New Surface Aerators Reduced Yuba City's Oxygen Dissolution Power Draw by 33%

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Abstract
The secondary treatment system at the Yuba City, California Wastewater Treatment Facility is a high purity oxygen UNOX System. Yuba City was the first high purity oxygen wastewater facility in California. The system consists of 3 aeration trains, each train containing 4 stages. Each stage is equipped with a surface aerator. Oxygen is supplied from a single 21 ton per day (TPD) pressure swing adsorption (PSA) oxygen generator.

Current dry weather influent flows average 6.0 mgd. During the summer, when power costs and demand charges are high, the temperature of the influent wastewater increases to approximately 29.4°C The only reliable way to handle the mass transfer requirements at these elevated temperatures has been to operate two UNOX System trains, even though hydraulically one train would be sufficient.

In early 2002, Yuba City had fabricated 4 new high efficiency surface aerator turbines under a special demonstration program agreement with the turbine's manufacturer. These turbines were then tested in the WTF's tanks using ASCE standard tap water test procedures. The testing indicated that these turbines, called the HI-FLO Surface Aeration System, had approximately 17% higher mass transfer efficiencies than the units that were originally installed in the WTF.

When retrofit on the WTF's existing, 25 year old gearboxes and shafts, the more efficient turbines increased the oxygen dissolution capacity of this equipment sufficiently so that single train operation was possible during the summer of 2002. Once installed, the new aeration system reduced oxygen dissolution power consumption by 33%, from 205 Hp. to 137 Hp. with no detrimental effects on biological performance. Similar savings may be available to wastewater facilities that have hydraulic capacity, but require increased oxygen dissolution capability.

Keywords
Surface Aerator, High Efficiency Surface Aeration, High Purity Oxygen, Power Savings, Mass Transfer Limitation, Optimization, Simulation

Introduction

The Yuba City, California Wastewater Treatment Facility (WTF) uses the high purity oxygen UNOX System for secondary treatment. The system consists of 3 independent aeration trains, each train containing 4 stages. The original design equipped each stage with a single, slow speed, pitched-blade (PBT) turbine type surface aerator. Oxygen is supplied from a single 21 ton per day (TPD) pressure swing adsorption (PSA) oxygen generator.

The secondary system was originally designed to handle 7 mgd of wastewater containing 492 mg/L BOD_5. Current dry weather influent flows average 6.0 mgd containing lower BOD_5 concentrations, currently averaging 380 mg/L. The lower influent loading is the result of decreased industrial loads, and hydraulically allows the plant to operate with only one of three UNOX System trains during most of the year. However, during the summer, when power costs and demand charges are high, the temperature of the influent wastewater increases to approximately 29.4^{o}C. The only reliable way to handle the mass transfer requirements at these elevated temperatures has been to operate two UNOX System trains, even though volumetrically one train would be sufficient.

Electrical demand charges are calculated for each billing cycle. Rates are divided into two rate periods, each about six months long – winter and summer. Winter demand charges average $2.60 per kW peak demand. Summer demand charges range from $2.55 for the period 6 p.m. until noon, and $11.80 per kW from noon until 6 p.m. For example, if maximum demand during the peak summer period were 1000 kW, the monthly demand charge would be $11,800, plus the demand charge of the non-peak period. A new demand charge will be established during the next month. Electrical energy costs also rise during summer non-peak period from $0.099 per kWh to $0.1640 per kWh during peak period. Shifting electrical demand and electricity usage from the peak demand period to off peak period results in significant reductions in total energy costs. Therefore, energy use minimization programs have been ongoing at the WTF for many years. These power minimization programs have been quite successful and have sensitized the plant staff to the mission critical nature of saving power.

