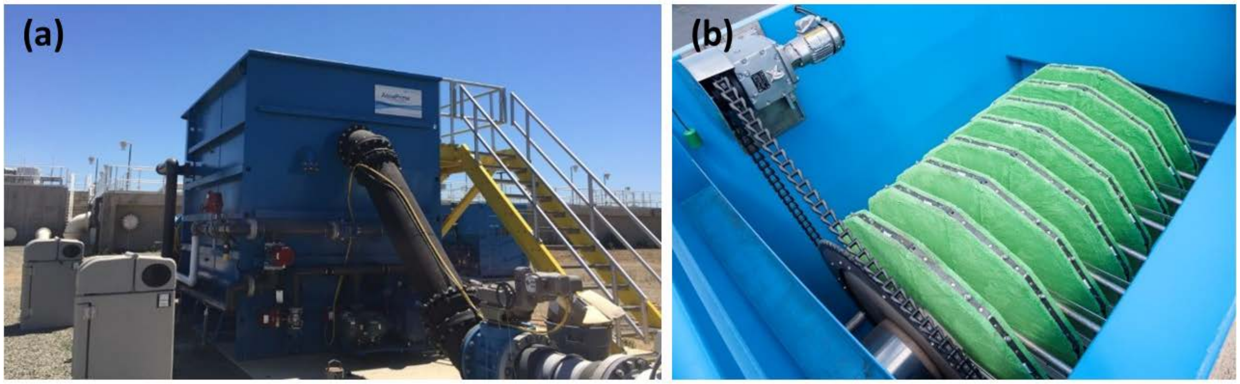

Figure 3. Primary Filtration System at Linda Wastewater Treatment Plant (Olivehurst, California) (a) Cloth Depth Filter Unit (b) Filter tank with Eight Individual Disks

