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Performance of a Dual-Power, Multicellular, Aerated Lagoon System in Corcoran, California

AUTHORS
Alex Drohobyczer, Ph.D., P.E., Terry W. Schroepfer, P.E., and Jenelle H. Armstrong, P.E.

ABSTRACT:

A dual-power, multicellular, aerated (DPMC) lagoon system was designed and constructed for the city of Corcoran, California. The new process brought the plant into a full compliance with California Regional Water Quality Control Board (CRWQCB) effluent limits while saving approximately $110,000 per year in energy costs. The project was a modification of an existing aerated/facultative (A/F) lagoon that was plagued by algal growth for several years. The results after the first 19 months of DPMC operation indicated that the monthly average effluent five-day biochemical oxygen demand (BOD_5) and total suspended solids (TSS) concentrations were typically less than half of what they were prior. The DPMC aerated lagoon is applicable to many small plants as a process upgrade to underperforming lagoons or as a new process.

Prior to the upgrade detailed in this case study, the wastewater treatment plant (WWTP) serving the city of Corcoran, California, employed a conventional aerated/facultative (A/F) lagoon to treat primary effluent. The conventional lagoon was ineffective and the effluent often exceeded the discharge limits of 40 mg/L for five-day biochemical oxygen demand (BOD_5) and 45 mg/L for total suspended solids (TSS). In 2001, the plant exceeded the average monthly discharge limits four times for BOD_5 and nine times for TSS. Most of the violations occurred during the summer months.

In spite of effluent reclamation on land, the California Regional Water Quality Control Board (CRWQCB) insisted that the plant adhere to the discharge standards. Frequent notices of violation (NOV) were sent by the CRWQCB to the city of Corcoran regarding the ineffective plant. In response, the city chose to upgrade the existing A/F lagoon using a dual-power, multicellular aerated (DPMC) lagoon system to bring the plant into compliance. The use of a DPMC lagoon as a secondary treatment process is innovative. This paper describes and analyzes the project and its results.

Methods and Materials

For this analysis, we have used mostly the available plant data, except a small amount of additional data obtained by taking several grab samples for chlorophyll a and influent BOD_5 and TSS to the A/F lagoon. Data available for raw wastewater consisted of average monthly flows, total BOD_5 and TSS based on samples taken at the headworks once per week (composite 24-hour samples). The plant permit does not require testing the influent to the secondary process for BOD or TSS. Thus, historical data was not available on the characteristics of the influent to the A/F lagoon.

After construction of the DPMC aerated lagoon, the data collection method did not change. As a result, data was available for raw influent and final effluent characteristics. The sampling location for carbonaceous BOD_5 and TSS in the final effluent is located at the aerated lagoon effluent weir. The plant operator also has the option of taking the samples at the effluent from the polishing lagoon. However, during operation of the A/F lagoon, the polishing pond effluent samples often showed BOD and TSS results higher than from the A/F lagoon weir.

A commercial laboratory analyzed the BOD samples. The plant laboratory was used to analyze the TSS samples. All effluent samples were grab samples.

Original A/F Lagoon Process

The Corcoran WWTP has two separate treatment plants: primary and secondary. The primary plant includes headworks with a Parshall flume, comminutor, auger screen, and two primary settling tanks. In addition, an anaerobic digester stabilizes the primary sludge. The digested sludge is then dewatered on sludge drying beds and disposed off in a landfill. The primary effluent is pumped approximately two miles to the secondary plant.

The original secondary plant consisted of an A/F lagoon and a polishing pond. Final effluent from the polishing pond is flows to three evaporation/ percolation ponds and is used for irrigation. The total area of evaporation ponds and treatment lagoons is 37 acres and the irrigation disposal fields cover another 160 acres.

A/F Lagoon Description

The original A/F lagoon, shown on Figure 1 and in Photo 1, was 8 ft deep with a total volume of 16.0 million gallons (MG). The lagoon had an effluent weir located at the southwestern corner and an emergency effluent structure located at the southeastern corner.

Twelve mechanical surface aerators, each rated at 20 horsepower (HP), provided aeration. These aerators operated 24 hours per day, equating to a mixing intensity of 15 HP/MG, which classified the lagoon as partially mixed. At an average daily flow rate of 1.2 million gallons per day (MG/D) the hydraulic retention time (HRT) in the aerated lagoon was just over 13 days. This HRT was long enough for algae to grow in the lagoon.

