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UPGRADING EXISTING ACTIVATED SLUDGE TREATMENT PLANTS WITH FINE PORE AERATION SYSTEMS

Michael K. Stenstrom

Civil Engineering Department, University of California, Los Angeles, CA 90024–1593, USA

ABSTRACT

Over the past ten years aeration systems development in the United States has centered around fine pore diffuser upgrades to existing activated sludge plants. A variety of older aeration systems have been replaced with new diffuser systems which include full floor coverage systems, composed of ceramic or plastic discs, ceramic and plastic tubes, and membrane tubes or discs. This manuscript reports on aeration system upgrades at six different full scale treatment plants. Seven different devices were evaluated using the off-gas analysis technique. Diffuser cleaning methods were also evaluated. Results are presented which show the economic incentives for upgrading and the increased plant capacity which resulted from increased aeration efficiency. It was found that the effects of process operation, such as step feed, F/M, MLSS concentration, mean cell retention time and air flux had a major impact on transfer efficiency. The effects of diffuser fouling and cleaning methods are presented.

KEYWORDS

oxygen transfer; aeration; activated sludge; fine bubble diffuser; fine pore diffuser; wastewater treatment.

INTRODUCTION

The U.S. EPA (1989) has performed research on fine pore aeration systems for the past five years in order to develop a better understanding of their benefits under process conditions. A number of research projects were commissioned and several were in the Los Angeles area. This manuscript describes the results of several such investigations along with the results from other plants which were not part of the EPA-funded studies. The objective of this manuscript is to summarize the improved oxygen transfer rates which resulted from plant upgrading, and to define the increased operational requirements of the fine pore diffusers. All the plants described herein are full-scale facilities. Testing was performed during normal plant operation.

EXPERIMENTAL PROCEDURE

Process oxygen transfer rates were determined using off-gas analysis. This procedure requires that air (off-gas) evolving from the aeration basin surface be collected for analysis. The volumetric flow rate and temperature are measured along with oxygen, CO_2 and water vapor content. Alternatively the CO_2 and water vapor can be removed from the off-gas sample. If there is no net change in nitrogen mass of the gas as it passes through the fluid being aerated, and if other conditions are at steady-state, the volumetric oxygen transfer efficiency (OTE) can be calculated from the ratio of the oxygen to nitrogen mole fractions. The inlet mole ratio is known. The change in mole ratio is related to OTE. The advantage of this technique is that no knowledge of the inlet gas flow rate and distribution across the basin surface are required. The procedure is described by Redmon, et al. (1983). In all cases

OTE data were converted to standard conditions (β = 1.0, DO = 0 mg/L, temp. = 20°C, barometric pressure = 760 mm Hg) using the ASCE (1984) standard procedure. The only parameter which was not corrected was the α factor. Therefore the corrected OTE is referred to as αSOTE.

For aeration basin geometries that are not completely-mixed, it is necessary to measure the OTE at a number of places in the basin and then average them in proportion to the gas flux at each measuring point. In this way a flow-weighted average of the entire basin is obtained. Under these circumstances it is useful to compare the measured air flux to the inlet air flux. As indicated previously this is not required but is useful to confirm a mass balance. The author has been able to achieve mass balances to within ± 5% when adequate plant instrumentation is available. Boyle, et al. (in press) have described the off-gas technique for noncomplete-mixing geometries, and compared the off-gas technique to other methods. After minor technique modifications precise and accurate results were obtained.

The plants were sampled at varying rates. One plant was sampled bi-weekly for over two years. Other plants were sampled only twice (before and after a diffuser upgrading) or only once if side-by-side comparisons were possible. In several cases this was possible because sampling was performed during retrofitting plants with multiple aeration basins.

In some cases process data are shown. In such cases these data were collected as part of the plant's normal operation, and were collected in accordance to Standard Methods (1985). In some cases clean water transfer rates were measured, which allows α factors to be calculated. More detailed information about procedures and plants are available (Stenstrom and Masutani, 1989).

PLANT AND DIFFUSER DESCRIPTION

The plants sampled in this study are shown in Table 1. They are all west coast plants operating in the temperate to warm Southern California climate. Most are treating exclusively domestic wastewater; two had significant quantities of industrial wastewater. In most plants it was possible to perform side-by-side testing. In these cases parallel basins existed in the plant which were operated under identical conditions with the exception of aeration device. Testing was performed with multiple off-gas collection hoods so that parallel testing, within a period of 15 to 20 minutes, was achieved. In three of the plants the old aeration system was removed and the new system was tested at a later date. Under these conditions it is more difficult to make exact comparisons, since process conditions could have changed during construction.