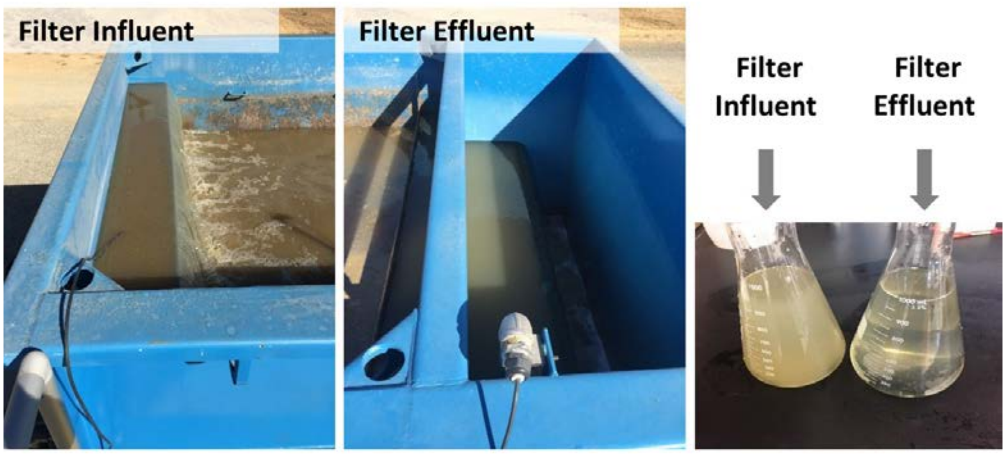

Figure 4. Primary Filter Influent and Effluent at Linda WRRF

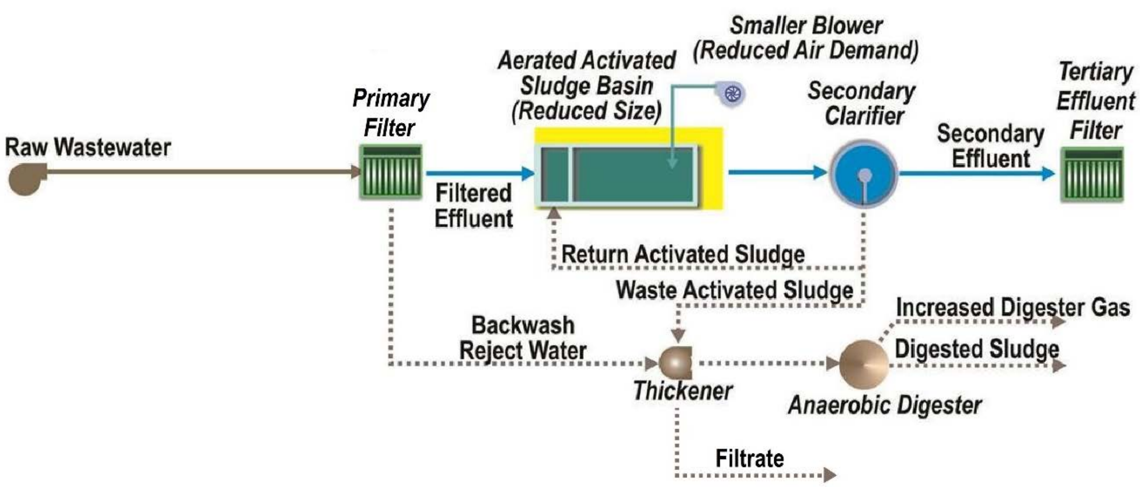

Figure 5. Linda WRRF Treatment Flow Diagram with Primary Filtration System

Figure 6. Sludge Thickener for the PF System at Linda WRRF

UNIQUE CHARACTERISTICS FOR PRIMARY FILTRATION

Two unique features of the PCDF technology which make PF possible and effective are: (1) the filter medium is submerged within the filter tank and (2) the filtering direction is from outside-in. These two features allow removal to occur in three different zones as illustrated in Fig. 7. First, a bottom zone below the filter media allows for the deposition of heavy solids which have a specific gravity greater than 1.0. PCDF creates a pathway for the heavy solids to settle and be collected at the tank bottom without contacting and accumulating on the surface of the filter medium. Second, an upper removal zone above the filter media permits the flotation of material such as FOG and floating debris to reach the top of the filter tank to be easily skimmed from the filter tank without contacting and accumulating on the surface of the filter medium. Third, a filtration zone enables filtration of nominally neutrally buoyant suspended solids.

The accumulation of suspended solids on the filter media results in additional removal mechanisms as the attached solids create a working layer that aids filtration. As more TSS is accumulated on the surface of the medium, the water level in the tank increases. When the liquid level rises a setpoint of approximately 30 cm (12 in.), the PCDF system backwashes automatically and removes the solids layer to restore the water level to its lower setting. An illustration of the PCDF technology is presented in Figure 8.