Performance Problems

The poor performance of the lagoon was analyzed with an objective of improving the effluent quality by operational means and avoiding the expense of constructing a new process.

The installed aeration power was more than sufficient to provide oxygen for a relatively weak influent with a total BOD_5 of just below 100 mg/L. The poor effluent quality was clearly a result of long detention time in the lagoon that enhanced algal growth. Based on the greenish color of the A/F lagoon effluent, it was evident that algae were contributing to the elevated BOD_5 and TSS. Average BOD_5 and TSS concentrations during 17 months prior to the process modification were 37

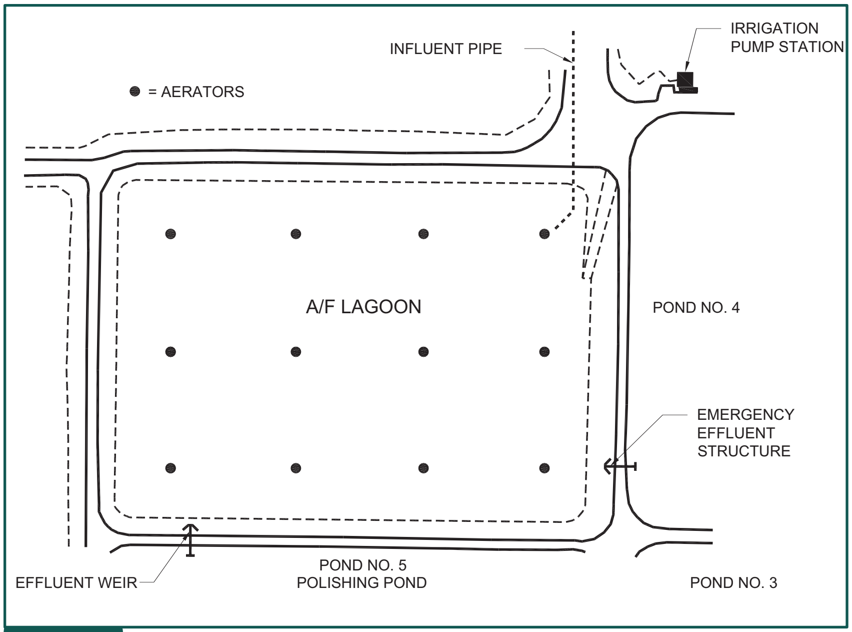

Figure 1 Original Corcoran, California, WWTP Aerated/Facultative Lagoon

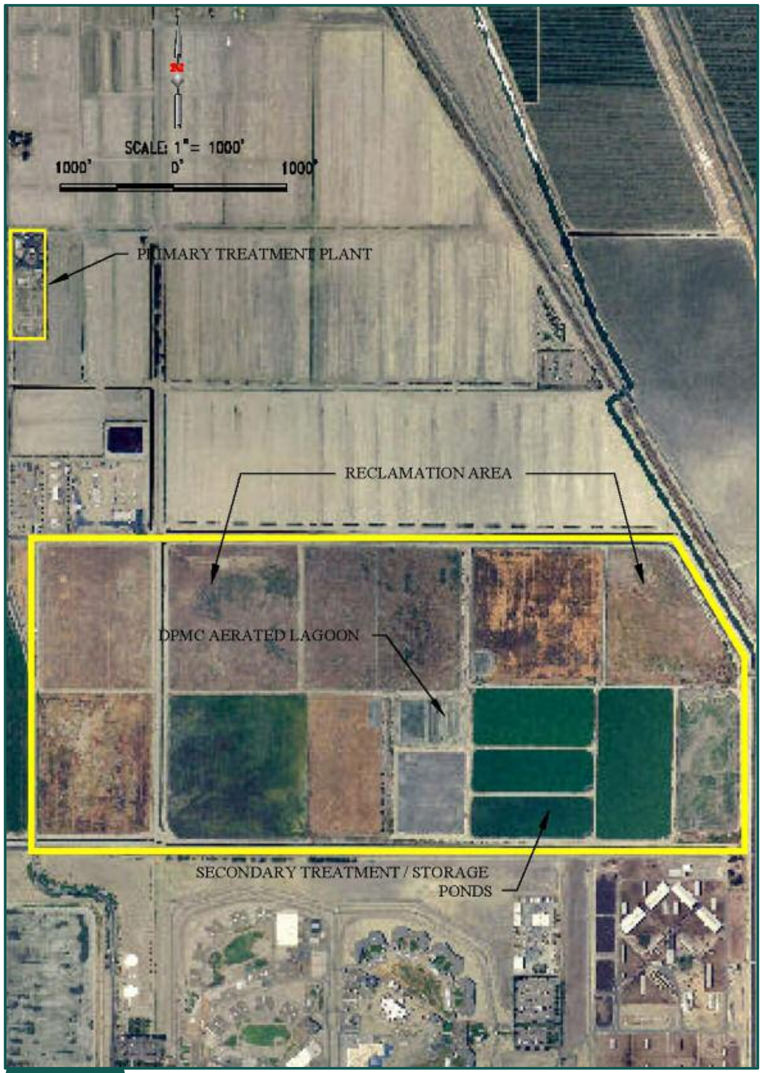

Photo 1 Aerial View of the Primary and Secondary Wastewater Treatment Facilities, Corcoran, California

mg/L and 50 mg/L, respectively, including four BOD5 and nine TSS permit violations.

Operational Changes

Before designing a new system, the plant staff experimented with the following operational changes to reduce the growth of algae:

- moving the compliance point from the effluent of the A/F lagoon to the effluent from the first storage lagoon and using that lagoon as a polishing pond;
- iIntermittent release of A/F lagoon effluent at night only to prevent release of floating algae;
- avoiding aeration during hours with high light intensity (around noon);
- application of copper sulfate to control algae;
- installation of a baffle around the effluent weir to reduce discharge of solids; and
- using different aeration patterns with some aerators on and some off.

The above operational adjustments proved unsuccessful and forced the city to search for an inexpensive process modification to control algal growth and increase process flexibility and reliability.

Wastewater Characteristics

Several years of flow monitoring data indicated that the average monthly flows to the plant were relatively stable at approximately 1.2 MG/D (see Figure 2).

Raw wastewater total BOD5 and TSS concentrations averaged 166 mg/L (see Figure 3) on a monthly basis. The expected BOD5 and TSS values in the primary effluent were approximately 95 mg/L and 50 mg/L, correspondingly. These values were calculated by assuming the raw BOD5 and TSS removal in the primary clarifiers at typical rates of 30 and 70 percent, respectively.

Several tests prior to final design of the DPMC lagoon confirmed these estimates. However, due to a lack of long-term records, we have applied a safety factor of 1.5 on influent BOD5 for design purposes. This safety factor also provides the flexibility for the modified lagoon to treat raw influent, if necessary.

