Case Study of Aeration Performance under Changing Process Conditions

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Abstract: Off gas analyses of oxygen transfer efficiency (OTE) at Terminal Island Treatment Plant of Los Angeles document changing performance of fine-pore diffusers in an activated sludge plant from 1991 to 1998. Although the plant treats a challenging waste stream, the aeration tanks are little different from other plants. Recent sessions provided improved time and space resolution, compared to previous work. Samples were more closely spaced, and some samples were taken in the intervals between the aeration grids, at the ends of the tanks, and near the edges of the grids. Very short term fluctuations in the data were assessed by leaving the hood in the same position for 1–2 h. The 1998 efficiencies were low. Analysis of the measurements since 1991 shows effects expected from fouling, and there was also extensive deterioration of the air distribution system that has now been remedied by a refurbishment program. These measurements show the degree to which efficiency losses may grow unrecognized if OTE measurements are not done. Hence, this study may serve as a prototype for similar measurement programs at other plants.

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Introduction

Improving oxygen transfer efficiency (OTE) in aeration tanks has substantial potential economic significance. For example, the potential savings from improved aeration efficiency at the Los Angeles plants have been roughly estimated at over a hundred thousand dollars per year. The importance of OTE follows from two simple considerations. First, typically around two thirds of the electricity consumed at such a plant goes for blowing air into the aeration basins. Second, for any treatable biological load, the need to maintain the oxygen transfer rate in equilibrium with biological oxygen consumption makes the required air input inversely proportional to OTE.

OTE is affected by many aspects of the environment in a tank. First, there are influences of quantities such as temperature, pressure, and concentration of oxygen that are already dissolved in the water (Redmon et al. 1981; Ewing Engineering, 1984; ASCE 1992), so they are used to adjust the raw OTE measurements to standard conditions. Second, deeper tanks tend to provide higher OTEs, because there is more time for oxygen transfer as bubbles rise, but the benefits are limited (Huibregtse et al. 1983). Third, OTE is lower in dirty water than in clean, which is typically represented by an adjustment factor denoted α, Rosso et al. (2001).

Making all allowances for other influences, it has been recognized (e.g., U.S. EPA 1989) that the accumulation of bacterial and mineral deposits on diffusers is one of the chief reasons for large long-term decreases in OTE and α for fine-pore diffuser systems. The other major reason is mechanical deterioration of the air distribution system (Stenstrom and Masutani 1989). Compared to fouling and mechanical damage, there are only minor effects from differences in loading or temporary changes in air flux, pressure, etc.

Since 1991 the Bureau of Sanitation of Los Angeles has occasionally assessed air flow and diffuser performance at its plants to gain insight into power consumption and the relative value of differing types of diffusers and cleaning methods. The recent samples were more closely spaced and comprehensive than in previous research, such as the earlier studies at the Terminal Island Treatment Plant (TITP) (included in graphs and tables below), or the measurements at Site A in Redmon et al. (1983). The new observations show aspects of aeration system performance that illustrate the value of both the measurement methods and the results (Iranpour et al. 2000b,c).

Experimental Setup

Terminal Island Treatment Plant

TITP has a capacity of about 30 million gallons per day of wastewater. The secondary treatment has been in operation since 1977. TITP receives some domestic wastewater, but around 10% of the influent is seawater and historically 40–60% has been industrial,

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including discharges from metal plating, fish canning, the Long Beach Naval Shipyard, oil refineries, and chemical plants. Thus, the plant always has had to cope with high sulfide and salinity in the influent, frequently high heavy metals and oil and grease, and highly variable pH, biochemical oxygen demand (BOD), suspended solid, and NH_3-N.

There are nine aeration tanks, 91 m by 9.1 m, with an average depth of 4.6 m. Each is an Aercor fine pore system, with 23 cm ceramic domes and hard rubber gaskets, secured by stainless steel bolts. The diffusers were installed around November, 1990, so by late 1998 they had been in service for nearly eight years, and were approaching the halfway point of their planned service life.

The diffusers are arranged in four grids, Grids A, B, C, and D. Each grid is a little less than 21 m long, leaving 3–4.5 m unaerated gaps between the grids, and each was designed with more diffusers than the one downstream of it, for tapered aeration to meet an anticipated greater oxygen demand at the influent end of the tank. Since 1994, however, in each of the observed tanks no air has been delivered through Grid A, so that these regions act as anoxic selector zones. Previously, Tanks 3 and 4 were being step fed as part of a nitrification process, with an additional infusion of dirty water at the beginning of each grid.