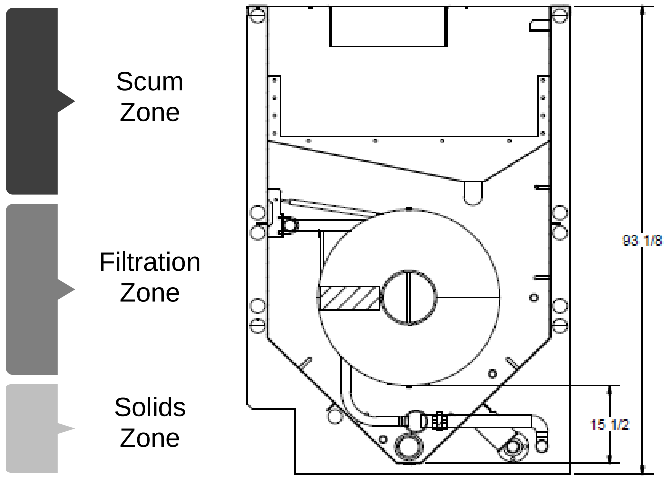

Figure 7. Treatment Zones in PCDF Unit

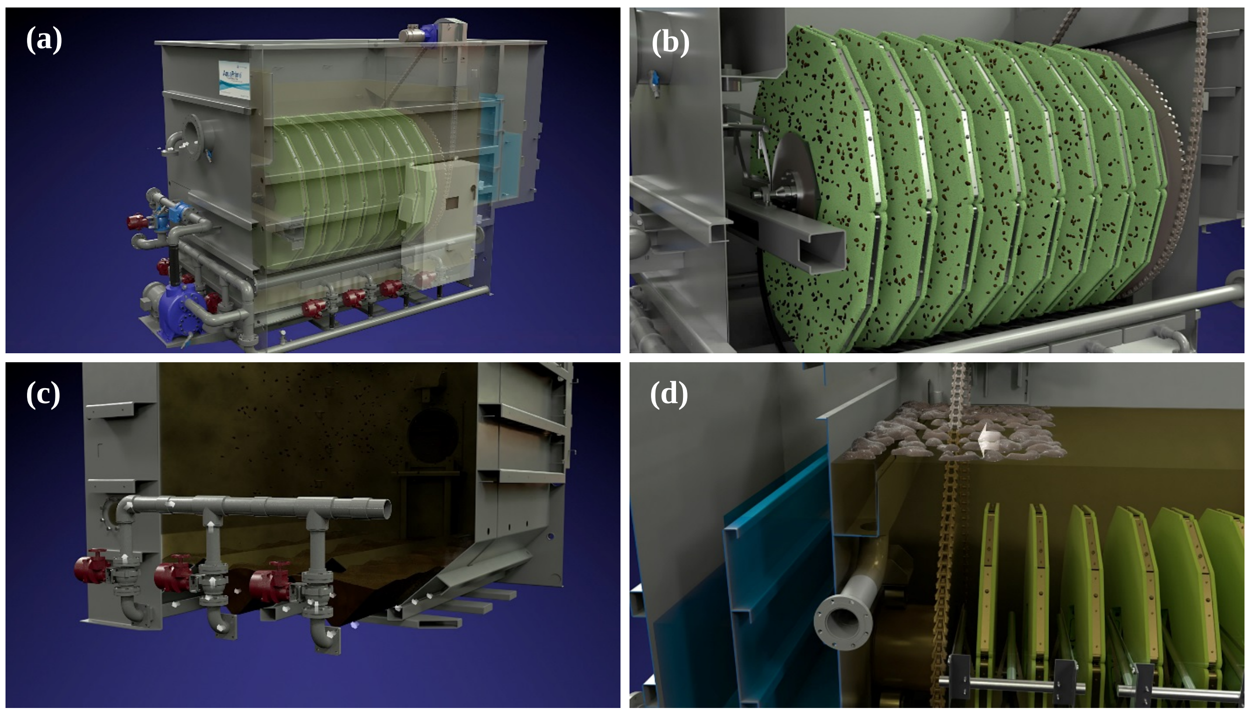

Figure 8. Operational Diagram of PCDF Unit For Following Operational Modes: (a) Filtration, (b) Backwash, (c) Solids Wasting, and (d) Scum Removal

As part of an on-going research and demonstration project conducted for the California Energy Commission (CEC), the PF system at Linda WRRF is operated and monitored to achieve the following specific objectives:

- Demonstrate long term treatment and hydraulic performances of the PF system
- Quantify the reduction in aeration power consumption in the activated sludge process
- Quantify the increase in digester gas energy production
- Evaluate footprint reductions in primary and secondary treatment

- Confirm the effect of particle size modification on the bioavailability of smaller particle-associated organics
- Evaluate overall impacts of PF on downstream processes including nitrification and denitrification
- Determine overall capital and energy savings resulting from PF
- Compare performance with other PF pilot and demonstration projects
- Demonstrate mechanical reliability

The PF system at Linda WRRF is operated in two distinct phases. During the first phase (estimated to continue until fall of 2018), the PF system diverts influent flow from the existing primary clarifier system in increasing proportion. The goal is to treat 100% of the flow using the PF instead of the primary clarifier. During the second phase, Linda WRRF is expected to receive raw wastewater from the neighboring City of Marysville. Average daily flow at the plant is anticipated to double to 2.6 mgd, and the PF system will treat half of the WRRF's total flow. As shown in Figure 9, Linda WRRF will employ the following two treatment trains in parallel: a conventional system with primary clarifier and emerging system with PF. By installing PF system upstream of one of the two activated sludge reactors, the relative savings in aeration power costs and other secondary treatment performance impacts can be evaluated directly by using the other reactor as the control system.