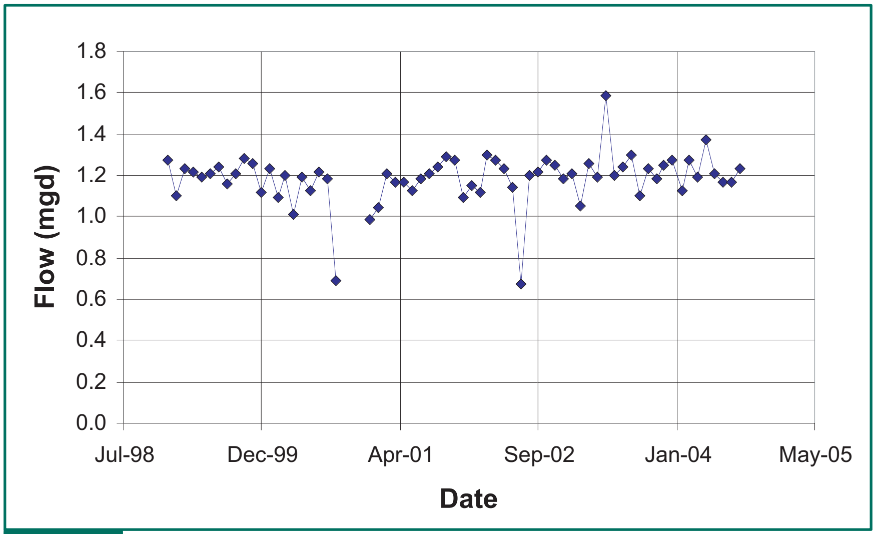

Figure 2 Raw Wastewater Flows

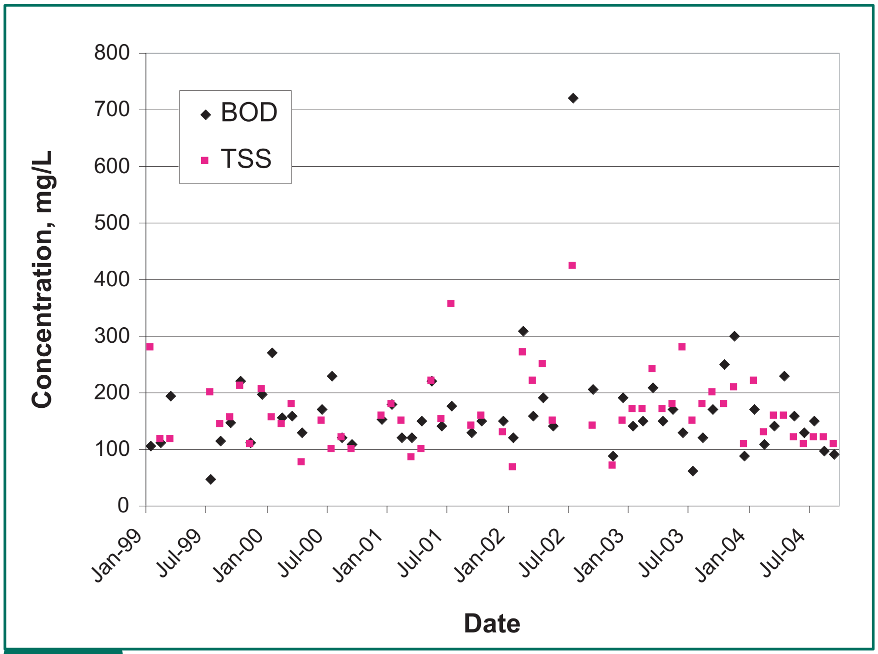

Figure 3 Raw Wastewater BOD and TSS

New DPMC Aerated Lagoon

Early in 2002, the city of Corcoran accepted the idea of converting the existing A/F lagoon to a DPMC aerated lagoon. The DPMC aerated lagoon is an innovative process that prevents algal growth by limiting detention time in the lagoon and compartmentalizing the settling process into a series of cells. DPMC aerated lagoon is a relatively new process. At the time when DPMC aerated lagoon was put in operation in Corcoran WWTP, it was one of the first such processes installed in California. This project was both an incredible opportunity and great risk for the city and engineer.

General Process Description

Dr. Linvil G. Rich (1999) who had developed the rationale for the process design pioneered the DPMC process. The DPMC aerated lagoon (see Figure 4 and Photo 2 below) uses multiple cells to treat either presettled or raw wastewater.

Aerators in the reactor cell vigorously mix and aerate to prevent biosolids from settling and to remove soluble organics. The role of the next three cells is to provide quiescent flow conditions for settling of biosolids and minimal aeration, at much lower power intensity than in the first cell, to prevent the odors. The first half of the process name, “dual-power,” is derived from the two different power intensities used.

The total HRT in the system is typically five days at the design flow rate. However, HRT is determined for each case by using a process design procedure and accounting for specific wastewater characteristics and other input parameters.

The DPMC aerated lagoon has a capacity to suppress algal growth due to its multicellular configuration. Rich (1996) proposed an equation to quantify algal growth in a series of n cells. The equation predicts a sharp decrease of algae numbers in the effluent with the increased number of lagoon cells for a given total retention time.