During much of the period since the first OTE measurements in 1991, the plant was operated to nitrify fully the plant's high load of ammonia nitrogen because previous operation in other modes had led to a prolonged period of frequent violations of discharge standards (Wada and Fan 1990). In recent years, with changing economic conditions and installation of some wastewater treatment equipment at nearby factories, the ammonia nitrogen load has decreased and become more stable. Moreover, in early 1998 it was decided that partial nitrification would now be acceptable, so the process was changed to reduce air consumption (Iranpour et al. 2000a,d).

More than three years ago, TITP completed extensive aeration tank refurbishment as part of a long-term program for full reclamation of its effluent. Thus, the low 1998 efficiencies in this paper do not reflect the current state of the plant.

Offgas Instrument

The analyzer was built by the Applied Research Group and UCLA, but used the established method: off gas was collected by a hood floating on the surface of the tank, and after removal of CO_2 and water vapor from the sample stream the O_2 partial pressure was measured by a fuel cell (Ewing Engineering 1994). A mercury thermometer and a DO meter were used to measure temperature and DO at the point of each OTE measurement.

Experimental Procedure

The first three columns of Table 1 summarize the procedures used in the measurements. Before 1998, samples were taken at the positions shown in Fig. 1(a). The midlines of the grids were avoided because leaks from the main pipes, which run along the midlines, could distort the results. Likewise, measurements in the interiors of the grids were expected to be most nearly characteristic of average performance. For the recent experiments, the sampling patterns [Fig. 1(b)] are less uniform than those previously used, but cover larger percentages of tank surfaces, since the tanks were subdivided into a larger number of partitions, and the edges of the grids and the gaps between them were sampled. Another sampling method was to leave the hood in the same place for 1 or 2 h to determine whether the samples were subject to significant temporal variations during these periods. This was done once in each grid. In addition, data were obtained from the control room and permanently installed tank instruments, including wastewater flows, return activated sludge flows, air flows, and dissolved oxygen.

Table 1. Summary of Sampling and Results

Date (time)	Tank	Number of samples	Efficiencies (average ±standard deviation) αSOTE
04/12/91	3	8(0)	20.00±3.87
(8:00 a.m.–11:30 a.m.)	4	8(0)	16.60±3.87
09/03/91	3	8(0)	15.60±3.18
(8:00 a.m.–11:30 a.m.)	4	8(0)	15.10±2.96
01/19/94	3	12(0)	11.40±1.03
(8:00 a.m.–11:30 a.m.)	4	12(0)	13.60±3.37
07/16/98 (8:00 a.m.–3:00 p.m.)	4	17(6)	5.42±4.21 (6.60±5.34)
08/12/98 (8:00 a.m.–3:00 p.m.)	4	21(7)	7.44±4.11 (8.06±4.52)
08/25/98 (8:00 a.m.–3:00 p.m.)	5	23(7)	3.35±0.94 (3.30±1.24)
08/26/98 (8:00 a.m.–3:00 p.m.)	6	20(6)	7.77±6.39 (8.23±6.06)

The measurement crew was careful to wait to record data until the O_2 partial pressure stabilized, showing that it had declined to its level in the offgas. This avoided sample contamination by ambient air that would have caused underestimation of oxygen depletion, and hence of OTE. The depletion of O_2 relative to the ambient air was found from the oxygen partial pressures, from which the raw OTE was computed (Campbell, 1983; Redmon et al. 1983). Correcting for departures from the standard atmospheric pressure and temperature, and for nonzero DO, gave the standardized OTE parameter, αSOTE, which provides the most uniform basis for comparing aeration efficiencies observed at different times and places. Once the local αSOTE values were com-

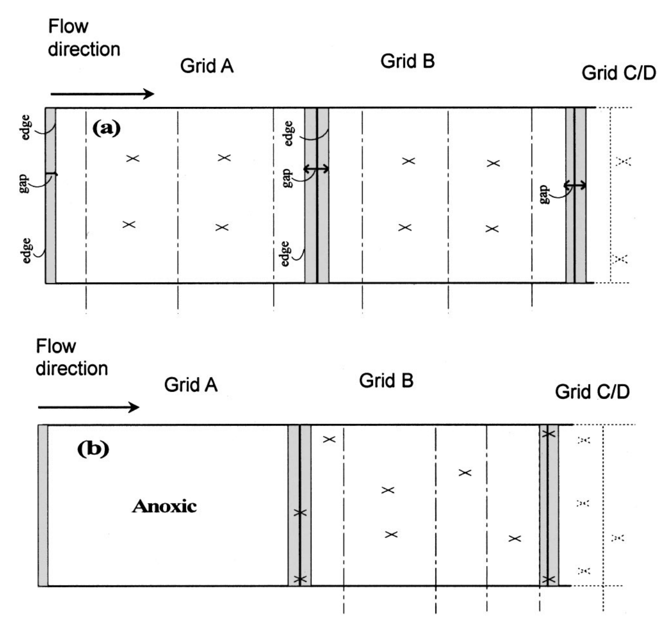

Fig. 1. Plan views of sampling locations: (a) uniform pattern (91–94), (b) random pattern (98)

