# CLEAN WATER TESTING OF INNOVATIVE SURFACE AERATORS PROMISES SIGNIFICANT SAVINGS FOR CHATTANOOGA'S MOCCASIN BEND WWTP

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## ABSTRACT

Chattanooga's Moccasin Bend Wastewater Treatment Plant includes an aging UNOX high purity oxygen activated sludge system. The original pitched blade turbine aerators and associated instrumentation are in need of replacement. The City awarded a contract for the oxygenation system replacement which involved the furnishing of unique, up-pumping, low speed surface aerators manufactured by Mixing & Mass Transfer Technologies, Inc. The project included witnessed, ASCE clean water factory testing to demonstrate satisfaction of performance guarantees by the manufacturer for oxygen transfer and maximum power draw. Factory tests were conducted at the Lightnin test facility in October, 2002. Results showed that the aerators were capable of standard aeration efficiencies in excess of 4 pounds oxygen per brake horsepower in the test tank. The aerators satisfied the clean water performance guarantees and will provide significant power savings for the operation of the City's treatment facility.

**KEYWORDS:** Low-speed surface aeration, clean water testing, standard aeration efficiency

## INTRODUCTION

Chattanooga's Moccasin Bend Wastewater Treatment Plant (WWTP) treats an average of 73 mgd of municipal wastewater from a regional sewer system serving twelve cities and four counties in southeast Tennessee and northwest Georgia. The plant's secondary treatment system has a design flow of 140 million gallons per day (mgd), and a parallel wet weather treatment system provides another 80 mgd of peak wet weather capacity. Unit processes include pumping, fine screening, grit removal, primary clarification, in-stream flow equalization, oxygen activated sludge, final clarification, chlorine disinfection, and dechlorination. Treated wastewater is discharged into the Tennessee River just downstream of Chattanooga.

Moccasin Bend WWTP was one of the first UNOX system high purity oxygen activated sludge wastewater plants in the U.S. The high purity oxygen system at Moccasin Bend was retrofitted into existing tanks and started operation in 1980. It consists of four covered oxygenation trains (rectangular tanks) and is supplied with oxygen from a 145-

ton-per-day cryogenic oxygen generator. Each oxygenation train consists of eight 60-foot-square by 17-foot-deep aeration stages. Each stage has a single 125-HP or 100-HP low speed surface aerator equipped with a down-pumping pitched-blade turbine (PBT) surface impeller. In addition to the surface impeller, each aerator also has a lower PBT-type impeller to facilitate mixing in the lower portions of the tank. Total nameplate horsepower (NHP) is 850 HP per train, or 3,400 HP for the entire system. High purity oxygen gas at 95 to 98 percent oxygen by volume is introduced into the gas space in the first stage of each train. Gas flows through each of the stages in series and is vented from the last stage. The vent gas contains about 40 percent oxygen, with the remainder consisting of carbon dioxide, nitrogen, and water vapor.

The oxygenation and oxygen generation systems have operated continuously since startup. After 20+ years of operation, the surface aeration equipment and instrumentation systems have exceeded their useful lives. Maintenance on the aerator gear reducers is now excessive, instrumentation is obsolete, and replacement parts are difficult and/or expensive to obtain. To design a replacement oxygenation system, the City of Chattanooga retained a joint venture made up of Consolidated Technologies, Inc. (CTI) and Arcadis, consulting engineering firms with offices in Chattanooga. CTI was responsible for the overall process design and equipment selection. To assist with process modeling of the oxygen activated sludge system, CTI in turn retained DWG Associates, Inc. of Atlanta.