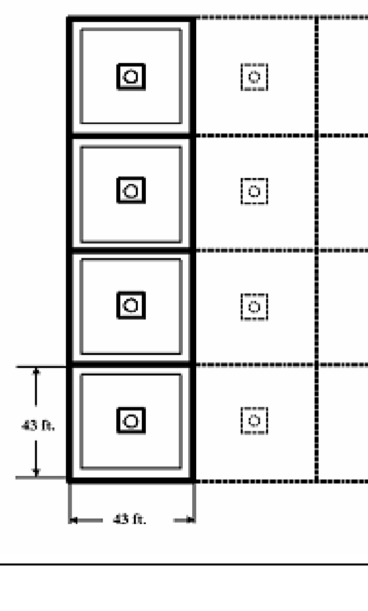
One such power saving program involves the shut down of the PSA oxygen generator during the summer peak demand period. From noon until 6 PM each day during the months of May through October, oxygen production at the WTF ceases. During these periods the operating UNOX System trains are supplied with vaporized liquid oxygen that is trucked into the plant. Detailed economic analyses indicated that this mode of operation minimizes the WTF's monthly demand charges, and reduces the amount of electrical power purchased at $0.1640 per kWh and is the most cost effective mode of operation for the plant.

In late 2001 the WTF staff surveyed the surface aeration system marketplace. This survey indicated that all of the major surface aerator vendors had developed "high efficiency" surface aerator equipment, of one sort or another. Among the "old line" surface aerator vendors was a new company called Mixing & Mass Transfer Technologies, Inc. (m^2t Technologies) of State College, Pennsylvania. Of all of the surface aerator vendors, m^2t Technologies' "high efficiency" HI-FLO surface aerator turbine appeared to be the easiest to retrofit to Yuba City's existing gearbox/shaft hardware. m^2t Technologies was contacted about demonstrating their new technology in an operating facility. Subsequently, a joint testing and full scale demonstration program was developed, resulting in a significant decrease in the WTF's summertime oxygen dissolution power consumption.

Methodology
Testing of various methods of increasing the mass transfer characteristics of the existing PBT aerators had been ongoing for approximately 1 year prior to the installation of the HI-FLO turbines. Simulation of the HPO dissolution system by DWG ASSOCIATES indicated that the PBT aerators could possibly meet summertime mass transfer requirements by increasing the submergence of these units. Full scale testing of the PBTs at various submergences indicated that this was not a viable, long-term solution for Yuba City. Yuba City tried single train operation during the summer of 2001. At maximum dissolution capability the existing PBT blades were not able to maintain adequate dissolved oxygen concentration at elevated summer wastewater temperatures. The system also experienced numerous hydrocarbon alarms, resulting in unplanned air purging of the train. Further simulation using the HI-FLO turbines in place of the PBTs indicated that the HI-FLO devices would allow single train operation during the summer.

The HI-FLO test program called for standardized tap water testing of m^2t Technologies' HI-FLO I Surface Aeration System impellers. The impellers were attached to Yuba City's existing gearboxes. DWG ASSOCIATES, Inc. of Marietta, Georgia conducted the aeration system test program. The largest of the original pitched blade turbines (PBT), plus each of the four HI-FLO I Surface Aeration System turbines fabricated under a special demonstration program agreement with Mixing & Mass Transfer Technologies were tested using the American Society of Civil Engineers (ASCE, 1992) standardized tap water reaeration test protocol. The objective of the test program was to confirm the simulation findings that the HI-FLO Surface Aeration System turbines could increase mass transfer sufficiently to allow dependable single UNOX System train operation during the summer months.

Figure 1
Yuba City WTF UNOX Train
(1 of 3 typ.)



All testing was conducted in the existing, covered UNOX System tanks at the Yuba City Wastewater Treatment Facility, shown schematically in Figure 1. In addition to being covered, the aeration tank at the WTF is divided into three equal volume UNOX System trains. Each train is separated from the others by a hydraulic wall, allowing for truly independent operation of each train. Each train is further divided into 4 distinct aeration stages, each with internal dimensions of 43' x 43' x 15'. Nominal side water depth is 11 feet. One of the UNOX System trains was used for tap water testing.