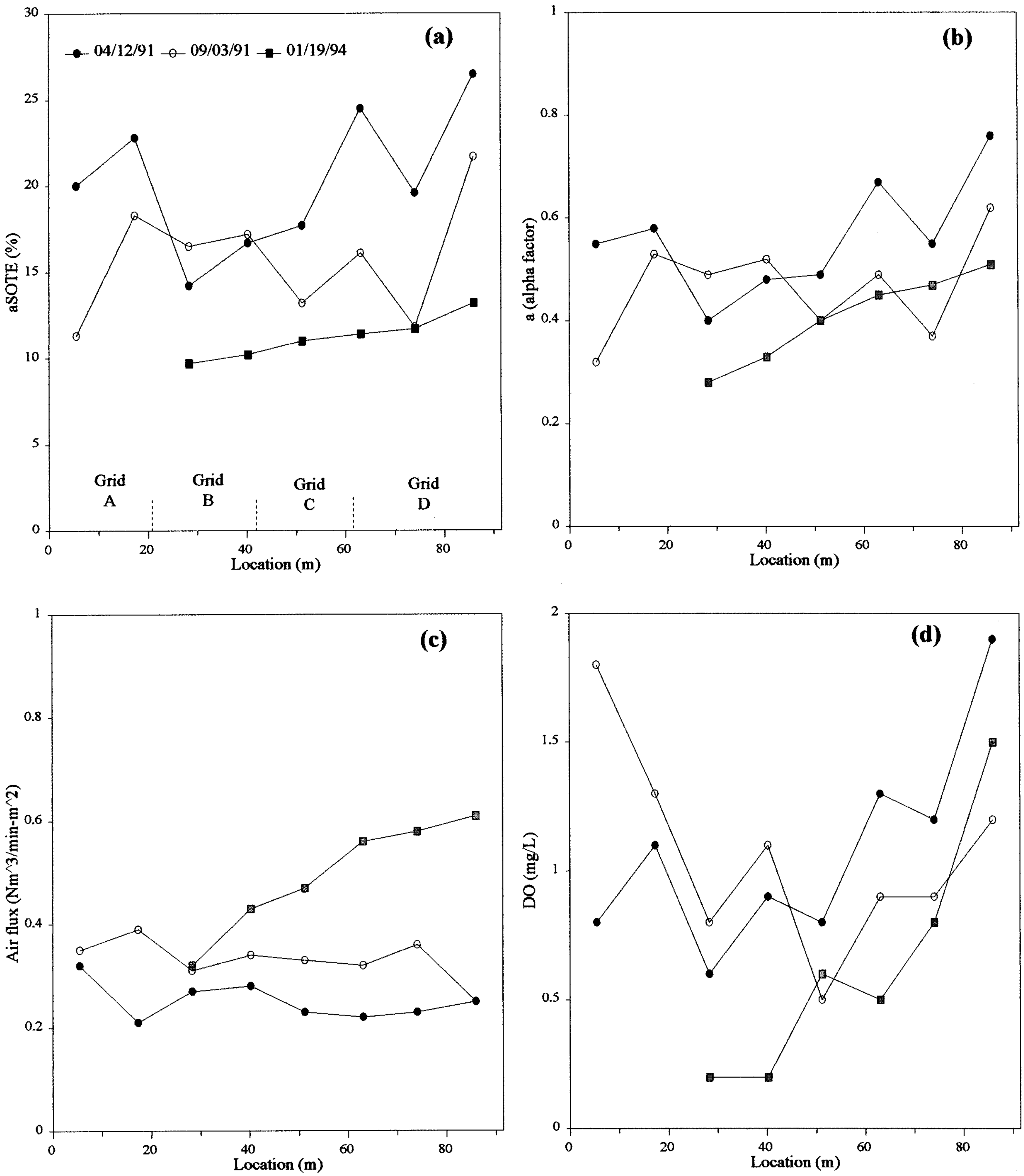

Fig. 2. Offgas data for grids A, B, C, and D (interiors only) of tank 3 at TITP, 91–94 (7:00 AM–5:00 PM): (a) efficiency; (b) alpha factor; (c) air flow; (d) dissolved oxygen

puted, an average αSOTE weighted by flow and area was computed. The α parameter, which measures reduction in OTE caused by dirty process water, was computed by α=αSOTE/SOTE, where SOTE is the standardized clean water OTE, estimated from the manufacturer's empirical formula (Iranpour et al. 1999a,b). Control room data are not available for measurement sessions before 1998. For 1998 sessions control room data are within expected ranges, reflecting normal tank operation at these times.