## APPROACH

Originally, the Moccasin Bend UNOX system was designed to handle an average flow of 65 mgd of wastewater containing 165,900 pounds $BOD_5$/day, 75 percent of which was generated by industries. Due to changes in the composition of the wastewater from industrial sources over the last 20 years, the projected design $BOD_5$ load has decreased somewhat to 152,200 pounds per day at a slightly higher average flow rate of 73 mgd. Because of this change and the availability of more efficient aeration equipment, the design team hoped to achieve significant reductions in aeration horsepower (HP) and operating cost over the existing PBT aerators. The team also decided to consider aeration technologies other than low speed surface aerators. The only constraints were that the replacement aeration equipment had to utilize high purity oxygen and had to be adaptable to the existing covered UNOX tanks. Three technologies were evaluated: a floating, shrouded, high speed oxygenator; an oxygen injector system with recirculation pump, submerged discharge nozzles, and a low speed mixer; and low speed surface aerators. The floating oxygenator and the oxygen injection/mixing system were both installed in the first stage of one of Moccasin Bend's trains to evaluate field performance over a period of several months during 2001.

At the conclusion of this evaluation period, design and bidding documents were developed and the project was publicly advertised for bids. The documents included stage-by-stage minimum oxygen transfer requirements under both field and standard clean water conditions. The successful bidder had to guarantee minimum oxygen transfer rate, maximum dissolution brake horsepower (BHP), and overall oxygen utilization efficiency. The bidder also had to demonstrate performance in both an ASCE clean water factory test prior to shipment and a field performance test following installation. Failure to meet the minimum guaranteed oxygen transfer rates would result in the assessment of liquidated damages equal to $3,600 times the difference between the guaranteed maximum BHP and the BHP actually required to achieve the minimum transfer rate. There was also a performance guarantee for mixing.

Bids for the oxygenation system replacement project were opened in December 2001. There were three bidders: U.S. Filter/Kruger Products; Linde Process Plants; and Chemineer. After an extensive bid evaluation, the City of Chattanooga selected Linde Process Plants to provide the replacement oxygenation system. Linde Process Plants chose Mixing & Mass Transfer Technologies, Inc. ($m^2t$ Technologies) to furnish the low speed surface aerators. The maximum dissolution system power guaranteed by $m^2t$ Technologies for the four trains was 1,749 BHP, which was 43 percent lower than the 3,066 BHP of the original PBT system.

Each surface aerator proposed by $m^2t$ Technologies consists of a low speed gearbox; a four-blade, up-pumping HI-FLO Surface Aeration System impeller; and a lower hydrofoil mixing impeller. Wetted parts are constructed of Type 316 stainless steel. Gearboxes, which are being manufactured for $m^2t$ Technologies by Lightnin, are right angle, hollow quill designs with minimum 3.0 service factor and a 10-year guarantee against mechanical failure. Aerator sizes are 60, 75, and 100 NHP.

The design team was somewhat concerned over the unusually high aeration efficiencies claimed by $m^2t$ Technologies for its low speed surface aerators, particularly since the aerator rotational speed was higher than that normally found in low speed devices. Thus, the clean water factory test was a critical milestone in the project.

**METHODOLOGY**

The $m^2t$ Technologies tap water performance tests were conducted in Rochester, New York at the Lightnin factory. All tests were performed in Lightnin's test tank in strict accordance with the latest edition of the ASCE tap water reaeration protocol (ASCE, 1992). Lightnin's tank has nominal surface dimensions of 49 feet by 49 feet, with a side wall height of approximately 35 feet. The nominal water depth used for testing ranged from 16 feet 6.5 inches to 17 feet 3 inches. Exact liquid levels and tank water volumes were determined after each test run. Witnessing the test were representatives of $m^2t$ Technologies, CTI, and GSEE.

To approximate Chattanooga's stage internals as closely as possible during testing, temporary anti-swirl baffles having the same dimensions as the baffles in Chattanooga's tanks were constructed of plywood in the test tank. These baffles were extended above the liquid level to the height of the underside of Chattanooga's tank cover (approximately 3.5 feet). Extending the baffles provided a semi-quantitative method for determining that the aerator umbrella would not impinge on the underside of the Moccasin Bend tank cover during operation.