The plants, with the exception of Plant B,were "plug flow" basins with lengths approximately 10 times their width. Plants D and E were operated in contact stabilization mode. Plant B was complete-mixing.

The diffusers used were commercial designs available in the 1980's. Some manufacturers have subsequently changed their designs or materials of construction. The ceramic discs, used in Plant A were 23 cm in diameter and were held in plastic holders by an "O" ring and locking nut which covered the entire disc perimeter. This construction was similar to Plant D, except the discs were plastic and only 18 cm in diameter. The ceramic domes used in plants E and H were 18 cm in diameter and were held in place by a single plastic bolt. The gas seal was maintained by a flat gasket along the bottom of the dome. The membrane tubes and membrane discs used in Plants C and F were composed of thin material with punched holes. The membrane tube used in Plant G was thicker and naturally porous.

The cleaning techniques were varied among plants. Plant A used a patented in-situ HCl gas cleaning technique. The cleaning procedure was applied to the diffusers at varying frequency. The diffusers in the inlet zone were cleaned every 3 months, while the diffusers in the middle zone were cleaned every 6 months. The diffusers in the effluent zone were cleaned every 9 months. The liquid HCl cleaning at Plant G has become a frequent practice in the United States. After dewatering the aeration basin, the diffusers are first hosed at close range with high pressure hoses (> 650 kPa). They are next rinsed with 5 to 15% HCl and are rehosed after approximately 30 minutes. The manual hosing technique is also a common U.S. practice. The aeration basins are dewatered and the diffusers are hosed, usually from tank top level, with high pressure hoses. No chemicals are applied.

RESULTS AND DISCUSSION

Table 2 shows the average αSOTE for all plants along with theoretical air savings which result from the increased transfer efficiency. In most cases these air savings were not entirely realized since some of the increased efficiency was used to provide more capacity. In one particular case the increased efficiency was used to provide elevated DO concentration (~ 4 mg/L) for improved nitrification.

Table 1 Plant and Aerator Description

Plant Code	Wastewater Type	Old Aeration System	New Aeration System	Diffuser Depth (m)	Test Conditions	Number of Observations	Cleaning Method
A	D	S,SR	CD_i,FF	3.75	R	36	HCl gas
B	I	CB,FF	PT,FF	6.1	R	2	-
C	60% D, 40% I	S,SR	MT,FF	3.4	S	8	M, Hose
D	D	-	PD_i,FF	3.95	-	7	none
E	D	S,SR	CD_o,FF	3.95	SBS	2	M, Hose
F	D	PT,SR	MD_i, FF	3.95	SBS	1	-
G	60% D, 40% I	S,SR	MT,SR	3.5	SBS	8	liquid HCl
H	D	S,SR	CD_o,FF	3.75	R	36	none

Keys:

Wastewater type: I = Industrial; D = Domestic

Aeration System: S = sparger; PT = plastic tube, CB = coarse bubble orifice; CD_i = ceramic disc; CD_o = ceramic dome; MD_i = membrane disc; MT = membrane tube; PD_i = plastic disc; SUFFIXES: FF = full floor coverage; SR = spiral roll.

Test Conditions SBS = side-by-side comparison of parallel aeration basins; R = comparison of new equipment after replacing old equipment.

Cleaning method HCl gas = HCl gas cleaning at periodic intervals; liquid HCl = manual hosing and cleaning with HCl; M, Hose = manual hosing at periodic intervals; - denotes new diffusers; none = no cleaning during the period of testing.

Table 2. Oxygen Transfer Results

Plant Code	αSOTE (old)	α (old)	αSOTE (new)	α (new)	Percent Gas Reduction
A	3.7*	-	9.0	0.3-0.4	59
B	9.9	0.63	16.2	-	39
C	3.5	-	6.7	-	48
D	-	-	7.1	-	-
E	3.7	-	7.3	0.3	49
F	54	-	12.0	-	55
G	3.5	-	11.8	0.3-0.55	70
H	3.7*	-	7.0	0.1-0.35	47

* Rates measured for a similar plant wastewater. αSOTE's expressed as percent

The gas savings average 52% which roughly corresponds to the expectations of the plant designers and managers when the aeration systems were constructed. The reported savings are probably too large for the plants with new diffusers, since the new diffusers have not experienced fouling. Plant B is not typical of municipal plants; even though its transfer efficiency is high, the savings are not too large. In summary one can probably expect a 40% to 50% reduction in aeration gas flow rates with the upgrading to fine pore diffusers.