Observations and Analyses

Column 4 of Table 1 summarizes the results from all the measurement sessions. These are tank averages derived by weighting the

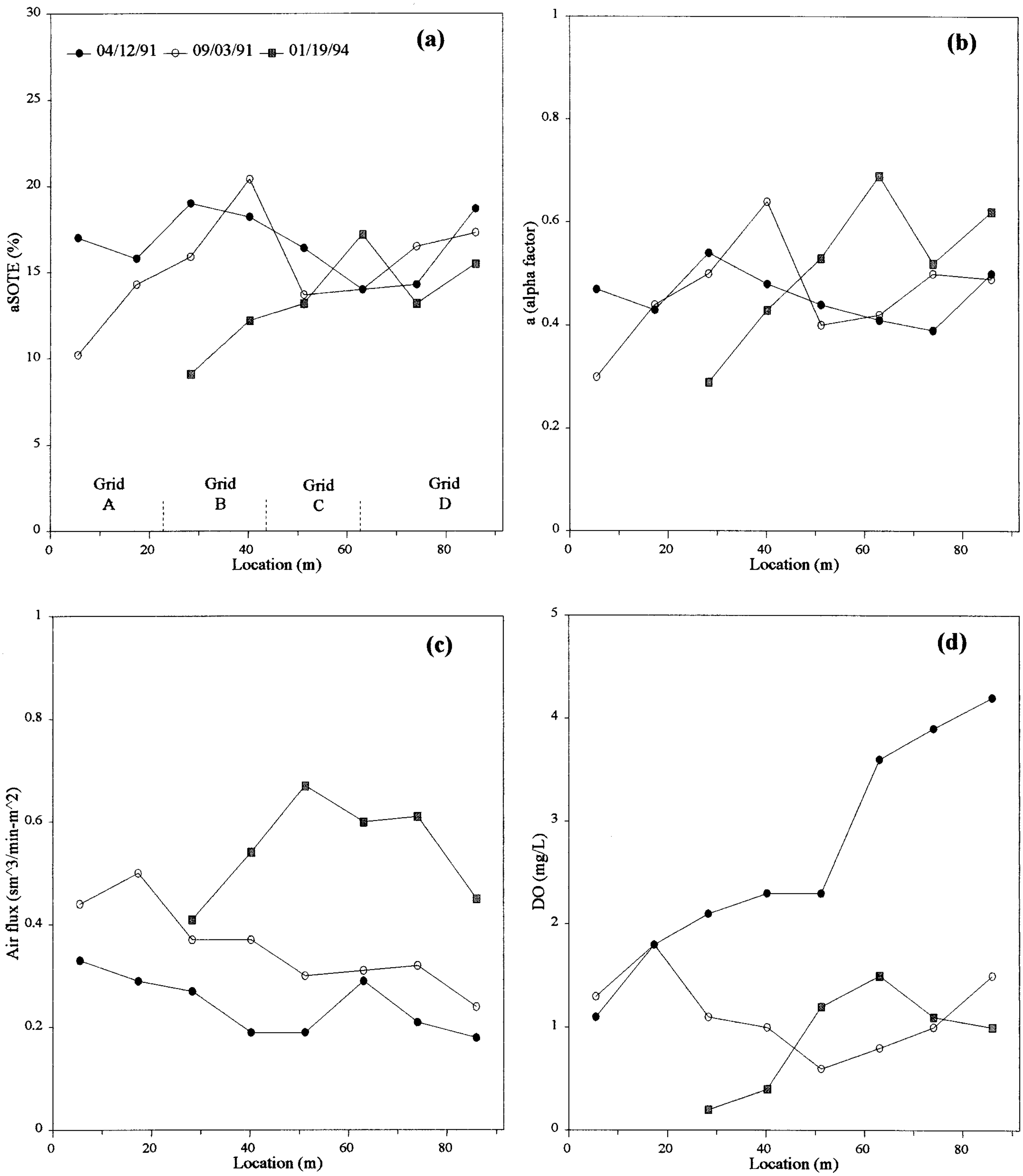

Fig. 3. Offgas data for grids A, B, C, and D (interiors only) of Tank 4 at TITP, 91–94 (7:00 AM–5:00 PM): (a) efficiency; (b) alpha factor; (c) air flow; (d) dissolved oxygen

individual measurements by observed airflow and the partition area surrounding the measurement location. The first values are based on the data from the grid interiors. The parenthesized values include the grid interiors, the edges of the grids, and the gaps between the grids.