The surface aeration impeller tested was identical to the equipment that was shipped to the Moccasin Bend WWTP, except it was constructed of carbon rather than stainless steel. The impellers were similar to the HI-FLO Surface Aeration System impeller shown on Figure 1. Three HI-FLO Surface Aeration System impellers were tested. The HI-FLO impeller characteristics are shown in Table 1.

**Figure 1**
**HI-FLO Surface Aeration System Turbine**

**Table 1**
**HI-FLO Surface Aeration System Tested Impeller Characteristics**

| Nominal NHP | Surface Impeller Diameter (inches) | Lower Impeller Diameter (inches) | Rotational Speed (rpm) |
|---|---|---|---|
| 100 | 83 | 63.5 | 56 |
| 75 | 80 | 63.5 | 56 |
| 60 | 75 | 63.5 | 56 |

The lower mixing impeller (LMI) used for all testing was a hydrofoil-type impeller. Its diameter, as shown in the table, was the same for all tests, even though this is larger than will be installed on the 75-HP and 60-HP impellers at Moccasin Bend. Changing the LMI during testing would have involved a minimum of 36 hours of downtime for each change. For testing expediency, the decision was made to use the single largest LMI to demonstrate the three different surface impellers. This decision was approved by the design team.

The drive unit for the test work was a 200-HP electric motor equipped with a variable frequency drive (VFD) coupled to a Model 762 Lightnin gearbox. This gearbox is a triple reduction unit with a yielding reduction ratio of 25.84. The gearbox is nominally rated at 460 HP at an output of 70 rpm. Since all testing was performed at 56 rpm, the gearbox rating was calculated by the manufacturer to be about 410 HP. The impellers (both the surface and LMI) were attached to the gearbox output shaft, which extended from the underside of the gearbox to the bottom of the tank. The shaft length is approximately 35 feet. To obviate harmonic oscillation and critical speed issues during test operations, the bottom end of the shaft was supported at the tank bottom with a steady bearing.

A calibrated torque cell was installed between the motor output shaft and the gearbox input shaft to ensure accurate power measurements. The torque cell measured the torque in inch-pounds at the gearbox high speed input shaft and was directly connected to the computerized data logger. Torque cell readings were recorded simultaneously with the dissolved oxygen (DO) readings for each test run.