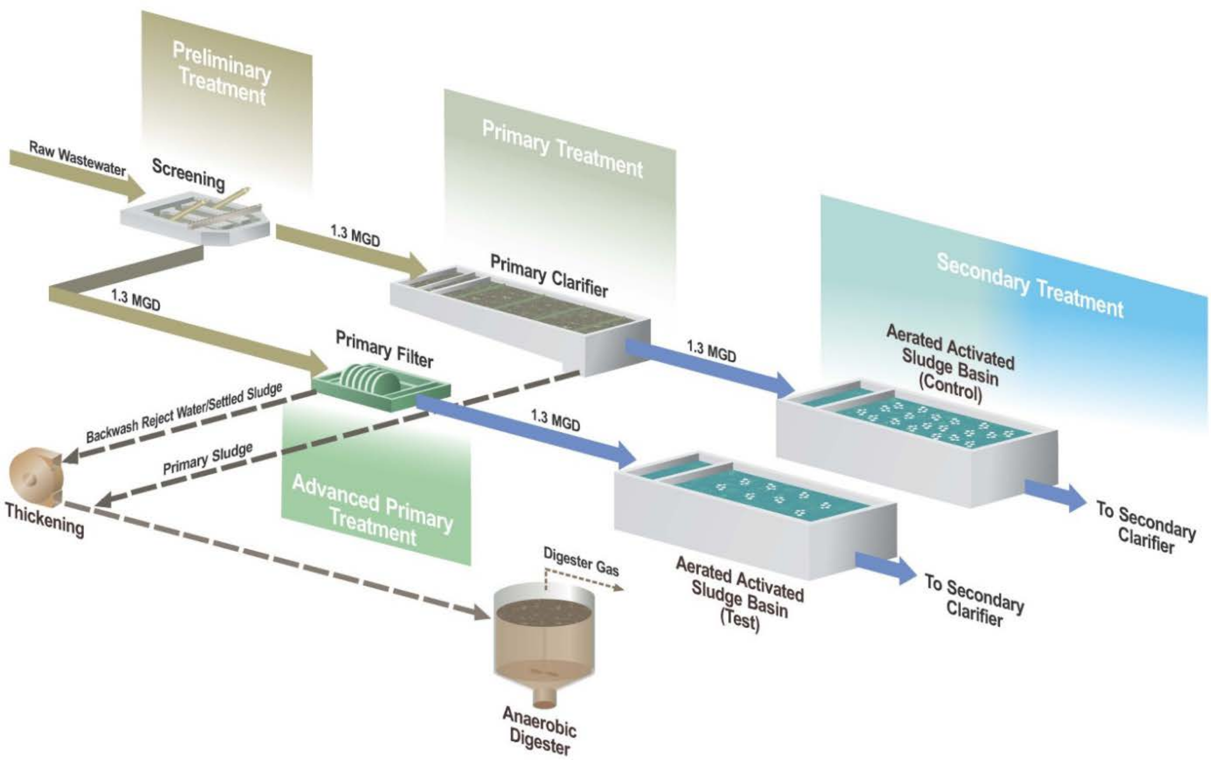

Figure 9. Parallel Operation of Primary Sedimentation and Primary Filtration Systems at Linda WRRF

MONITORING AND SAMPLING FOR PF SYSTEM AT LINDA WRRF

The PF system is equipped with a supervisory control and data acquisition (SCADA) system, which logs data at 5 second intervals. Filter influent and effluent turbidities are monitored continuously using immersion-type infrared turbidity sensors (Hach, Solitax sc). Influent, FS, and BRW flow rates are measured by electromagnetic flowmeters (Siemens Corporation, SITRANS F M Mag500).

In addition to inline turbidity measurements, composite samples of PF influent and effluent are taken weekly over 24 continuous hours using refrigerated samplers (Hach, SD900; Teledyne ISCO, Avalache). Samples are analyzed for TSS, VSS, BOD, chemical oxygen demand (COD), and Total Kjeldahl Nitrogen (TKN) by a California Environmental Laboratory Accreditation Program (ELAP) certified laboratory

PRELIMINARY OPERATIONAL AND TREATMENT PERFORMANCE OF PF SYSTEM AT LINDA WRRF

Since start-up in July 2017, the PF system has operated continuously at between 20 to 50% of the total Linda WRRF flow. During storm conditions in March 2018, the PF system filtered up to 2.6 mgd of flow, as shown in Figure 10. Daily average hydraulic loading rate (HLR) is between 0.5 to 3.0 gpm/ft^2.

Average daily influent and effluent TSS for the PF system based on inline turbidimeters are 293 and 59 mg/L, respectively, as shown in Figure 11. TSS values were calculated based on best available correlation factors between TSS and turbidity for PF influent and effluent. Treatment performance based from laboratory analyses is summarized in Table 2. Removal efficiencies for TSS and COD from laboratory data are approximately 86 and 57%, respectively.