All tests followed the prescribed American Society of Civil Engineers tap water test procedures. Each test was conducted with air as the aerating gas and tap water as the liquid media. All D.O. versus time data were collected automatically using calibrated D.O. probes connected to a personal computer (DWG ASSOCIATES, 2002). All collected D.O. versus time data were analyzed using American Society of Civil Engineers (ASCE, 1996) software.

At one time or another during the life of the plant, all UNOX System trains had been used to treat Yuba City wastewater. Therefore, the tank chosen as the tap water test tank had to be thoroughly cleaned prior to test commencement. This cleaning was done by Yuba City personnel prior to the arrival on site of DWG ASSOCIATES' test personnel. By mutual agreement, the cleaning procedure consisted of removing all settled grit from the bottom of the tank and then "pressure" washing the tank walls with fire hoses. The tank was then filled with tap water and the existing aeration equipment was run for a few days. The tank was then drained and left empty until the HI-FLO Surface Aeration System equipment was installed and test personnel arrived.

During normal operation with wastewater, mixed liquor and oxygen gas flow through a train from stage to stage via openings in the interstage walls. There are liquid and gas openings in each of the three walls that divide a train into stages (see Figure 1). The liquid openings are relatively large and could have resulted in significant tap water interchange between the active test stage and the inactive stage during testing. Therefore for tap water testing, all liquid openings were "closed" with plywood and fiberglass panels. Each liquid opening cover was installed so that a small gap (e.g., 9" x 32") was left in each wall to facilitate tank draining and refilling. Although no quantification was done, liquid that may have passed through these openings (from the active test stage and the inactive stage) during testing was considered inconsequential. The gas openings in the interstage walls were not blocked. Other than the addition of these temporary liquid opening covers, no modifications were done to the internal tank walls, bottom, or anti-swirl baffles.

The entire Yuba City WTF UNOX System is covered with a concrete cover that is approximately 8 inches thick. As such, there is only limited access to the tank internals. Sampling points, sulfite addition points, and observation ports for this testing program were, therefore, dictated by the pre-existing openings or ports in the concrete cover. Dissolved oxygen (D.O.) sample port locations and sampling techniques, as well as sulfite addition points, have been described elsewhere (DWG ASSOCIATES, 2002). Suffice it to say that the location and operating characteristics of all sampling and chemical addition points met recommended ASCE test standards.

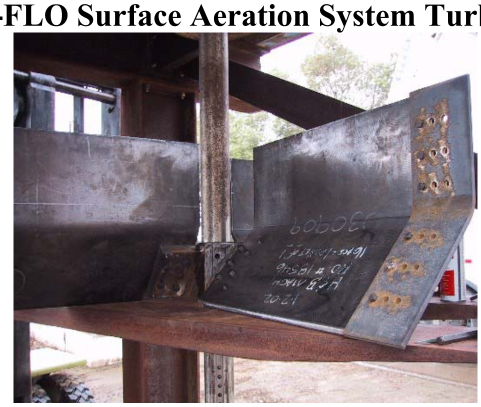
Because the test tank is covered, air was positively forced under the cover during tap water testing using one of the two installed hydrocarbon safety system purge blowers. The 10 Hp. purge blower, which has a rated capacity of 4020 cfm at 7.5 inches of water, provided sufficient air to ensure that oxygen purities remained at 21% under the cover for the duration of all tests. To confirm this, gas phase oxygen purity measurements were randomly taken during actual testing. Measured oxygen purity under the tank cover was never under 21%, even during maximum oxygen uptake periods.

Four HI-FLO Surface Aeration System turbines and hubs were constructed by a local fabricator, H & B Machinery, Inc. of Yuba City under a special demonstration program agreement with Mixing & Mass Transfer Technologies, Inc. The turbines were delivered unassembled in early February, 2002, and were subsequently assembled by the Yuba City staff under Mixing & Mass Transfer's supervision. The dimensional characteristics of the HI-FLO Surface Aeration System turbines were as shown in Table 1, and a picture of an assembled turbine is shown in Figure 2. Each turbine blade was also drilled to accept "tips," which are small extender tabs that can be bolted onto the blade to increase the turbine's diameter. In general, sufficient "tips" were available for each size turbine to allow for increasing diameters in increments of approximately 4 inches, up to the maximum diameters shown in Table 1.