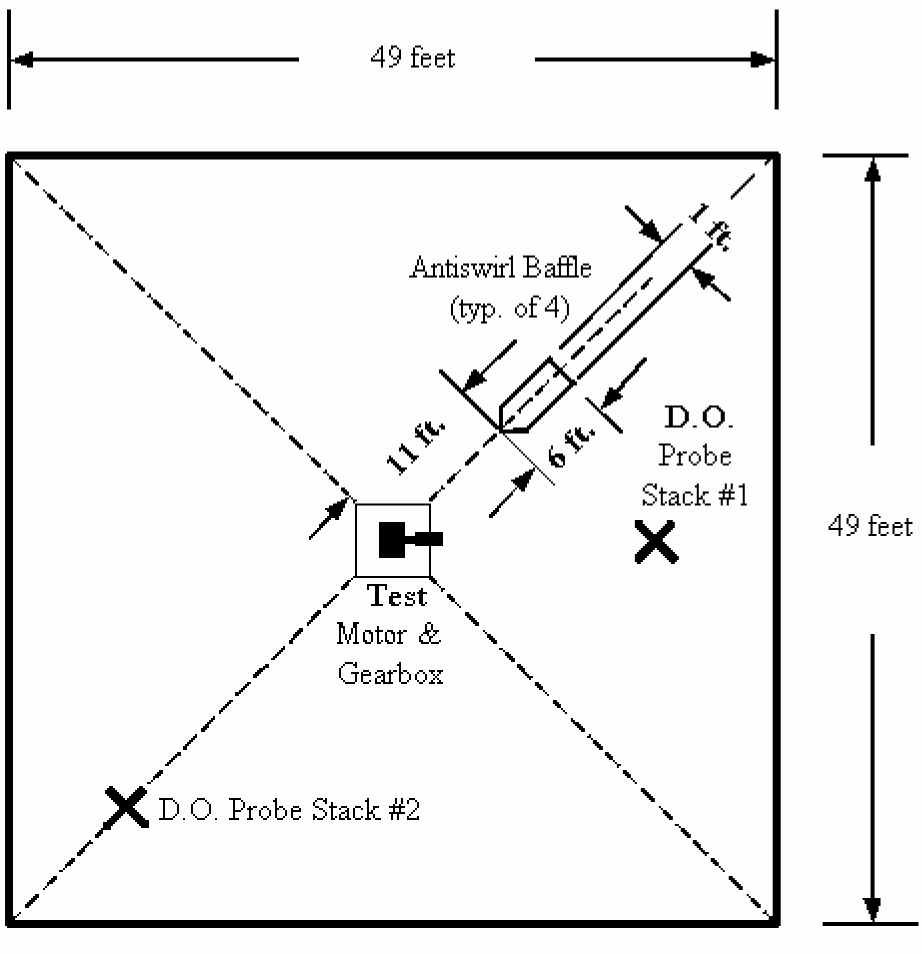
DO concentrations were monitored in the test tank using six YSI probes and meters. The probes were calibrated prior to each run by setting the probe output to the saturation value for DO based on the water temperature and ambient barometric pressure at the test tank. Winkler titration values for DO of the saturated tank water were run periodically as a check of this procedure.

As indicated on Figure 2, the six YSI probes were installed in “stacks” of three at two locations. The first stack of three probes was located 19 feet from the center of the tank on a line perpendicular from the aerator to the tank wall. These “stacked” probes were located 2 feet off the bottom, at mid tank depth, and 14 feet 6 inches off the bottom, respectively. The second stack of probes was located 25 feet from the center of the tank on the diagonal to the tank corner. These probes were located at the same elevations as the first stack. DO meter output was recorded by the data logger at 14-second intervals. Observations continued up to 98 percent of saturation. At the conclusion of the test run, the recorded DO and time values were converted to an electronic data set for use by the ASCE computer program (ASCE, 1996) that calculated the standard oxygen transfer rate (SOTR) of each test run.

Ambient barometric pressure during the testing was obtained from hourly readings recorded at the Buffalo, New York NOAA weather station. To account for differences in elevation between Buffalo and Rochester, 0.13 inch mercury was added to the weather station reading. The weather station pressure magnitudes were then averaged with a barometric pressure reading from a locally mounted pressure gauge and barometer to establish the ambient barometric pressure for test periods. Both test water and ambient air temperatures were recorded from locally mounted thermometers. All pressures and temperatures during the test period were within ASCE prescribed ranges.

Figure 2

**Test Tank Baffling and Sample Point Locations**




Notes: Drawing not to scale.
Only one baffle (of 4) shown for clarity.
Baffle dimensions: 6 ft. nose to tail, 1 ft. thick.
D.O. Probe Stack locations: #1 - 19 ft. from tank center
#2 - 25 ft. from tank center

Technical grade, anhydrous sodium sulfite ($Na_2SO_3$) dissolved in approximately 550 gallons of tap water was added to the tank prior to each test to deoxygenate the test tank water. The dissolved $Na_2SO_3$ was always added with the aerator running. Sufficient sulfite was added to reduce the DO level to essentially zero at all probe locations for all tests. The amount of sulfite added ranged from 300 pounds to 425 pounds. Samples of the tank water were analyzed for total dissolved solids (TDS) concentration at the conclusion of each test run. To keep TDS concentrations within the ASCE recommended range, water was drained from the test tank at the conclusion of each day's testing. The wasted water was then replaced with clean tap water during the overnight hours. TDS concentrations ranged from 1,280 milligrams per liter (mg/L) to 1,880 mg/L over the test period and averaged approximately 1,500 mg/L.