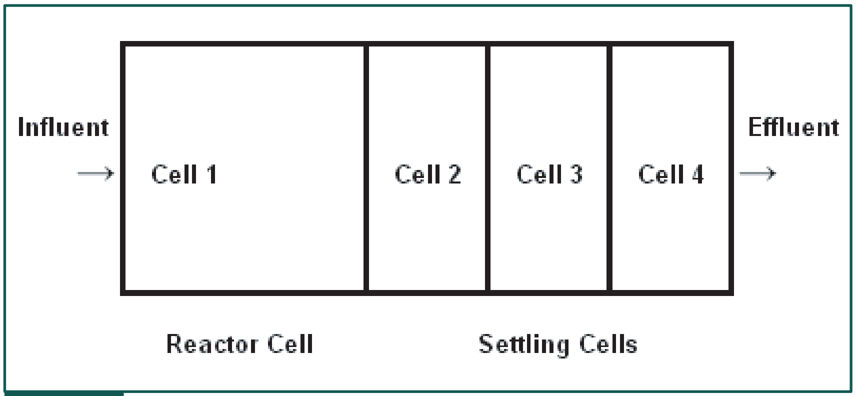

Figure 4 Single-Basin DPMC Aerated Lagoon

Reactor Cell

The minimum HRT for the reactor cell (Cell 1) is 1.5 days, which is necessary for flocculation of biosolids and effective settling in the downstream settling cells. Rich (1999) provides kinetic model and parameters for rational calculation of the retention time, biosolids production, oxygen, and power requirements for the reactor cell. Mechanical surface aerators provide aeration in the reactor cell. Aerators satisfy the higher of the two critical requirements: mixing and oxygen demand. Since the reactor basin must be a complete-mix reactor, the mixing power requirements depend on solids concentration in the basin. Rich (1999) provides information on calculating the required power input using low-speed mechanical surface aerators to maintain solids in suspension and a general procedure for process design based on a biokinetic approach.

Settling Cells

Settling cells (Cells 2 through 4) in the DPMC aerated lagoon system prevent algal growth by using serial multicellular configuration and by

Photo 2 DPMC Aerated Lagoon Cells. The Motor Control Center With a New Sun Shed and Cell 1 Are Shown at the Top of the Photo. Floating Baffles Separate the Cells.

limiting the overall hydraulic retention time. The HRT for the settling cells is determined using process design approach proposed by Rich (1999). The purpose of minimal aeration in the settling cells is to satisfy the benthal oxygen demand for odor control. The aeration energy is low enough to prevent any excessive turbulence. Biosolids settled at the bottom of the settling cells undergo aerobic and anaerobic decomposition as a benthic deposit.

Impact of Algae on Effluent BOD and TSS

Algae are generally the main component of BOD$_5$ and TSS in the lagoon effluent, especially during the summer months. Chlorophyll *a* is responsible for biosynthesis found in algal cells. *Standard Methods* (2003) includes an analytical procedure for its quantification. Chlorophyll *a* content in algal cells varies from species to species, but its measurement provides a good estimate of algae concentration. The algal TSS concentration determines the fraction of carbonaceous BOD$_5$ due to chlorophyll *a* Toms et al. (1975) proposed expressions relating algae concentration to TSS and particulate carbonaceous fraction of CBOD.

Design Criteria

The DPMC system for the city of Corcoran was designed for 2.0 MGD average daily flow. System configuration included a total of four cells (one reactor cell and three settling cells) in a single basin with a total water volume of 10 MG and total installed aeration power of 150 HP. The cell dividers consisted of three baffles made of synthetic membrane material. Table 1 presents a summary of the basis of design.

The volume of the cells provides a total of 5 days HRT at the design flow rate (2.0 MGD). The volumes of the reactor cell and each Settling cell were 4 MG and 2 MG, respectively. The design included six existing 20 HP aerators in the reactor cell and six new 5 HP aerators in the settling cells. Under normal operating conditions, five 20 HP aerators are used in the reactor cell and one 5 HP aerator is used in each settling cells. The normal aerator power load is, therefore, 115 HP, or 48 percent of the original A/F lagoon operating aeration power.