1991–1994 Results

Figs. 2(a) and 3(a) show the individual measurements on which the 1991–1994 averages in Table 1 are based. The plots for January 19, 1994 in all panels of these figures begin at 100 ft. because

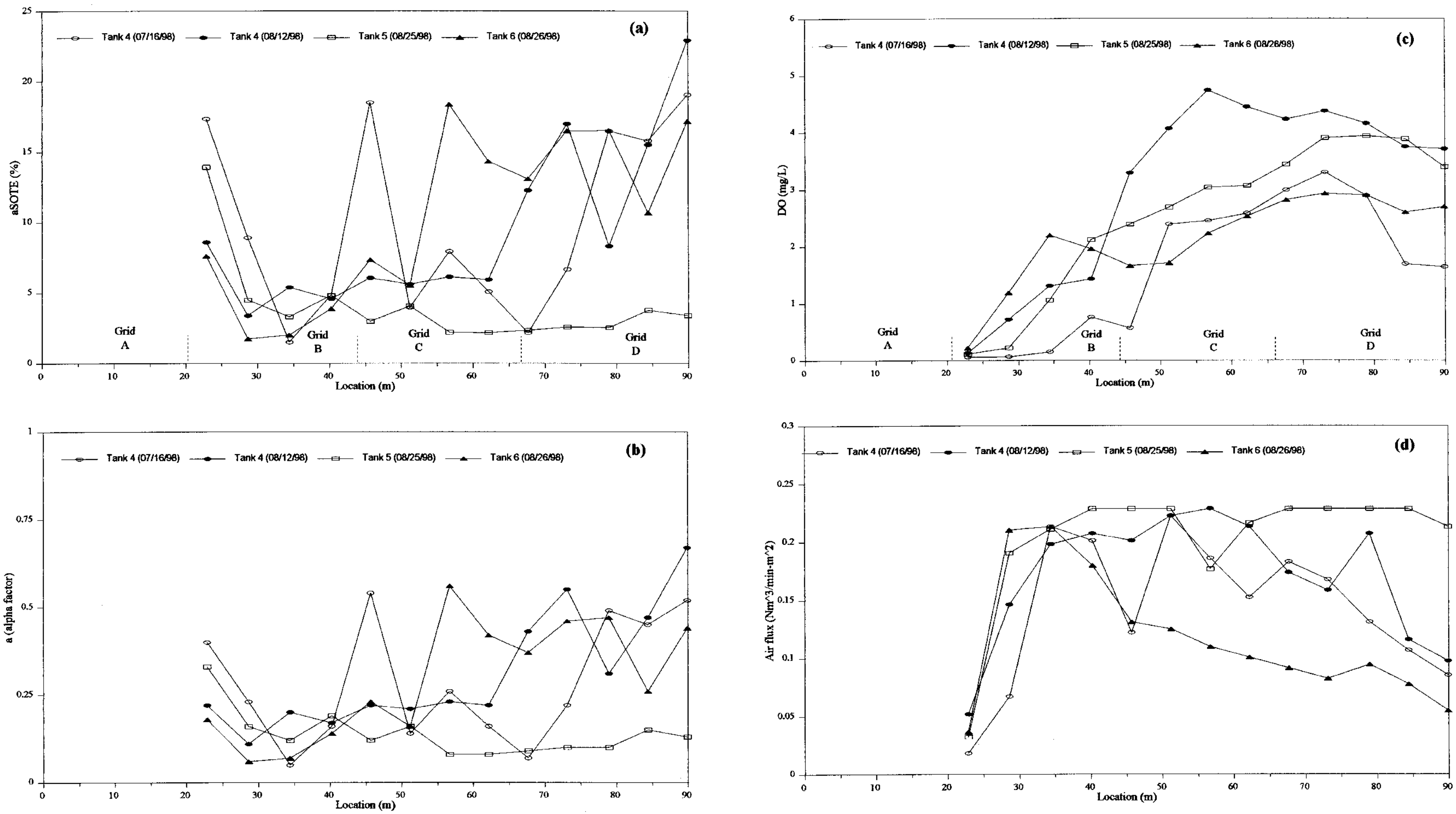

Fig. 4. Offgas data for grids A, B, C and D (interiors, gaps, and edges) of Tank 4 at TITP, (7 AM–5 PM): (a) efficiency; (b) alpha factor; (c) dissolved oxygen; (d) air flux