Cobalt chloride catalyst was also added to the test tank water to facilitate the deoxygenation reaction. The cobalt ion concentration was determined at the start of the factory test program, as well as prior to testing each successive surface aerator impeller diameter. Since some catalyst was lost each time the tank was partially drained and refilled, additional cobalt catalyst was added each time the surface impellers were changed to a different diameter. Cobalt ion concentrations ranged from 0.186 mg/L to 0.391 mg/L during testing.

**RESULTS**

Sixteen individual SOTR tests were performed for the three distinct surface impeller diameters tested ($m^2t$ Technologies, 2002). The testing was conducted over a contiguous 4-day period in October 2002. Since all aerator impellers to be supplied to the Moccasin Bend plant operate at 56 rpm, all tests were conducted at that rotational speed. Power draw variation for each impeller size was therefore constrained to that which could be obtained by impeller submergence variations. A summary of the collected data is shown in Table 2. The HP draws shown in the table include the power draw of both the surface impeller and the LMI.

**Table 2**
**Tap Water Test Data**

| Surface Impeller Dia. (inches) | Test Water Temp. (°C) | Impeller Submergence (inches) | Motor Output Shaft Power (BHP) | SOTR (lbs. $O_2$/hr) | SAE (lbs. $O_2$/BHP-hr) |
|---|---|---|---|---|---|
| 75 | 13.6 | 1.50 | 52.8 | 232 | 4.4 |
| 75 | 13.2 | -0.50 | 49.6 | 212 | 4.3 |
| 75 | 13.1 | -2.00 | 47.6 | 204 | 4.3 |
| 75 | 13.2 | 3.00 | 54.9 | 232 | 4.2 |
| 75 | 13.3 | 5.63 | 59.3 | 246 | 4.2 |
| 75 | 13.2 | 2.00 | 53.7 | 231 | 4.3 |
| 75 | 13.1 | -0.25 | 49.2 | 210 | 4.3 |
| 75 | 13.1 | -2.25 | 45.4 | 196 | 4.3 |
| 80 | 13.3 | 5.25 | 76.8 | 279 | 3.6 |
| 80 | 13.3 | 3.63 | 73.3 | 280 | 3.8 |
| 80 | 13.1 | 1.75 | 69.6 | 268 | 3.9 |
| 80 | 12.9 | 0.00 | 65.9 | 270 | 4.1 |
| 83 | 12.9 | 0.00 | 79.4 | 312 | 3.9 |
| 83 | 12.9 | 2.00 | 83.8 | 329 | 3.9 |
| 83 | 12.8 | -1.50 | 76.3 | 301 | 3.9 |
| 83 | 12.8 | 1.00 | 82.4 | 314 | 3.8 |