Table 1 **Basis of Design Summary**

Parameter	Unit	Design Value	Value at the Time of Design
Average Flow	MGD	2.0	1.2
Influent CBOD$_5$	mg/L	150	100 (total)
Influent TSS	mg/L	100	<100
HRT Cell 1	Day	2	3.3
HRT Cells 2, 3 and 4	Day	1	1.7
Total HRT	Day	5	8.4

Hydraulic Retention Time Flexibility

Changing HRT is one of the methods available to control the DPMC system performance. The final effluent weir has two removable weir planks to vary the water surface elevation within the system (see Photo 3). In addition, the existing emergency effluent structure provides the fourth and the lowest water level control option. There are four effective water depths available for operation: 10.0, 9.5, 9.0, and 8.5 ft. Each lower water depth reduces the HRT by approximately 3.5 percent. Therefore, the plant has the flexibility for up to 14 percent volume reduction when needed during periods of low flow. This flexibility in controlling water level in the lagoon was invaluable for reducing solids in the effluent during the first summer after the new system construction. Figure 5 shows the plan view of the Corcoran DPMC aerated lagoon.

Summary of Modifications to the Existing Process

Modifications to the original A/F lagoon that were necessary for its conversion to the DPMC aerated lagoon consisted of the following:

- increasing the total depth of the existing lagoon from 10 to 12 ft (10 feet side water depth plus two feet freeboard);
- using part of the excavated soil for construction of a dyke in the middle of the existing lagoon to create two lagoons, each capable of holding 10 MG. The east part of the A/F lagoon became the present DPMC aerated lagoon and the west part of the A/F Lagoon be-

Photo 3 **New Effluent Structure with Baffled, Adjustable Weir (Water-Level Control Planks Are Removed)**

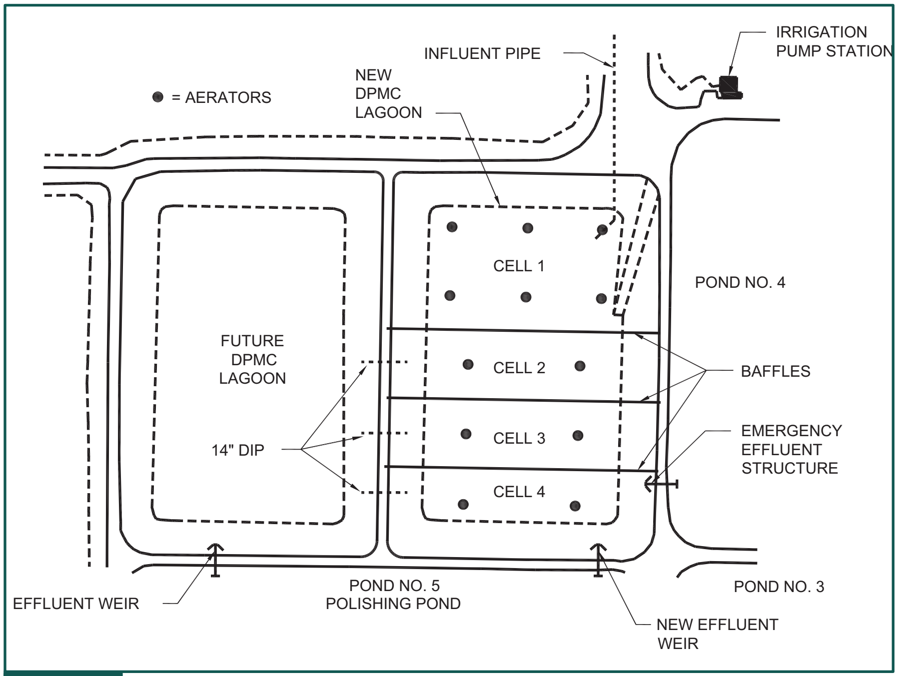

Figure 5 DPMC Aerated Lagoon

came the future DPMC aerated lagoon;

- the DPMC lagoon consisted of four compartments constructed using synthetic membrane baffles with curtains/windows for passage of flow in a meandering pattern from one cell to another;
- upgrading the motor control center (MCC) with new aerator motor timers (since overall power requirements were reduced, it was possible to reuse all the existing motor starters and posts with motor disconnects—most of the existing underground cables were left unexcavated to power the aerators that were simply relocated);
- Installating 14-inch ductile iron pipes (DIP) with butterfly valves between the East and West DPMC aerated lagoons provide flexibility for future rerouting of the flow.
- Stabilization of the lagoon embankments, initially with soil-cement, later, after deterioration due to aeration and wave action, with Shot-Crete ® lining.

