ASSESSMENT OF AERATION BASIN PERFORMANCE EFFICIENCY

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Dedicated to the memory of the late Tito Jugo

ABSTRACT

Studies in 1997 and 1998 of oxygen transfer efficiency (OTE), measured by offgas analysis at the Tillman Wastewater Reclamation Treatment Plant (TWRP) of Los Angeles have significantly added to the information previously obtained from offgas measurements of OTE in aeration basins at wastewater treatment plants in Southern California. These studies have been carried out by collaborations between UCLA and the Sanitation organizations operating the plants, in an effort to quantify the effect of fouling and the value of different cleaning methods for ceramic diffusers.

The combined air flux and OTE measurements not only agree with the expected inverse relationship between OTE and air flux, but have allowed detection of strong evidence of serious leakage in the air distribution systems of Tanks 4 and 5, which has been indirectly confirmed by observation of water ejection from the air release valves on the tanks. However, the detail provided by the OTE measurements allows more specific understanding of the magnitude of the problem and its significance for the operation of these tanks. Analysis of the measurements made at TWRP since 1991 also indicates that the diffusers in some of the tanks may be in need of cleaning or replacement, for they have clearly lower efficiencies than the tanks that are known to have been recently cleaned.

The recent work also includes some innovations in measurements. A larger number of measurements per day and revisiting tanks after a few days or weeks provides higher time resolution. Samples were more closely spaced than in the previous studies 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. Also, a new "longitudinal" sampling pattern was compared to the conventional "transverse" pattern and series of measurements were made with the hood in fixed positions for periods of several hours, to check measurement stability and diurnal variation.

The data also show enhanced efficiencies near the upstream and downstream ends of the grids, and in the areas beyond the ends of the grids. This is at least partly the result of known variations in diffuser fouling, resulting from air flows in the distribution pipes. However, it may also reflect hydrodynamic and aerodynamic effects of the operation of the tanks and the distribution channel supplying them.

Improved OTE has large potential economic significance, for in a typical activated sludge plant about 2 / 3 of the electrical load is provided by the blowers for the aeration basins, costing hundreds of thousands of dollars per year at large treatment plants. Saving significant fractions of this would justify substantial efforts to monitor tank performance and improve efficiency.

KEYWORDS

aeration, offgas, oxygen transfer efficiency, diffuser, activated sludge

INTRODUCTION

Since 1991 the Bureau of Sanitation of City of Los Angeles and UCLA have collaborated on studies of oxygen transfer efficiency at wastewater treatment plants operated by the Bureau (Stenstrom 1991, 1992, 1993, 1994; Iranpour, et al. 1997, 1998). These measurements have assessed air flow and diffuser performance to gain insight into power consumption and the relative value of differing types of diffusers and cleaning methods, with the goal of eventually reducing costs of secondary treatment.

Since control system design treats oxygen transfer as the fundamental purpose of an aeration system, air require for any rate of biological oxygen consumption is inversely proportional to OTE. However, comparison of past studies (Stenstrom, 1991, 1992, 1993,1994; Stenstrom and Masutani, 1989) shows that a fouled aeration system or one with a poor type of diffuser can have less than half the OTE of a clean system [illegible] diffusers. As around two thirds of the electricity consumed at each plant goes for blowing air into the aeration basins, even small improvements in OTE can therefore be economically important.

We report results of recent work done with some innovations in sampling, which was carried out at the Tillman Wastewater Reclamation Plant (TWRP), (Iranpour, et al. 1997, 1998). More closely spaced and comprehensive sampling has permitted observations of aspects of aeration system performance that were not evident in previous research with more widely spaced samples such as Site A in Redmon, et al. (1983) and the Stenstrom reports cited above. The bulk of this paper is devoted to describing these results.

Additional measurements are planned at the Los Angeles plants, and these results argue for the value of making similar measurements to assess the conditions of aeration tanks at other activated sludge plants. Stenstrom et al. (1998) discusses very important issues and refers to many useful references in this field, e.g., ASCE (1993), USEPA (1989), etc.