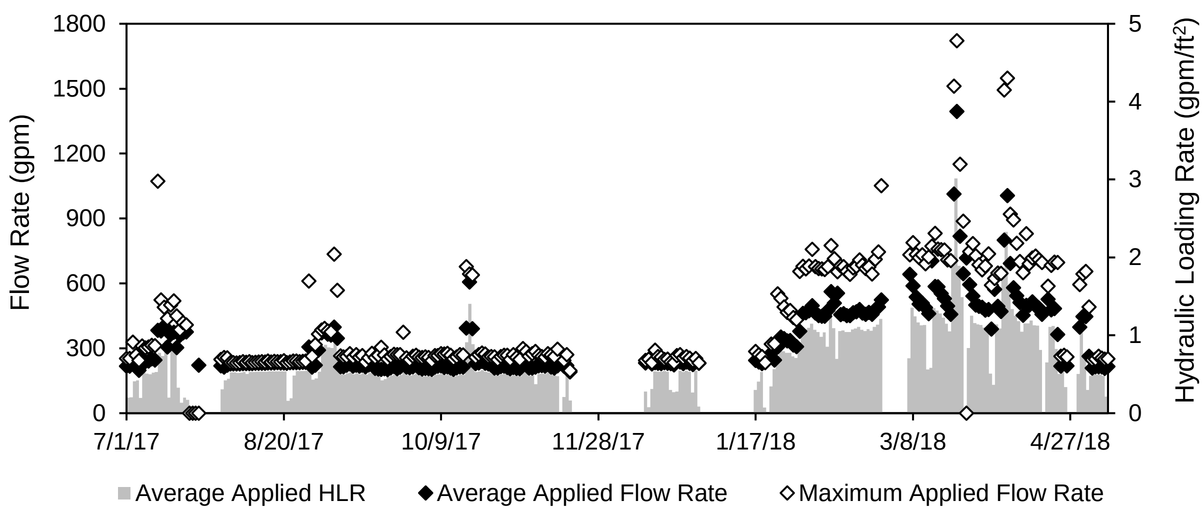

Figure 10. Flow Rate and HLR for Linda PF System
(Note: filter was in operation from November 2017 to January 2018. Gaps in data reflect loss of communication in data logging system.)

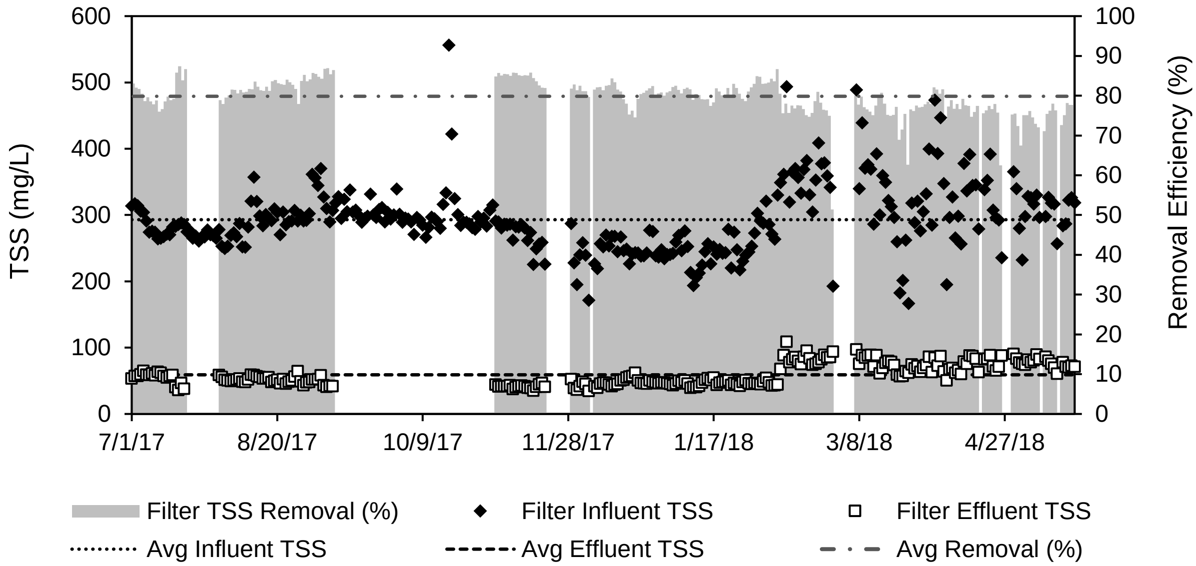

Figure 11. Average Daily TSS Reductions for Linda PF System Based on Correlations from Turbidities
(Note: Effluent values were not recorded from September 8 to November 3 due to malfunctioning of turbidimeter.)