This reduction can translate into substantial savings. For the majority of these plants the submergence of the diffusers is roughly the same, which translates to a blower pressure of 40 to 45 kPa. For a plant of the sizes shown here a gas flow rate of 5 m^3/s is common. If this gas flow rate can be reduced by 50%, the resulting savings in energy consumption, assuming a combined, overall blower motor efficiency of 60%, is $125,000/year at $0.08/kW hr. This savings is usually sufficient to justify the capital required for upgrading. Stenstrom et al. (1984) surveyed a number of plants to determine cost. Using these figures, in 1984 dollars, the projected cost of an upgrade of this magnitude, not including replacement blower costs, would be approximately $360,000. This investment could be recovered in three to four years with the savings reported here, depending upon interest rate, inflation or increasing energy cost, and increased maintenance requirements of the fine pore diffusers.

It is difficult to determine maintenance cost. Some fractions of the maintenance cost are subjective. For example, how much cost should be attributed to the inconvenience of dewatering an aeration basin, above the actual labor costs? Furthermore, it may not be possible to dewater basins at all times of the year (rainy versus dry seasons), and small plants may have great difficulty in maintaining plant capacity with aeration basins out of service.

Diffuser Cleaning

The labor and material cost associated with diffuser cleaning will also vary. Dewatering and cleaning a basin containing 3,000 diffusers using tank-top and/or HCl liquid cleaning can easily be accomplished in two days with 32 man hours, if adequate preparations and spare capacity exist. If tank dewatering is difficult then greater time and manpower are required.

In reviewing manpower requirements with operators from the various plants represented in Table 1, several trends are noted. In two cases, the plants are operated by large organizations which have adequate staffing that can be focused at a single location for intensive and rapid maintenance. These types of organizations usually prefer to assume low manpower costs in their economic calculations, since capacity exists and they are well trained and equipped. The cleaning manpower is small compared to the total requirements of operating the facilities. For the smaller facilities, no manpower may exist for cleaning. Contractors may be required which may be equivalent or less costly, but their use results in an identifiable expense which competes with other needs. This situation often creates a negative incentive to clean diffusers.

Prior to upgrading a system, a management commitment must be made to perform cleaning. Otherwise, the economic benefits will not be realized. Gradual decline of efficiency will be observed. Figure 1 shows the decline in efficiency, for the worst fouling rate encountered in this study. The fouling rate is reflected through the α factor which shows a steady decline. Liquid acid cleaning restored the diffusers to nearly 60% of their original transfer efficiency. The reduction in α factor with fouling (α factors under these circumstances are sometimes called "apparent α factors") is usually accompanied by increased pressure drop. Fouled diffusers in this study often had pressure increases of 5 kPa and in some cases higher pressure increases. Extremely fouled diffusers were selectively removed at some of the plants and tested. These had pressure drops often in excess of 20 kPa, suggesting that almost no gas flow was possible. Several basins in this study experienced reduced gas flow rates due to increased diffuser head loss.

The in-situ HCl gas cleaning at Plant A was effective in maintaining diffuser low pressure drop for a 2 year period, until the basin was dewatered for inspection. A gradual and modest decline in αSOTE was noted over the 2 year period, suggesting that gas cleaning by itself was not adequate to maintain aeration efficiency. The disc diffuser system at Plant A provided the best performance of any alternative over the greatest period of time. This may only in part be attributable to the cleaning technique. The disc design with the locking ring provides a superior gas seal as compared to alternative dome designs.

The alternative dome designs for a plant at a similar location was not nearly as effective. The transfer rate over the 2 year period was 2 percentage points less. Furthermore, more than 50% of the domes experience some sort of malfunction, ranging from total blockage to leaking base gaskets, to uneven air distribution. Domes were replaced in the middle of the study due to poor performance. This problem may be attributed to the use of plastic hold down bolts, which may have experienced fatigue or stretched. The problems have prompted public agencies in this area to prohibit domes in their new plant construction, or to require stainless steel hold down bolts. Acid gas cleaning