EXPERIMENTAL SETUP

TWRP is located in the San Fernando Valley, and provides primary, secondary, and tertiary treatment to about 60 mgd of wastewater, with a design capacity of 80 mgd. It was built upstream of the Hyperion Treatment Plant in two phases. Phase I began operation in 1984 with a design capacity of 40 mgd and 9 aeration basins. Phase II began operation in 1991, and added another 40 mgd of capacity, and another 9 basins.

The basins are rectangular, 30 feet wide, 300 feet long, and 15 feet deep. In each basin air is distributed by three grids of diffusers, designated Grids A, B, and C, respectively, from the influent to the effluent end. Aeration is tapered by having the highest density of diffusers, and the largest total number of them, in Grid A, and successively lower densities and numbers in Grids B and C.

The secondary treatment systems of phases I and II operate almost independently. They receive primary effluent from a common distribution channel from primary treatment, but the clarifiers and RAS systems for the two phases are separate, resulting in the two secondary systems being some what biologically isolated from each other. Thus, one phase sometimes suffers foaming or some other result of an unfavorable bacterial population that does not occur in the other phase. Since the two phases were built at different times, Phase I was equipped with Sanitaire disk diffusers, and Phase II was equipped with Aercor dome diffusers.

At any given time, some of the eighteen aeration basins are out of service. The air control systems in these basins differ from each other, since in Basins 15 and 16 the valve on the downcomer to each grid is controlled by feedback from a DO probe in that grid. All other tanks have less detailed control, for they are operated in pairs with the valves for all six grids in a pair controlled according to the readings from a DO probe in Grid B of one tank of the pair. For example, the control DO probe for Tanks 13 and 14 is in Tank 14.

The instruments used follows the same principles as the commercially available Ewing Mark V (Ewing Eng. Co., 1993), but are specialized for convenient offgas measurements from aeration basins.

EXPERIMENTAL PROCEDURE

The offgas measurements are performed in the conventional manner (Redmon, et al., 1981, 1983; Campbell, 1982): offgas is 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 is measured by a fuel cell. The operation of the instrument produces a number of other parameters that are recorded as the fundamental data from which later results are derived. These include sensor pressure, hood pressure, sensor voltage, gas flow rate and others.

The depletion of O_2 relative to the ambient air is then computed, from which one derives the raw OTE, as described in the references. Hence, air contamination leads to underestimation of depletion and thus of OTE, so that an important limitation on the speed of offgas measurements is the need for waiting after the hood has been moved until sample contamination by ambient air has decreased to a negligible level.

[illegible]

which provides the most uniform basis for comparing aeration efficiencies observed at [illegible] places. It is also valuable to compute the alpha parameter, *a* = *aSOTE / SOTE*, where *SOTE* is the standardized clean water OTE, estimated from formulas fitted to laboratory measurements in clean water, provided by Sanitaire and Aercor. Alpha measures the reduction in OTE under process conditions.

A brief summary of the sampling procedures are given in Table 1 **(See Table 1 "Summary of Experimental Parameters and OTEs")**. Before 1997, samples were taken at the positions shown in Figure 1a. **(See Figure 1 "Sampling layouts")** 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 "transverse" and "longitudinal" sampling patterns are less uniform than those previously used, but cover larger percentages of tank surfaces, Figures 1b and 1c, respectively. The fixed hood approach left the hood in one position for a period of several hours and made frequent measurements there, Figure 1d.

OBSERVATIONS

Only grids A and B of Tank 15 were observed on October 16. On October 22, measurements were made on all three grids of Tank 16. Another set of measurements was made the next day, October 23, on Tank 14, using a similar pattern and covering all three grids. Resulting estimates of *aSOTE* and *a* for October 22 are graphed as functions of position in Figure 2a **(See Figure 2 "Offgas analysis of Tank 16 at TWRP, 10/22/1997")** and the corresponding DO and temperature measurements at the sampling stations are shown in Figure 2b.