The design of the new process took four months, including preparation of drawings, specifications and bid documents. The client received grant assistance from both Community Development Block Grants and Pacific Gas and Electric's SB 5X Incentive Fund grant based on peak load reduction. The Pacific Gas and Electric grant was sufficient to purchase six, 5-HP surface aerators for settling cells.

Process Comparison

The plant permit does not require testing for characteristics of influent to the aerated lagoon. Therefore, data for BOD and TSS is not available for the old A/F lagoon or for the new DPMC aerated lagoon. Therefore, the removal efficiencies of BOD_5 or TSS across the secondary treatment process have not been calculated. Instead, the performance of the new treatment process was evaluated by comparing effluent data and number of permit violations. Table 2 presents the performance data of the original A/F lagoon versus the new DPMC aerated lagoon.

The results presented in Table 2 demonstrate the superior performance of the DPMC aerated lagoon versus the conventional A/F lagoon. The new process drastically reduced both the BOD_5 and TSS average monthly concentrations. More importantly, the plant eliminated all violations caused by an under-performing treatment process. The single TSS violation on the record was due to a batch discharge of industrial wastewater containing concentrated oils. For the same reason, the effluent TSS concentrations were also elevated during three months in 2003 (March, May, and June). Figure 6 presents the DPMC aerated lagoon effluent characteristics for the period 19 months after DPMC system construction.

After construction of the new DPMC aerated lagoon, there was no increase in the difficulty of plant operation. The new process uses the same type of aerators (six of old ones, included); the same motor control center with improved timers; new, but low-technology equipment, such as synthetic membrane baffles, pipes, and butterfly valves interconnecting the east (future) and the west (new) DPMC lagoons; and the new weir with adjustable planks for varying the water level in the lagoon. The plant operators did not have any difficulty operating the new lagoon and no additional training was required. Once the new process started to produce effluent in compliance with the discharge requirements, the client and the operators were greatly relieved.

The DPMC aerated lagoon offers the following advantages as compared to a conventional A/F lagoon:

- the DPMC aerated lagoon is less costly to construct and operate than an A/F lagoon;
- it can achieve better effluent quality with a smaller footprint and less power input;
- it can be constructed in earthen basins—thus, an existing lagoon system can be easily modified to a DPMC aerated lagoon;
- it does not require external mechanical clarifiers;
- the only mechanical parts required are the aerators;
- sludge can be accumulated in the lagoon for years without disposal (sludge in one existing DPMC aerated lagoons has not been removed in 16 years of operation);
- the DPMC aerated lagoon is free of odor

Table 2 Performance of A/F Lagoon Versus DPMC Aerated Lagoon

Effluent Characteristic	Original A/F Lagoon ^{1} Effluent	New DPMC Lagoon ^{2} Effluent	Percent Reduction
BOD_5, mg/L	37	14	62%
TSS, mg/L	50	24	52%
BOD Violations	4	0	100%
TSS Violations	9	1^3	89%

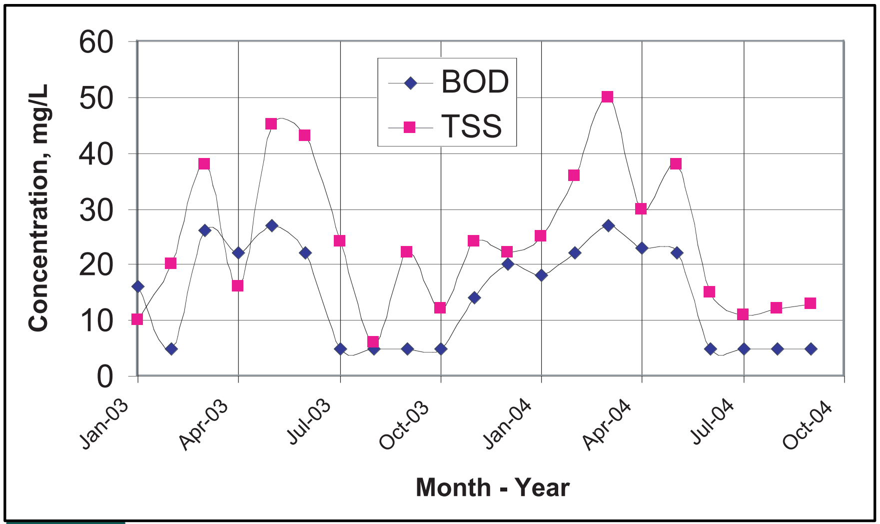

Figure 6 DPMC Aerated Lagoon Effluent BOD and TSS

- it produces effluent BOD_5 and TSS concentrations typically below 30/40. In addition, effluent BOD_5 is frequently in single digits.