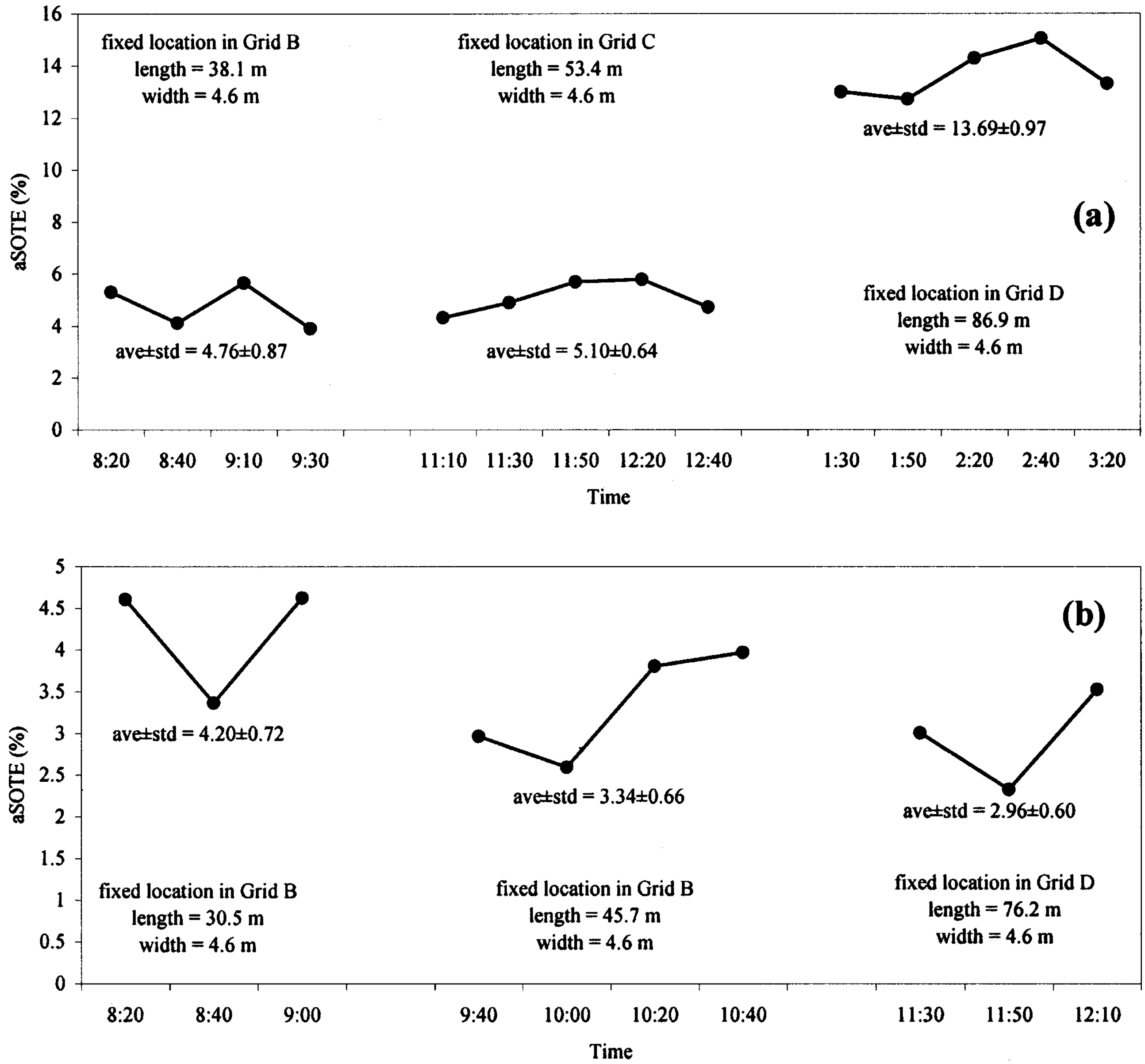

Fig. 5. Offgas data for fixed hood locations: (a) efficiency, tank 4, 9/10/98; (b) efficiency, tank 5, 10/12/98

by this time these tanks were being operated with Grid A as an anoxic selector zone. It is evident that the declining average αSOTE readings obscure considerable variation in the individual measurements, but examination of the plots for the days confirms the general trends. Fig. 3(a) shows that five of the eight individual September measurements are below the corresponding April measurements, and only two September measurements are higher, so this is evidence that the lower mean indicates a modest genuine decline. The importance of correcting raw OTE values to αSOTE readings is shown by the large variations in dissolved oxygen concentration.

The January 19, 1994 results include a much smoother trend in αSOTE and α factor results in Tank 3, as well as lower efficiencies in both tanks. Again, α factors vary with αSOTE readings, and this time the α for Tank 3 in Fig. 3(b) is persistently lower than it was in September 1991.

1998 Results

The salient characteristic of the 1998 results for all three tanks is the low mean efficiencies, as shown in Table 1. The mean αSOTEs are in the range 3–8%, but, as shown by the parenthesized values, the slightly higher values in the gaps and edges raise the estimates for the whole-tank averages, compared to the estimates from the grid interiors.