Table 1
HI-FLO Surface Aeration System turbine characteristics

Stage	Base Hp.	Base Dia., in.	Dia. Range with "tips"
1	50	74.9	74.9 – 89.9
2	40	71.1	71.1 – 79.1
3	30	66.9	66.9 – 74.9
4	25	57	57 – 65

Figure 2
HI-FLO Surface Aeration System Turbine



Once assembled, the turbines were installed on the existing equipment shafts and reinstalled in the test train. The existing gearboxes were originally designed to handle the motor sizes listed in Table 2, "Original Horsepower." However, for testing (and subsequent actual operation) each gearbox was equipped with a motor that was one frame size larger. Mechanical analysis indicated that at the increased horsepower load all of the gearboxes should have service factors substantially above 1.0, and therefore should be sufficiently robust to handle the increased input and output horsepower. The horsepower used for testing per stage is also shown in Table 2. A single variable frequency drive (VFD) was used during the tap water testing. This drive was moved from stage to stage as required and used for turbine speed adjustment during the test program. Turbine assembly and aerator installation activities proceeded without problems and the test train was ready for tap water operation on February 20, 2002.

Table 2
Stagewise Horsepower Profiles

Stage	Original Horsepower	Test Horsepower
1	40	50
2	30	40
3	25	30
4	20	25

Results

The test tank was filled with fresh tap water and testing commenced on February 23, 2002. The test plan called for first testing the original first stage 40 Hp. PBT to establish a base efficiency for the existing equipment. Once the PBT efficiency had been established, the HI-FLO Surface Aeration System equipment was tested. There were a total of 76 individual ASCE tap water tests run during the approximately 2 month test program. The approximate operating ranges tested for each turbine size, including the original 40 Hp. PBT, are shown in Table 3.

A representative sample of the raw data for the 40 Hp. sized aerators (the only PBT data generated) is shown in Table 4. Analysis of the entire set of 40 Hp. test data indicates that the HI-FLO turbines produced SAE magnitudes of 3.4 to 3.7 lbs. O_2/sHp-hr., compared to approximately 3.0 lbs. O_2/sHp-hr. for the PBT. These results are for equivalent power draws at similar RPMs and submergences. In Yuba City's tank, the HI-FLO Surface Aeration System therefore showed a 15% to 20% improvement in SAE over the PBT.

Further analysis of the test data indicates that both the 40 Hp. PBT and HI-FLO turbines produced mass transfer efficiency magnitudes somewhat lower than would be expected for units of this size. Normally, a 40 Hp. PBT-type aerator operating in a well baffled tank would exhibit SAE magnitudes of 3.3 to 3.45 lbs. O_2/sHp.-hr. Likewise, m^2t Technologies expected performance for the HI-FLO Surface Aeration System turbine to be in the 4.0 lbs. O_2/sHp.-hr. range or higher. No quantitative analysis was done to establish the reasons for these lower than expected SAE magnitudes, but it is postulated that the decrease is due to a combination of tank geometry and tank baffling.

The WTF tank geometry (43' x 43' x 11' side water depth) is relatively "flat," presenting the aerator with a very large surface area. This is thought to mitigate some of the mass transfer effects of the aerator's umbrella. A second, and probably more significant factor is the tank's anti-swirl baffles. Although these baffles are properly positioned in the Yuba City tank, each of the four baffles is a mere 2 feet in length. For a tank of this geometry, properly sized baffles could be expected to be more than twice this size. Consequently, the relatively small anti-swirl baffles are probably not completely preventing vortexing, or swirl, of the liquid in the vicinity of the turbine. This will adversely affect the ability of the turbine to pump liquid into the umbrella, thereby decreasing the mass transfer capabilities of the unit.