Table 2. Concentration Ranges and Average Removal Performances of Key Constituents for Linda PF System

Constituent	Primary Filter Influent, mg/L		Primary Filter Effluent, mg/L		Constituent Average Removal Efficiency, %
	Range	Average	Range	Average	
TSS	250-520	358	30-59	44	86
COD	490-680	588	190-290	233	57
BOD_5	250-500	369	120-160	141	57
TKN	36-53	46	31-43	38	16

COMPARISON OF FULL SCALE PF SYSTEM PERFORMANCE WITH OTHER PILOT AND DEMONSTRATION SYSTEMS

To establish the design and operational standards for the PF technology, the results obtained from the full-scale PF system at Linda WRRF are compared with other pilot and demonstration PF projects. Two other demonstration projects are being conducted for the CEC for technology demonstration and development. One-year PF demonstration testing using PCDF was conducted for Los Angeles County Sanitation District at the Lancaster WRRF between November 2016 and December 2017. The PCDF unit at Lancaster WRRF consists of one pile cloth disk with a total filtration area of 10.7 square feet. The hydraulic performance of the Lancaster PF system is summarized in Figure 12 in terms of daily volumes of filtered effluent and reject flows. Average BRW ratio was approximately 10%, although unusually high spikes of influent TSS at the Lancaster WRRF necessitated more frequent backwashing.

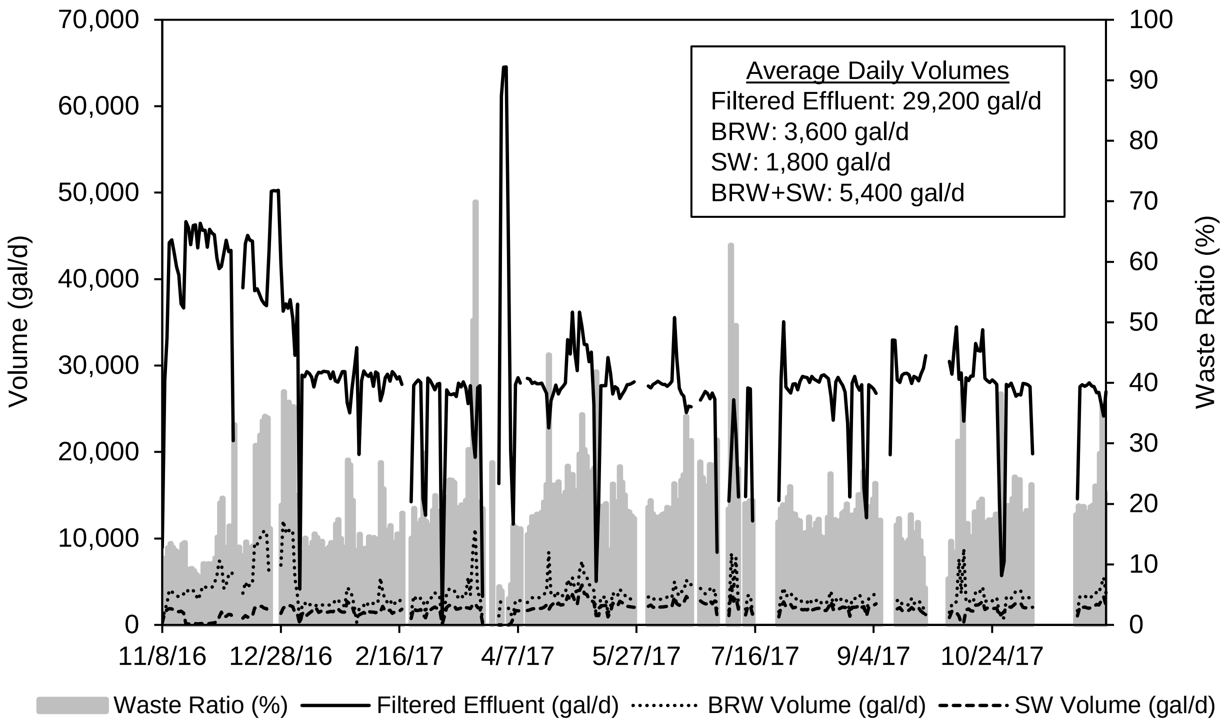

Figure 12. Daily Volumes of Filtered Effluent and Reject Flows for Lancaster Primary Filter Demonstration

