TECHNICAL ARTICLE

Optimizing Aeration Transfer in Activated Sludge Systems

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INTRODUCTION

Oxygen transfer efficiency (OTE) is a critical factor in the economics of activated sludge plants, for a combination of two reasons. First, since the goal of aeration is to maintain an adequate oxygen supply to the bacteria in the wastewater, the air flow needed to do this for a given oxygen demand is inversely proportional to OTE. Second, the power consumed by the blowers for the aeration tanks is typically 50%-90% of the total electrical demand of such a plant for secondary treatment (or a modestly lower percentage if tertiary treatment or solids handling are performed), and the electricity cost is a large part of the total plant budget.

For fine-pore diffusers OTE is not a single parameter, but a function, decreasing with increasing air flux. Hence, it is the key relationship in aeration control, determining the change of air flow needed to respond to a change in oxygen demand. This relationship was studied at several wastewater treatment plants operated by the Los Angeles Bureau of Sanitation.

Qualitatively, the decrease of OTE with air flux is understood: increasing air fluxes increase the average diameters of the bubbles; this reduces the surface/volume ratio and increases the rise speed of the bubbles, both of which work against oxygen transfer. Hence, manufacturers routinely test their diffusers in clean water for the dependence of efficiency on air flux. Also, a general anticorrelation of air flux with OTE is evident in data obtained from many operating tanks.

Quantitatively, however, very little information about the relationship is available under operating conditions. There is a study completed in 1985 by Allbaugh, et al. in which such measurements were made. They summarize two other studies apparently done similarly, although none of this is as thorough as work completed by the City of Los Angeles, Bureau of Sanitation.

Hence, aeration control in activated sludge plants is conducted now without any ability to predict the effect of an air flow change. If the reading from a tank DO sensor gets out of its desired range, operators or automatic systems guess at the appropriate adjustment of air flow, and continue until DO again becomes satisfactory.

The limitations of this approach become clear on considering that, although one usually expects increasing air flows to transfer more oxygen, this is not always true. At high enough air flows a further air flow increase decreases oxygen transfer, because the reduction in OTE counteracts the effect of additional oxygen availability in the higher air flow.

This is easily seen from the quantitative relationships. The O_2 mass flow in the air is the product of the air flux and the mass fraction of O_2 in the air. The OTE is the mass flow of O_2 transferred into the water divided by the O_2 mass flow in the air. Thus, multiplying OTE by the O_2 mass flow in the air gives the O_2 mass transfer rate into the water. Since the decline of OTE with air flux has been observed to be approximately linear, while the O_2 mass flow in the air is proportional to air flux, the O_2 mass transfer rate into the water as a function of air flux is approximately an inverted parabola. A schematic depiction of this appears in Figure 1.

This mass transfer curve (MTC) is the most informative representation of the relation between OTE and air flux because it displays the variation of the oxygen supply to the bacteria. Hence, in this study, constructing MTC plots from our measurements is the key step on which all else will be based.

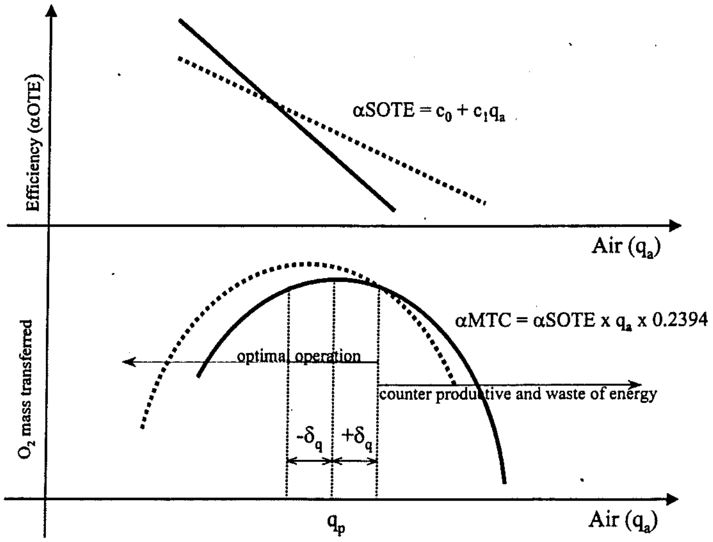

Figure 1. Schematic example of MTC and max. allowable air estimation

Our previous efforts have focused on meeting the needs for basic OTE data by developing an offgas instrument that is easier to use, testing alternative sampling patterns, and demonstrating the value of more frequent and comprehensive OTE observations. This has built on work by many other researchers such as Ewing Eng. Co. in 1993, Campbell in 1982, Redmon, et. al. in 1981 and 1983, Stenstrom and Masutani in 1989, Stenstrom, et al. in 1984, EPA manual of 1989, ASCE publication of 1993, Fisher and Boyle in 1999, Newbry in 1998, and Semmens, et al. in 1999.