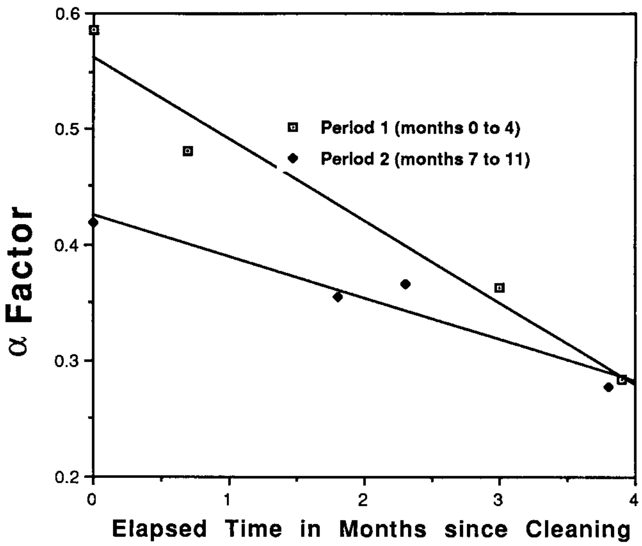

Figure 1. Decline in oxygen transfer efficiency, as indicated by α factor, over time due to fouling.

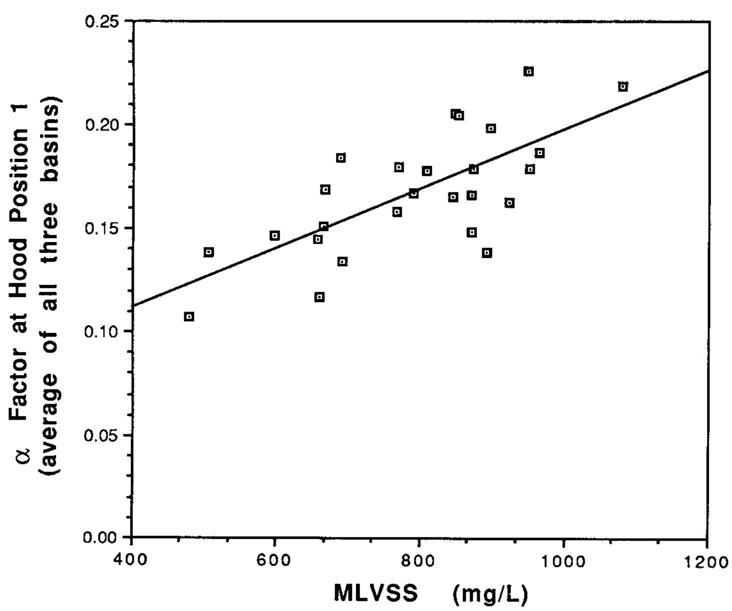

Figure 2. Alpha factor as a function of MLVSS concentration at the aeration basin inlet.

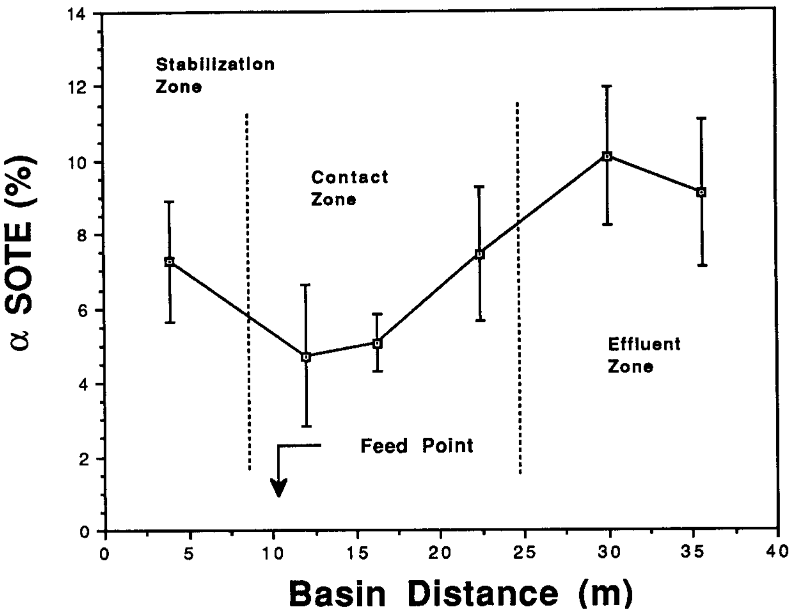

Figure 3. αSOTE versus basin distance for a contact stabilization aeration basin.