Table 3
Surface Aerator Operating Ranges Tested

Aerator Size	Turbine Type	Total # Tests	Diameter, in.	RPM Range	Submergence Range
50 Hp.	HI-FLO	25	80.9, 85.9 & 89.9	45 to 58	-2.5" to +2.5"
40 Hp.	PBT	18	77.5	52 to 61.5	-5.25" to +1"
40 Hp.	HI-FLO	16	71.1 & 77.1	50 to 65	-5.75" to +0.75"
30 Hp.	HI-FLO	9	72.9	53 to 65	-2.75" to +4.25"
25 Hp.	HI-FLO	8	63	56 to 71	-1.75" to 2.38"

(1) Submergence measured relative to top of HI-FLO and PBT angled turbine blades [positive number indicates water is over the top of the angled part of the blade by that amount].
(2) Diameter measured blade tip to opposite blade tip.

Table 4
Comparative SAE & SOTR Test Data for the 40 Hp. Aerator

Date	Water Temp., ^{o}C	Impeller Type	Submergence (in.)	RPM	sHp.	SOTR $\#O_2$/hr.	SAE #/sHp-hr
3/24/02	14.8	PBT	0.79	61	34.0	102.9	3.02
3/24/02	14.9	PBT	-1.21	61	30.8	93.4	3.03
3/26/02	15.0	PBT	2.79	58	32.7	98.3	3.01
4/2/02	17.7	HI-FLO	-0.59	52	33.7	123.7	3.67
4/2/02	18	HI-FLO	0.93	52	35.7	124.3	3.48
4/3/02	18.1	HI-FLO	-0.59	48	27.0	90.2	3.35

Liquid velocities in the tests were measured using a Gurley Price meter installed 3' from the wall and 1' off bottom. Measured bottom velocity magnitudes for the PBT turbine, which were expected to be about 0.5 feet per second, were higher than anticipated. For all tests, the PBT turbine exhibited average velocities at the bottom of the tank of between 0.65 and 0.7 feet per second. These velocities are relatively high and may not seem consistent with the low pumping theory associated with the low SAEs. However, the high liquid velocities may be the result of liquid swirl in the tank and therefore are not inconsistent with decreased pumping. In fact, high liquid velocities and low SAE tend to support the theory that the tank baffling is inadequate.

The HI-FLO Surface Aeration System turbines consistently exhibited average velocities at the bottom of the tank approaching 0.8 feet per second. Since the Gurley Price meter does not indicate flow direction, it was not possible to determine if the velocity was the result of liquid swirl or turbine pumping for either the PBT or HI-FLO turbines. However, the HI-FLO turbine consistently showed bottom velocities that were approximately 12% to 13% higher than the PBT turbine when both units were operated at their optimum setup (i.e., speed, submergence, and diameter) conditions.

Representative test results for 50 Hp., 30 Hp., and 25 Hp. aerator sizes are shown in Table 5. Analysis of the test data for the 30 Hp. and 50 Hp. units indicate that the HI-FLO Surface Aeration System turbines exhibit SAE and liquid velocity magnitudes similar to the 40 Hp. unit. The 25 Hp. HI-FLO Surface Aeration System turbine

Table 5
Representative SAE & SOTR Test Data for the 50 Hp., 30 Hp. and 25 Hp. HI-FLO Surface Aeration System Turbines

Date	Water Temp., °C	Impeller Size, Hp.	Submergence (in.)	RPM	sHp.	SOTR #O_2/hr.	SAE #/sHp-hr
4/2/03	17.6	50	-2.46	58	42.6	145.7	3.42
4/11/03	18.9		0.41	48	45.4	155.9	3.43
4/3/03	18.1	30	-0.59	48	27.0	90.2	3.35
4/3/03	18.2		0.93	48	28.1	94.3	3.36
4/3/03	18.2	25	-0.59	45	24	74.3	3.17
4/3/02	18.3		0.93	45	25	79.9	3.23

exhibited lower SAE magnitudes than the larger units, although bottom velocities for this unit were the same as for the larger units. It is assumed that the PBT turbine mass transfer efficiencies of the units not tested vary from their HI-FLO counterparts by the same percentages as were measured for the 40 Hp. units tested.