The goals of the study are: 1) to optimize air usage and thereby to reduce costs; 2) to assess the effect of diffuser

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(continued)

fouling on the ability of the aeration system to respond to changing loads; 3) to demonstrate the value of making this kind of measurement. The specific objectives are: a) to obtain standardized OTE measurements at several points in one or more grids; b) to compute the equivalent mass transfer values at these points and the aggregate values over the grids; c) to obtain curves from the data to estimate the maximum useful air flow in each grid.

Since the absence of MTC data is a significant gap in current methods of aeration control, this project is likely to provide greatly increased insight into system response to changing loads. For the long term, it opens the possibility of improvements in aeration systems, such as improvement of the placement of tank DO sensors, or in the interpretation of their results; or better blower and distribution systems that have the ability to operate efficiently while delivering only as much air as is needed to the places it is needed. It is also likely to provide further insight into the value of cleaning or other maintenance of diffusers and distribution systems.

EXPERIMENTAL SETUP / PROCEDURES

The study was carried out at the Tillman Water Reclamation Plant (TWRP), which is located in the San Fernando Valley, with an average flow around 60 MGD. The tanks are rectangular aeration basins, 30 feet wide, 300 feet long, and 15 feet deep, equipped with Aercor ceramic dome diffusers 9 inches in diameter.

MTC measurements were made in Grid A on April 13 and 14, 1999, and in Grid B on April 19, 1999. Additional measurements were conducted in Grid A on August 7 and 8, 1999, more than a month after the diffusers were cleaned.

The measurement crew records the temperature and the DO at the location of the collection hood, and the offgas instrument has a fuel cell that measures the O_2 partial pressure after removal of CO_2 and water vapor from the sample stream.

Every few minutes the control room equipment also automatically records data from the plant's built-in instruments, and so the researchers reviewed these records and tabulated four parameters for the grids from the times closest to the times of the offgas measurements. The parameters were process water and RAS flows into the tank, air flow to the grid, and DO from the grid's sensor were also recorded from field instruments and control room.

The MTCs in this paper are calculated from the (SOTE values. This not only makes them more comparable to each other on successive days, but also allows comparison with the standardized results reported by Allbaugh in 1985.

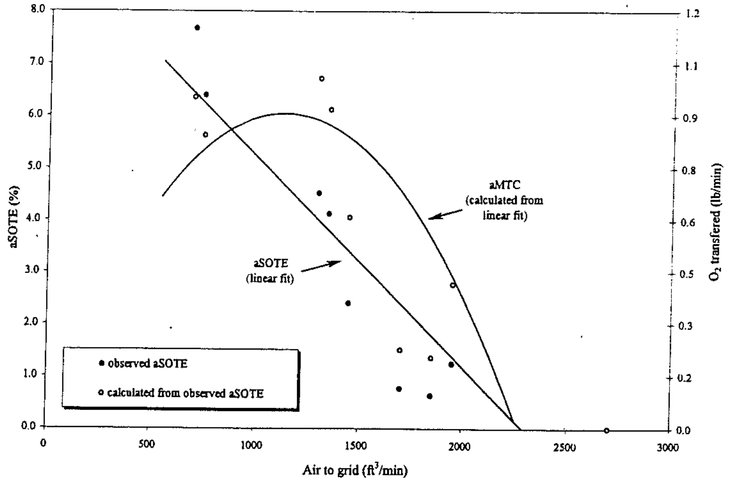

Figure 2. Efficiency and mass transfer curve for grid A, tank 15, TWRP, 4/13 and 4/14/99

OBSERVATIONS AND ANALYSIS

Grid Averages for Moderate to Severe Fouling: Figure 2 presents aggregate data for Grid A from the two days (April 13 and 14 combined), where each point is obtained by averaging over the four locations at one of the air flow settings. As would be expected from the plots for the individual days Figure 2 shows steady or increasing mass transfer between 750 and about 1000 scfm, and decreasing mass transfer at higher flows. This is clear despite the previously noted moderate differences between the April 13 and 14 data, which can be easily seen when they are combined on one plot.

Recently Cleaned Diffusers: Figure 3 shows the results from the August 7 and 8, 1999 sessions with cleaner diffusers. This figure combines results from both days, as in Figure 2. As expected, the OTEs are much higher than in Figure 2, and the peak of the MTC appears at a much higher flow. On the other hand, the slope of the line fitted to the

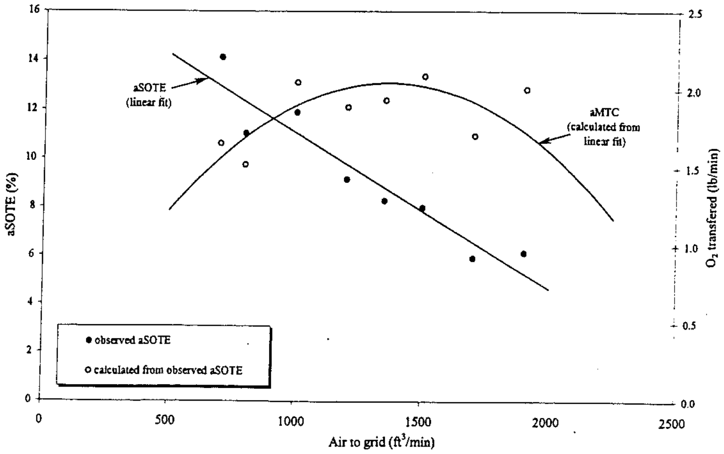

Figure 3. Efficiency and mass transfer curve for grid A, tank 15, TWRP, 08/07 and 08/08/99

OTE data is steeper than the lines fitted to the earlier data, presumably reflecting changed bubble formation fluid dynamics after cleaning.