Conclusions

The DPMC aerated lagoon system brought the city of Corcoran WWTP into discharge compliance while saving $110,000/year on energy expenses in the process. Total construction cost was approximately $650,000, including the cost of road improvements around the lagoons. The next least expensive alternative considered for this project was conversion of the aerated lagoon to a six-cell A/F lagoon estimated to cost over $2 million. The new DPMC aerated lagoon is approximately half the area and 62 percent of the volume of the original A/F lagoon and requires less than half the horsepower.

The DPMC aerated lagoon produces significantly better quality effluent than the original A/F lagoon. Average BOD_5 and TSS concentrations during 17 months prior to the process modification were 37 mg/L and 50 mg/L, respectively. Average BOD_5 and TSS concentrations during 19 months after modification were 14 mg/L and 24 mg/L, correspondingly, with nine months showing BOD_5 of less than 5 mg/L.

The DPMC aerated lagoon in Corcoran, treating presettled wastewater is unique since, originally, the process was developed for treatment of raw wastewater. Even though Rich (1999) does not recommend application of the DPMC aerated lagoon when the influent soluble CBOD (carbonaceous biochemical oxygen demand) is below 100 mg/L, the system in Corcoran is performing well with total presettled BOD_5 of just about 100 mg/L. The reason for it might be the presently high HRT in the reactor cell, 3.3 days and the process should be reevaluted when the flow reaches its design value of 2.0 MGD.

As a process, DPMC aerated lagoon is applicable to many small towns and rural wastewater agencies that currently operate underperforming lagoon systems. Therefore, DPMC aerated lagoon is a viable alternative for a new process or a process modification.

References

American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF). 2003. *Standard methods for examination of water and wastewater.* 20th ed.

Rich, L. G. 1999. *High performance aerated lagoon systems.* Annapolis, Maryland: American Academy of Environmental Engineers.

————. 1996. Modification of design approach to aerated lagoons. ASCE: *Journal of Environmental Engineering Division*. 122. 149–153.

Toms, I. P., et al. 1975. Observations on the performance of polishing lagoons at large regional works. *Water Pollution Control.* 74. 383–401.

CONTRIBUTING AUTHORS

Alex Drohobyczer, Ph.D., P.E.,

is a principal engineer with Brown and Caldwell, El Paso, Texas. He has over 22 years of experience in process design for municipal and industrial wastewater and water treatment facilities, piloting, modeling, and troubleshooting of treatment processes. He was recently involved in pilot studies and the design of six different arsenic treatment facilities and the design of ozonation, nitrification and denitrification processes. However, he counts this paper's subject project as one of his most satisfying professional experiences. If you have questions about the project, please contact Drohobyczer at **adrohobyczer@brwncald.com**.

Terry W. Schroepfer, P.E.,

is principal civil engineer and vice president of Quad Knopf, Inc., Bakersfield, California. He is a licensed civil engineer in California with over 30 years' experience in planning, special studies, design, and construction management of water and wastewater facilities. He earned B.S. degrees in civil and environmental engineering and biological sciences from the University of California, Irvine, and a M.S. degree in sanitary engineering from the University of California, Berkeley. He is the author/coauthor of over five technical papers. He can be contacted by e-mail at **TerryS@quadknopf.com.**

Jenelle H. Armstrong, P.E.,

is a senior engineer and project manager with Brown and Caldwell, El Paso, Texas. She earned a B.S. degree in civil engineering and an M.S. degree in environmental engineering from the University of Texas at El Paso. She has ten years' experience in water and wastewater systems modeling, preliminary engineering, and detailed design. She is currently managing numerous wastewater improvements projects for the Fort Bliss Water Services Company and the El Paso Water Utilities, which provide water and wastewater services to Fort Bliss and the El Paso community. She can be contacted at **jarmstrong@brwncald.com**.