Although the changes in α and αSOTE in Fig. 4 usually agree very closely, there are occasional modest divergences corresponding to changes in the air flux shown in Fig. 4(d). Further examination of Fig. 4 shows many differences between the results for the individual tanks. The means for Tank 4 for July 16 and August 12 are within one quarter of a standard deviation of each other, and so are not significantly different by established statistical standards, but Fig. 4 shows that the near constancy of the means obscures the changes in the local values. The especially low mean for Tank 5 is the result of nearly uniformly low efficiencies in Grids C and D. The large variations in the individual measurements in Tank 4 and Tank 6 are the reason that the mean efficiencies for these tanks have standard deviations that are at least half the sizes of the means. Thus, the statistical significance of the means is poor.

Fig. 5 shows the results of the measurement sessions conducted with the hood positions left fixed for 1 h or 2 in each grid for September 10 and October 12, 1998. These observations agree relatively well with the tank scan data at corresponding positions in Fig. 4, but show substantial variability.

Discussion

Operation Effects

As noted in the Introduction, there is no doubt that most of the long-term decline in OTE seen for Tank 4 in Table 1 was due to fouling. In adjacent tanks that were dewatered for the refurbishment program, the measurement team observed mechanical deterioration, such as broken diffusers, blown gaskets, and loose pipes, so leakage and fouling on both sides of the diffusers were probably present in Tanks 4 through 6 during the 1998 OTE observations. However, several significant changes in operation have occurred during these years, and evidence for at least one of these changes can be found in Figs. 2 and 3, as follows.

The sawtooth appearance of the αSOTE plots for both 1991 measurements of Tank 3 (Fig. 2) and the September 1991 measurements of Tank 4 (Fig. 3) appears to be explained because these are the times when these tanks were being step fed. As the water progressed to the downstream side of the grid some of the food was consumed, so that each grid reproduced on a small scale the behavior observed in tanks in which all feeding occurs at the influent end. On the other hand, the smoother appearance of the αSOTE plots for 1994, especially for Tank 3 (Fig. 2), reflects the abandonment of step feeding with the establishment of anoxic selector zones at the influent ends of these tanks.

The reduction in nitrification may also contribute to the low αSOTE for 1998. Figs. 3–19 and 3–23 (U.S. EPA 1989) are examples of the evidence for the belief (e.g., Fisher and Boyle 1999, p. 92) that nitrifying plants tend to have higher α values than nonnitrifying plants that are otherwise similar. However, more data would be needed to check whether this is a significant consideration.

Costs and Energy Conservation

Combining the results of this study with those of Stenstrom and Masutani (1989) suggests that diffuser fouling and air distribution system damage may be widespread in large activated sludge wastewater treatment plants. They may, like TITP in the recent OTE observations, be performing below, for example, the design expectations recommended in (U.S. EPA 1989), which recommends designing for lower performance than was observed in April, 1991. Thus, it is possible that many plants might be able to take actions that would realize substantial savings in energy consumption if they were alerted to tank efficiency problems by off-gas OTE measurements. Achieving large savings may involve more than diffuser cleaning or replacement if, as has been the case at TITP, they have old blower systems with limited capabilities to save energy when air consumption is reduced (Iranpour and Stenstrom 2001). Nevertheless, OTE measurements are the first step in assessing the possibilities for saving energy and money.

Conclusions and Final Remarks

1. Off gas measurements (1991–1998) at TITP show substantial variations of OTE.
   - Efficiencies in Tanks 3 and 4 in April 1991 (new diffusers) were very high. Losses in efficiency, presumably due to fouling, had occurred by September 1991.
   - Although Tank 3 diffusers were cleaned by water hosing in February 1993, by January, 1994 the average efficiency in this tank had declined below the level of Tank 4.
   - By 1998 efficiencies in Tanks 4, 5, and 6 had declined to unacceptable levels. These low efficiencies are evidence of serious fouling and system deterioration.
   - Readings in the gaps and edges tend to be higher than in the interiors of the grids, as shown by the higher averages when these areas are included.
   - These data may also be influenced by the reduction in nitrification after early 1998, but additional measurements would be necessary to determine this.
   - Measurements in 1998 with the hood left in the same place for 1–2 h also showed relatively short-term variations.
   - These measurements also confirmed the low efficiencies seen at some points in the tanks during the scans a few weeks before.
2. The earlier data show evidence of the changes in tank operation from 1991 to 1994.
   - The September 1991 αSOTE and α results show sawtooth variations that probably reflect the step feeding that was practiced at that time.
   - The January 1994 αSOTE and α results show smoother variations that probably reflect the change to feeding through an initial anoxic zone.
3. Innovations in OTE sampling, with increased tank coverage and more measurement sessions, provided increased detail in 1998 compared to the earlier observations.