Estimating Maximum Allowable Air Flows: Since the air flow at the peak of the MTC is the top of the usable range of air flows, from Figure 1, maximizing the MTC equation gives q_p

$$q_p = - c_o / 2c_1.$$

If c_o and c_1 were determined by conventional least-squares fitting methods, then this uncertainty would be expressed by the estimated standard errors δ_o and δ_1 of c_o and c_1, which would propagate into a standard error estimate δq for q_p according to the formula

$$(\delta_o / c_o)2 + (\delta_1/c_1)^2 = (\delta_q/q_p)^2.$$

Thus, a prudent approach to using MTC data would be to operate over the interval from the minimum allowed by the manufacturer up to $q_p + \delta_q$.

From estimated peaks and standard errors for the Grid A measurements before cleaning, a reasonable maximum air flow is seen to be approximately 1004+121 scfm, corresponding to a valve opening around 25%. This would apply as long as the dependence of OTE on air flow was not significantly changed by diffuser system deterioration or maintenance. A quantitative indication of the improvement made by cleaning, gives the estimated maximum for the cleaned diffusers to be approximately 1317+177.

DISCUSSION

Comparison to Previous Reports: An informative comparison with these new measurements is provided by the results reported by Allbaugh in 1985. They computed MTCs not only for their own data from Lansing, Michigan on September 22, 1983, but for results from a New York brewery not otherwise identified, and for a test performed in clean water at a depth of 20 feet by the Los Angeles County Sanitation District. As these tests were performed with differing numbers of diffusers, computing the fluxes in units of scfm per diffuser provides the best available comparison.

Since the conditions of the Los Angeles County test were different from the others, the peak in this test at the high flux of 3.5 scfm/diffuser probably is not directly comparable to the other two. The peak in the Lansing data occurs at 1.63 scfm per diffuser, and the New York brewery data peak at 2.0 scfm/diffuser. Allbaugh et al. present dynamic wet pressure data and other evidence indicating that the diffusers in the Lansing test were no more than modestly fouled in September, 1983 but they do not give the diameters of the diffusers in any of the tests. On the other hand, all three of these studies observed peaks at fluxes at least twice the minimal for the respective diffusers, as was the case for the TWRP diffusers after cleaning.

Economic Perspectives: It is obvious that if this work led to recommendations for substantial modifications and upgrades to presently installed wastewater aeration systems, then the costs of the changes would be large. However, they may be justified by the large costs of present treatment methods.

For a perspective on the economic magnitudes involved, we note that the design of the tanks in the Los Angeles wastewater plants is typical of many large wastewater treatment plants. The power cost per tank in the Los Angeles plants is around $300/day, and there are almost always more than twenty tanks in operation. Hence, just a 10% rise in average tank OTE (such as from 10% to 11%) would cut costs by around $600/day, or about $200,000/year. For comparison, Currie and Stenstrom reported in 1994 that a prospective saving to the Union Sanitary District of California (located southeast of San Francisco) of around $140,000/year in processing 25 MGD of sewage, based on installing membrane diffuser systems rated at 13.8% efficiency instead of the present ceramic disks with efficiencies of 10.8%.

In short, modest-seeming improvements in average OTEs have the potential for saving many thousands of dollars per year at individual large plants, adding up to millions per year if widely achieved across the US and foreign countries. Hence, improved understanding of aeration system responses to changing loads has the potential to contribute to large savings in aeration costs. This study is the most direct possible investigation of system responses.

CONCLUSIONS

A. Measurements of OTE conducted with fixed valve settings on both cleaned and moderately to severely fouled diffusers have observed OTE decreasing so rapidly with increasing airflow that providing more air actually decreases the amount of oxygen transferred into the process water. In such a case the system is beyond the peak of the MTC, and control procedures that assume increasing mass transfer with increasing air flow are useless or counterproductive.

B. This behavior is more prevalent for the fouled diffusers, for which the usable range of air fluxes was as narrow as 0.5—0.75 scfm/diffuser. This is much less than the maximum reported by Allbaugh, and leaves little scope for air flow adjustments to meet changing loads.

C. Better performance was restored by cleaning. Not only was the usable range widened to 0.5—1.0 scfm/diffuser, but the higher OTEs resulted in increased mass transfer at all air flows.

D. The large amounts of money currently being spent on secondary treatment at large plants could justify substantial investments in improving aeration efficiency.

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