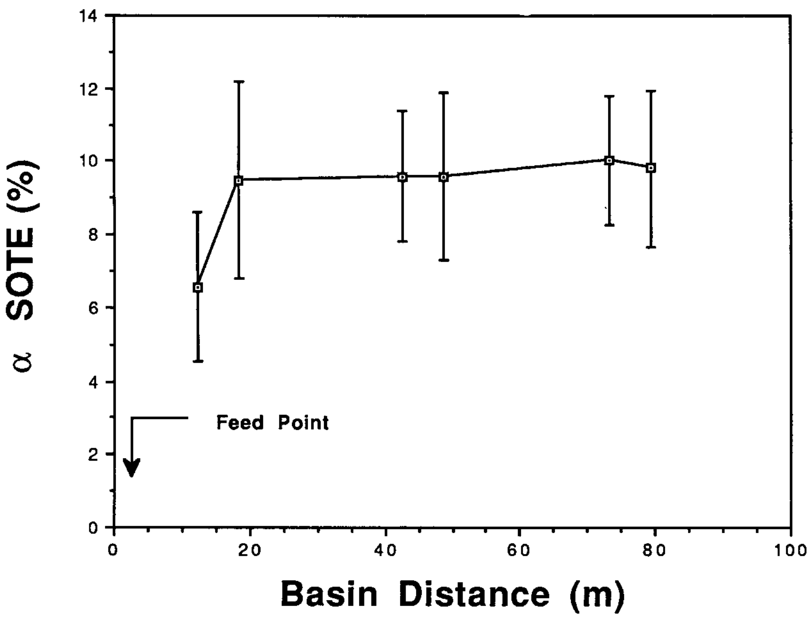

Figure 4. αSOTE versus basin distance for a conventional aeration basin.

was not effective on these dome diffusers, which may be attributed to the leakage problem.

PROCESS OPERATING CONDITIONS

Process operation has a major impact on gas transfer efficiency. This is one of the major findings of this study. The transfer efficiency appears to be a function of mean cell retention time (MCRT) and food-to-mass ratio (F/M). Many attempts were made to correlate these parameters to αSOTE and α factors. General correlations were not successful, although trends in data and boundary points support the correlation (e.g. the lowest αSOTE and α factors occurred when the MCRT was lowest). The best correlation was observed between MLSS or MLVSS concentration and αSOTE, as shown in Figure 2.

Two of the plants were operated in the contact stabilization mode (D and E). A particular trend in αSOTE as a function of basin distance was observed as shown in Figure 3. Figure 4 shows the typical trend for a conventional aeration basin.

CONCLUSIONS

This manuscript reports on fine pore diffuser oxygen transfer rates under process operating conditions for six treatment plants with seven different types of diffusers. In general the increased oxygen transfer rate could provide 40 to 50% reduction in air requirements, or a comparable energy saving. For all of these plants some type of diffuser cleaning program is required to maintain the energy savings. The energy savings suggests that it is possible to justify the capital investment required to retrofit the aeration system, under economic conditions typical of Southern California.

The alpha factors observed in this investigation were somewhat lower than "textbook" fine more alpha factors (0.4 to 0.6). This study suggests a range of 0.2 to 0.4 is more indicative of typical operation.

The plants described in this manuscript experienced greater rates of fouling than other plants in the EPA study (1989). This may in part be attributed to the low MCRT's (generally 1 to 3.5 days for plants A, D, E and H), or the warm wastewater. Fouling is visually worst near the wastewater feed point, but measured parameters such as diffuser pressure drop can be just as bad in the effluent sections.

REFERENCES

ASCE Standard - The Measurement of Oxygen Transfer in Clean Water, American Society of Civil Engineers, New York, NY, 1984.

Boyle, W.C., Stenstrom, M.K., Campbell, H.J. and Brenner, R.C. (in press), "Oxygen Transfer in Clean and Process Water for Draft Tube Turbine Aerators in Total Barrier Oxidation Ditches," *J. Water Pollut. Control Fed.*.

Redmon, D.T., Boyle, W.C., and Ewing, L. (1983), "Oxygen Transfer Efficiency Measurements in Mixed Liquor using Off-Gas Techniques," *J. Water Pollut. Control Fed.*, **55**, 1338.

Standard Methods for the Examination of Waters and Wastewaters (1985), American Public Health Association, Washington, D.C.

Stenstrom, M.K., Vazirinejad, H.R. and Ng, A.S. (1984), "Economic Evaluation of Upgrading Aeration Systems," *J. Water Pollut. Control Fed.*, **56**, 20.

Stenstrom, M.K. and Masutani, G. (1989), "Fine Pore Diffuser Fouling," UCLA Engr. Report No. 90-02, Los Angeles, CA.

U.S. EPA Design Manual on Fine Pore Aeration Systems, 1989.