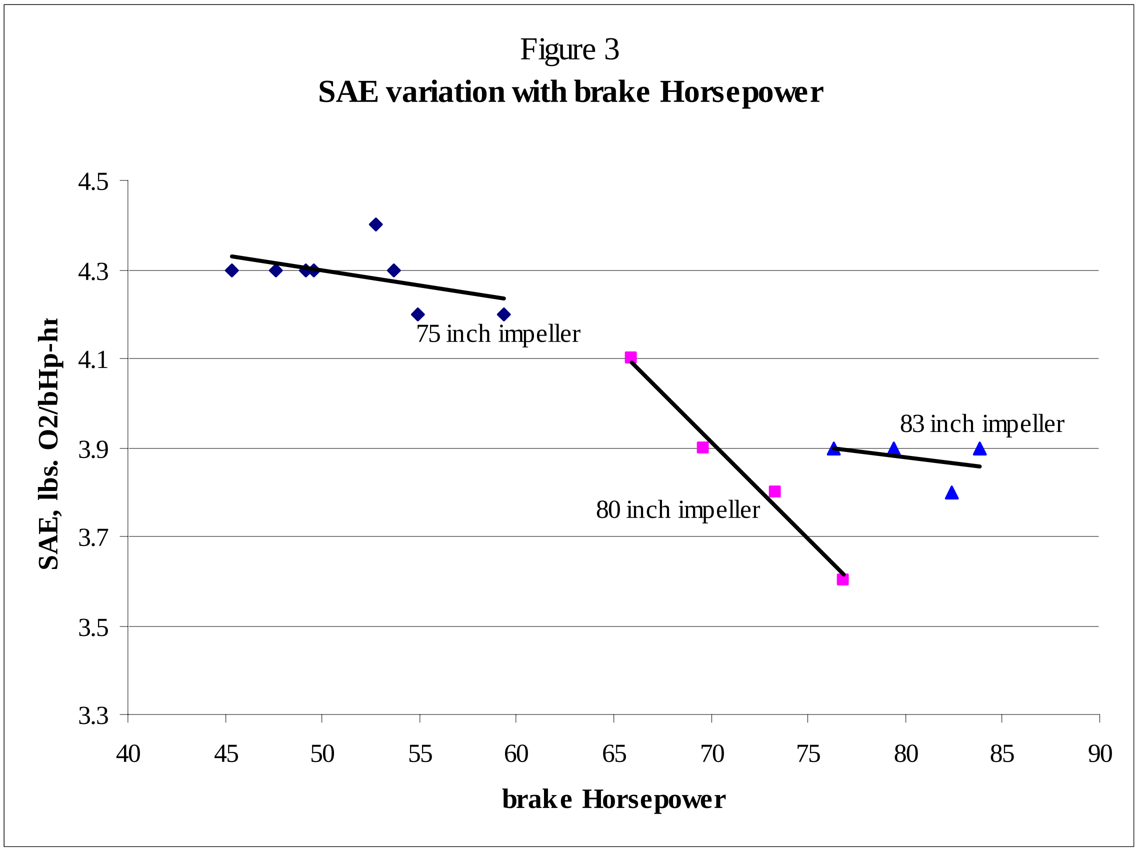
**Table 3**
**Guaranteed and Factory Test Power Draw for the Moccasin Bend WWTP**

| Stage | Guaranteed SOTR lbs. O2/hr. | Required Test Tank SOTR lbs. O2/hr. | Guaranteed Maximum Power (BHP) | Required Power based on Factory Testing (BHP) |
|---|---|---|---|---|
| 1 | N/A | N/A | 7.4 | 3.8 |
| 2 | 295 | 323 | 79.7 | 83.3 |
| 3 | 267 | 290 | 74.0 | 73.0 |
| 4 | 238 | 257 | 67.6 | 55.2 |
| 5 | 210 | 225 | 61.2 | 52.9 |
| 6 | 170 | 176 | 50.9 | 40.0 |
| 7 | 160 | 164 | 47.9 | 36.9 |
| 8 | 162 | 166 | 48.5 | 37.1 |
| Totals: | | | | |
| Tank | 1,502 | 1,601 | 437.2 | 383.2 |
| **System** | **6,008** | **6,404** | **1,748.8** | **1,528.8** |

Notes: Stage 1 is anoxic with only a submerged mixer. Test tank required SOTR corrected for surface power density.

As the table shows, SOTRs varied in direct proportion to increasing HP draw. During the tests, SOTR magnitudes ranged from a low of 196 pounds $O_2$/hr. at 45.4 BHP to a high of 329 pounds $O_2$/hr. at 83.8 BHP. Standard aeration efficiency (SAEs) ranged from a low of 3.6 pounds $O_2$/bHp-hr. to a high of 4.4 pounds $O_2$/bHp-hr. As expected and shown on Figure 3, the SAE magnitude decreased as input HP increased. Figure 3 also shows the trend line exhibited by each impeller during the tests.