From October to December of 2016, the PF system at Lancaster WRRF operated at an average HLR of 3.25 gpm/ft^2, or overall flow rate of 35 gpm. After January, filtration rates were lowered to HLR of 2 gpm/ft^2 and flow of 23 gpm. Operational changes were made during the demonstration period due to frequent high influent solids loading events experienced at the Lancaster WRRF. Turbidity of PF influent regularly exceeded 500 NTU and on multiple occasions surpassed turbidimeter's reading range of up to 4,000 NTU.

Despite high solids loading events, the PF system produced relatively constant effluent solids concentration based on both onsite turbidity measurements and laboratory TSS measurements. As shown in Figure 13, a large variation in daily average influent TSS from 90 to 700 mg/L was observed. Daily average effluent TSS, however, remained relatively stable between 25 to 80 mg/L. TSS removal efficiency averaged 84% during the 12-month demonstration.

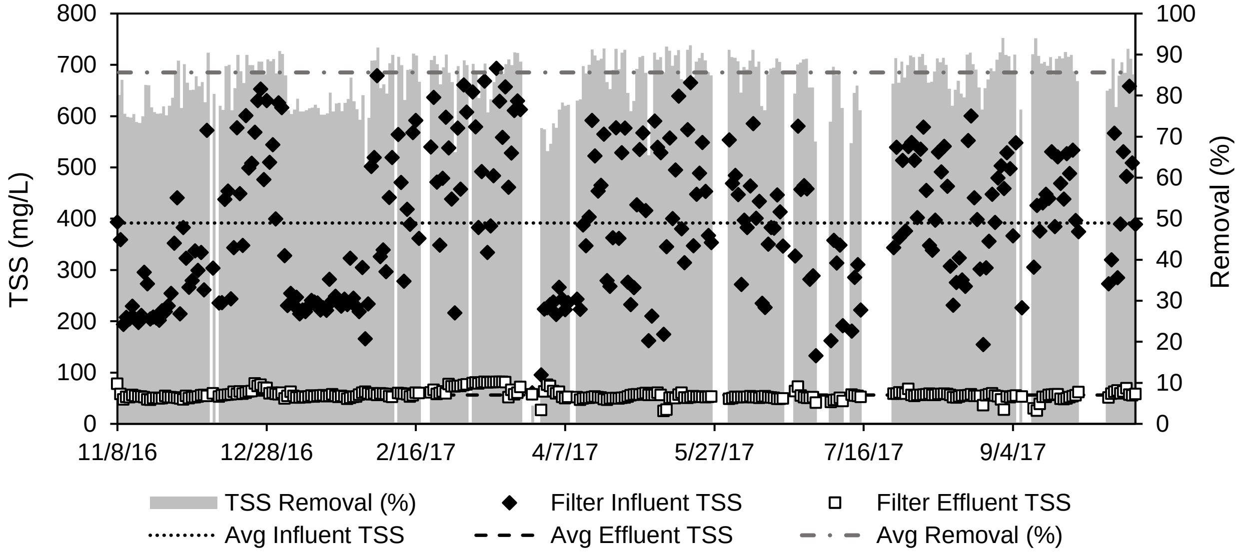

Figure 13. Average Daily TSS Reductions for Lancaster PF System Based on Correlations from Turbidities

Results from the laboratory analyses of grab and composite PF influent and effluent samples are summarized in Table 3. Average TSS removal efficiency is 83%, consistent with removal efficiency estimated from turbidity data. Other constituents were also removed through primary filtration. Average BOD and COD removal efficiencies are 52 and 54%, respectively. Average Total Kjeldahl Nitrogen (TKN) removal efficiency is 15%. These constituents were likely removed in their particulate form.

PCDF demonstration was also started at City of Manteca (Manteca) WRRF in February 2018 (see Figure 14). The system at Manteca has two pile cloth media disks. The PF system is expected to run for one year and will be operated at HLR of 2 to 4 gpm/ft^2.