Discussion

In late April 2002, the HI-FLO Surface Aeration System equipment was moved from the clean, tap water test train to an operating train. Additional VFDs were purchased by Yuba City and installed on the first three UNOX System stages (stage 4 is operating without a VFD). On May 1, 2002, the HI-FLO aerator train was fed sewage. Power draws for each stage were "dialed-in" such that each motor was drawing approximate nameplate horsepower. During the first month or so of operation, tweaking of the power draws in the first three stages occurred by adjusting the impeller RPMs with the VFDs.

Comparing the summer of 2001 two train operation to 2002 single train operation (influent conditions are about the same), dissolution power consumption has decreased from about 205 Hp. with two trains on-line to approximately 137 Hp., a 33% power reduction. Operating D.O. concentrations are well above 6 mg/L, and all process variables are excellent. Qualitative analysis using D.O. meter readings indicates that the stage contents are much more uniform than when the aeration devices were PBTs. D.O. meter readings at any given location in the tank are very steady with the HI-FLO aerators, whereas they fluctuated considerably when the PBTs were operating.

Two problems have occurred since the HI-FLO Surface Aeration System went on line. The 25 Hp. motor on the aerator in the fourth stage burned out and the second stage high speed gearbox input shaft has broken, been repaired, and broken again. Both Yuba City personnel and m^2t Technologies have attributed these problems to the age of the equipment.

The motor was an original from 1975, and may have burned out regardless of which turbine was installed on its shaft. A new motor was installed and has operated without problems since installation. The second stage gearbox is also an original from 1975. m^2t Technologies' analyses indicate that service factors on all components of the gearbox far exceed 1.0. However, one old high speed shaft has broken, and its brand new replacement has also broken. The second, or new shaft that broke was analyzed, and the breakage is clearly due to stresses being applied to the shaft. Analysis of the gearbox housing indicates that all parts of this unit appear to be within spec. Therefore, no definitive reason for this breakage has been determined. At this time, no further analysis of this problem is planned. In fact, the solution to this problem has been to replace the stage 2 gearbox with one of the unused, larger stage 1 gearboxes. No breakage problems have been experienced since this change has been made.

Conclusions

Minimization of operating costs, especially power consumption, has been and will continue to be an ongoing program at the Yuba City Wastewater Treatment Facility. In late 2001, the WTF staff became aware of high efficiency surface aeration equipment that appeared to offer an opportunity to save considerable dissolution system power at the plant. Computer simulation of the secondary system using the high efficiency surface aeration equipment supported and quantified the potential power savings.

Based on the simulation results, Yuba City and Mixing & Mass Transfer Technologies, Inc. jointly conducted ASCE tap water testing of the HI-FLO Surface Aeration System turbines at Yuba City's Wastewater Treatment Facility. The tap water test results indicated that the HI-FLO turbines had 15% - 20% higher Standard Aeration Efficiencies (SAE) than the existing PBT aerators at the plant. At these elevated SAE magnitudes, the WTF could theoretically operate with only one aeration train during high temperature summer operation, instead of the two trains that was normal with the PBT aerators.

During the summer of 2002, the Yuba City WTF successfully operated using only a single aeration train equipped with the HI-FLO Surface Aeration System. Single train operation reduced operating power draw from the normal 205 Hp. with two trains operating to 137 Hp. All process variables (e.g., D.O., mixing, etc.) with single train operation were excellent, as was effluent quality. The HI-FLO Surface Aeration System has therefore resulted in a 33% reduction in dissolution power draw during summer operation at the WTF.

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