As noted earlier, the total dissolved solids concentrations in the test water averaged approximately 1,500 mg/l during testing. The test procedure for this project did not require normalization of test SOTR to a particular TDS concentration (i.e., 1,000 mg/l). It is anticipated that this will be included in pending revisions to the ASCE clean water test procedure. Normalization of test results to 1,000 mg/l TDS would result in slightly lower test SOTR's.




Although not shown in the Table, the umbrella height was visually observed during each SOTR test. The HI-FLO Surface Aeration System umbrella was well below the exposed height of the baffles at all power draws. Therefore the umbrellas will not impinge on the underside of the Moccasin Bend UNOX system tank covers.

**DISCUSSION**

The test results were generally consistent with HI-FLO Surface Aeration System results collected elsewhere. Power consumption variation with impeller submergence was essentially as $m^2t$ Technologies had expected. Likewise, the variation of SOTR with power draw was, in general, as expected, especially for the 75-inch and 83-inch impellers. The 75-inch and 83-inch impellers showed almost identical variations in SOTR and SAE with power draw. Although all three impellers were geometrically similar, the 80-inch impeller exhibited a very shallow, or flat, SOTR variation with power. This is shown in Table 2 and also on Figure 2 as a very significant variation in SAE with power draw.

The test period was much too short to allow an investigation of the reason behind these results. Therefore, no quantifiable explanation has been developed. However, it is postulated that impeller submergence may possibly play a role in the phenomenon. Table 3 shows that of all the impeller sizes, only the 80-inch impeller was tested exclusively at positive submergences. Another potential explanation may be the impeller/tank geometry. In any case, the SOTR variation exhibited by the 80-inch impeller during the tests was used for design purposes.

The 80-inch impeller anomaly notwithstanding, the results of the factory test exceeded expectations. The “guaranteed SOTR” and the “required test tank SOTR” are shown in Table 3. To establish the “required test tank SOTR,” the “guaranteed SOTR” for the actual field installation was adjusted to correct for differences in surface power densities between the actual tanks (approximately 60 feet square) and the 49-foot square test tank. The “guaranteed SOTR” was adjusted in cases where surface power density exceeded 17 BHP/1,000 SF of surface area. Since test tank power densities exceeded those in the field, test tank required SOTR’s were 3 to 8 percent higher than those guaranteed in the actual installation. Both SOTR magnitudes are shown in Table 3.

## CONCLUSIONS

The results of Chattanooga’s Moccasin Bend WWTP factory testing exceeded expectations. In the bid proposal of Linde Process Plants, the aeration equipment supplier, $m^2t$ Technologies, guaranteed that the total system power draw for the Moccasin Bend WWTP oxygenation system replacement would not exceed 1,749 BHP. From the data collected during the clean water factory testing, the cumulative power draw of the installed aerators and mixers, as shown in Table 3, will be approximately 1,529 BHP, or 12.6% less than that guaranteed in the bid proposal and one-half the power draw of the existing PBT aerators. The originally bid power draw will save Moccasin Bend approximately 43% annually compared to its existing system. The additional power reductions revealed by the factory testing will result in additional power and cost savings for the City of Chattanooga. In fact, these additional 12.6% power savings are equivalent to a present worth value of $792,000 using the performance liability power value of $3,600/BHP.

It is further interesting to note that this testing indicates that at the mass transfer rates measured, the HI-FLO surface aerators appear to be competitive with fine bubble aeration efficiencies in wastewater. Taking into consideration the differences in apparent wastewater alpha between mechanical surface aerators and fine bubble diffusers in conjunction with the typical fouling factors of fine bubble devices, field transfer efficiencies for the 75-inch HI-FLO impeller should yield field transfer efficiencies equivalent to those of fine bubble diffusers at tank depths of up to approximately 20 feet.

## REFERENCES

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