Table 3. Concentration Ranges and Average Removal Efficiencies obtained for PF at Lancaster WRP

Constituent	Influent* (mg/L)			Effluent* (mg/L)			Avg. Removal Efficiency* (%)	No. of Samples
	Min.	Max.	Avg.	Min.	Max.	Avg.		
TSS	132	652	372	28	90	59	83	64
VSS	160	370	296	28	78	49	83	7
BOD	130	450	321	63	150	117	52	16
COD	440	1070	712	240	407	319	54	57
FOG	10	34	25	4	17	11	56	4
TKN	38	65	50	35	49	42	15	48
Ammonia	30	38	34	29	40	34	0	30
Settleable Solids	13	75	28	0.1	0.2	0.2	99	30
COD, Soluble	118	255	181	102	228	165	9	30

* Based on values within 2 standard deviations. Nonvolatile SS not included due to only one sample measured.

Figure 14. PF Demonstration System at Manteca WRRF

Several other agencies are currently conducting pilot and demonstration projects prior to considering PF for full-scale installation. Pilot testing of a CDF system for sidestream and PF occurred between August 2016 and June 2017 at City and County of Honolulu Sand Island (SI) WRRF in Honolulu. PF treatment performance results from SI WRRF are summarized in Table 4. Consistent with performance at Linda and Lancaster, average PF COD removal efficiency was approximately 54% at SI.

Table 4. Concentration Ranges and Average Removal Performances of Key Constituents for PF System at SI WRRF

Constituent	Primary Filter Influent (mg/L)		Primary Filter Effluent (mg/L)		Constituent Average Removal Efficiency (%)
	Range	Average	Range	Average	
VSS	110-190	155	17-40	27	82
TSS	120-260	188	24-62	41	78
COD	230-1000	389	67-270	178	54
BOD_5	110-210	154	55-86	73	53
Soluble COD	100	100	96	96	4
TKN	22-27	24	20-26	22	8

INDUSTRY SIGNIFICANCE

Construction of the full-scale PF installation at Linda WWTP was completed in June 2017. Following start-up activities, a detailed performance analysis began in August 2017 and will continue through March 2019. The detailed evaluation of this first full-scale PF installation at Linda WWTP will provide significant information for wider implementation of this technology at other WWTPs.
In addition to the full-scale installation at Linda WRRF, viability of primary filtration using PCDF has been tested at a number of WRRFs, and PF has been established as an APT treatment method that can be used to achieve significant capital and energy savings while increasing overall plant performance and reducing footprint requirements. Unit cost savings of WRRFs employing PF technologies were estimated to be approximately $1,100,000 per mgd (*i.e.*, per mgd average flow capacity). Estimated capital and energy savings are presented in Table 5.

Table 5. Wastewater Treatment System Cost Savings Resulting from Primary Filtration

Cost Savings	Savings (per mgd)
Capital	$600,000
Annual Operations and Maintenance*	$30,000
Net Present Value	$1,100,000

* *Based on $0.09/kWh*

CONCLUSIONS

The feasibility and performance of PF using CDF has been demonstrated at several WRRFs. PF has proven to be a treatment method which can achieve significant capital and energy savings at WRRFs. Aeration power requirement in the downstream aerated activated sludge process is estimated to decrease by approximately 20-30% depending on specific WRRF operating conditions. The resultant increase in biogas energy production is estimated to be between 30 and 40%. The capacity increase in secondary treatment processes would be approximately 15 to 20%. The footprint requirement is reduced by approximately 75 % with PF as compared to conventional primary clarifiers.

The PF system at Linda WRRF is scheduled to remain in operation until March 2020. The detailed evaluation of the first full-scale PF installation at Linda WRRF along with the performance results obtained from pilot and demonstration projects provide essential information enabling wider implementation of this proven technology at other WRRFs.

ACKNOWLEDGEMENTS

The authors would like to thank the following agencies and entities for their participation and aid throughout this project: California Energy Commission; Linda County Water District (Olivehurst, California); Los Angeles County Sanitation Districts (Los Angeles, California), City of Manteca (Manteca, CA), City and County of Honolulu (Honolulu, Hawaii), City of Roseville (Roseville, CA), Aqua-Aerobics Systems, Inc. (Rockford, Illinois); Process Wastewater Technologies, LLC (Rosedale, Maryland); BASE Energy (San Francisco, California), and Kennedy/Jenks Consultants, Inc. (San Francisco, California).

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