Although several aspects of the operation and aeration system conditions probably contributed to the low efficiencies observed in the summer of 1998, many of them have now been improved by an extensive refurbishment program. As the research program has progressed, the operators and management at the Los Angeles plants have become strongly interested in regular monitoring of the OTE in their tanks. The authors believe that the experiments reported here demonstrate the general value of more frequent and comprehensive OTE measurements in providing guidance for decisions about maintaining, repairing, and replacing aeration systems.

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References

ASCE. (1992). "Measurement of oxygen transfer in clean water." *Standard Am. Soc. Civ. Eng.* Committee on Oxygen Transfer, New York.

Campbell, H. J., Jr. (1983). ''Oxygen transfer testing under process conditions.'' *Proc., Workshop on Aeration System Design, Operation, Testing and Control*, EPA/Environment Canada, Madison, Wis.

Ewing Engineering Company (1994). *Operating manual for aerator-rator offgas analyzer*, Milwaukee.

Fisher, M. J., and Boyle, W. C. (1999). ''Effect of anaerobic and anoxic selectors on oxygen transfer in wastewater,'' *Water Environ. Res.*, 71(1), 84–93.

Huibregtse, G. L., Rooney, T. C., and Rasmussen, D. C. (1983). ''Factors affecting fine bubble diffused aeration,'' *J. Water Pollut. Control Fed.*, 55(8), 1057–1064.

Iranpour, R., Magallanes, A., Stenstrom, M., Lee, J. J., and Torkian, A. (1999a). ''OTE of fine-pore diffused aeration sys: Energy intensity as a unifying evaluation parameter,'' *Water Environ. Res.*, 71, 506.

Iranpour, R., Magallanes, A., Zermeno, M., Magallanes, A., Shao, Y. J., and Stenstrom, M. K. (2000a). ''Activated sludge system efficiency under different process conditions in wastewater treatment plants.'' *Proc., Water Environ. Fed. 73rd Annual Conf.*, Anaheim, Calif.

Iranpour, R., Magallanes, A., Zermeno, M., Mayer, R., Patel, D., Oh, S., Moghaddam, O., Garnas, G., Langley, J., and Stenstrom, M. (1999b). ''An OTE prototype to optimize maintenance and air consumption: Full scale analysis at city of Los Angeles' wastewater treatment plants,'' *Proc., Water Environ. Fed. 72nd Annu. Conf. Exposition, New Orleans, La*.

Iranpour, R., Magallanes, A., Zermeno, M., Moghaddam, O., Wilson, J., and Stenstrom, M. K. (2000b). ''Assessment of aeration system performance efficiency: Frequent sampling for damage detection.'' *Water Environ. Res.*, 72(3), 363.

Iranpour, R., Magallanes, A., Zermeno, M., and Stenstrom, M. (2000c). ''Assessment of aeration basin performance efficiency: Sampling methods and tank coverage.'' *Water Res.*, 34(12), 3137.

Iranpour, R., Stenstrom, M. K. (2001). ''Relationship between oxygen transfer rate and airflow for fine-pore aeration under process conditions.'' *Water Environ. Res.*, 72(3), 266.

Iranpour, R., Zermeno, M., and Miller, D. (2000d). ''Effect of anaerobic and anoxic selectors on oxygen transfer in wastewater.'' *Water Environ. Res.*, 72(4), 507.

Redmon, D., and Boyle, W. C. (1981). ''Preliminary findings: Offgas analysis.'' *Report presented to the ASCE Oxygen Transfer Standard Committee*, Detroit.

Redmon, D., Boyle, W. C., and Ewing, L. (1983). ''Oxygen transfer efficiency measurements in mixed liquor using off gas techniques.'' *J. Water Pollut. Control Fed.*, 55(11), 1338–1347.

Rosso, D., Iranpour, R., Stenstrom, M. K. (2001). ''Fifteen years of offgas transfer efficiency measurements.'' *Proc., Water Environ. Fed. 74th Annual Conf*., Atlanta.

Stenstrom, M. K., and Masutani, G. (1989). ''Fine bubble diffuser fouling: The Los Angeles studies.'' *A final report to the ASCE and the USEPA*.

U.S. EPA (1989). *EPA/ASCE design manual on fine pore aeration*. Cincinnati, EPA/625/1-89/023.

Wada, F., and Fan, S. (1990). ''Innovative secondary treatment process control using high MCRT, low F/M, and complete nitrification to treat high industrial loads.'' *CWPCA Conference Proc.*