Parameters from the control room at corresponding times are shown in Figures 2c and 2d. These control room data include return activated sludge (RAS) flow rates, wastewater flow rates to the tanks, air flow rates to each grid, and DO readings from the oxygen sensors mounted in the tanks. Since these readings are reported every six minutes, but the offgas measurements were made at more widely spaced times, only the control room values closest in time to the offgas measurements have been plotted. Also, since each offgas measurement was made in one grid, the analysis has concentrated on the DO and airflow in the grid where a particular offgas measurement was made. Thus, the comparison was always between each offgas measurement and the Control Room data closest in time and, when relevant, in position, to that offgas measurement.

On November 5, Tank 14 was remeasured using the longitudinal sampling scheme. Figures 3 **(See Figure 3 "Offgas analysis of Tank 14 at TWRP, 11/05/1997, longitudinal sampling, right side")** give the right side measurements and corresponding control room results. Likewise, the results for the left side are given in Figures 4. **(See Figures 4 "Offgas analysis of Tank 14 at TWRP, 11/05/1997, longitudinal sampling, left side")**

A total of six measurement sessions were conducted on Tanks 4 and 5 at TWRP in February, March, and April, 1998, and measurements were also done on Tanks 11, 15, and 16 in February and March. These measurements were made with the hood fixed in one position for an entire measurement session, with consecutive sessions devoted to Grids A, B, and C of each tank.

Figure 5a **(See Figure 5 "Offgas analysis of Tank 4 at TWRP, 02/12/1998 and 04/13/1998")** shows the *aSOTE* and *a*, and 5b shows DO and air flux, for Tank 4 on February 12, 1998. Figures 5c and 5d show the corresponding data for the same tank for April 13, 1998.

ANALYSIS

Three observations are easily seen from these data. First, Figures 3a through 4d show that the efficiency results on the right side of Tank 14 are systematically higher than the results on the left side, although they show similar variations within and between the grids. It is not clear now whether this is a real systematic difference in efficiency, presumably due to differences in diffuser fouling, or whether it is the result of a systematic measurement error. Haste in making the left side measurements may have led to low estimates.

Second, the plots of wastewater and RAS flows together show that these flows were relatively stable during the period of offgas measurements in each day, but the plots of DO and air flow show that, as expected, these parameters varied somewhat during most of the measurement sessions. The control room data confirm that DO in Grid A is usually less than in Grids B and C in the tanks. In most of the 1998 data air flows were more nearly stable than those recorded during the measurement sessions in the fall of 1997.

Another conclusion follows from the measurements at fixed hood positions. The short-term, relatively random-looking variations observed in these sessions indicate that individual measurements of OTE are subject to an uncertainty of one or two percentage points, as shown in Table 1c. Thus, the uncertainties of two or three percentage points derived for the averages in Tables 1a and 1b are valid, or might even be slight underestimates. This in turn implies that a change of only one percentage point in a tank average estimate over a few months is not likely to be statistically significant. Hence, it would not justify an expensive effort to clean or repair a diffuser system, unless the performance were already so poor that cleaning or repair seemed warranted, as in the situation observed by Stenstrom and Masutani (1989), where dewatering showed serious deterioration in the air distribution system in Basin 3 of the Whittier Narrows wastewater treatment plant.

The rest of this analysis addresses two major topics. The first is the assessment of diffuser and air distribution system condition based on comparing these results with previous OTE measurements at TWRP, and the second is the interpretation of the peaks observed in the new *aSOTE* data at the ends of grids or the gaps between them.

Air System Condition

For the assessment of diffuser and air distribution system condition, Table 1a summarizes the tests that have been done on the tanks in Phase II over the past several years. Likewise, Table 1b summarizes the results from Phase I, and Table 1c gives the results from the measurements with the hood in a fixed position. The results from 1991, 1992, and 1993 were all obtained with the same sampling pattern, so they are easily compared, but the new sampling patterns require a little more consideration.

The salient results in these tables are the rapid declines in the efficiencies of Tanks 4 and 5. The average *aSOTE* of Tank 4 was around 19% on February 12, 1998, but only 8% to 9% on April 13 and 27. Likewise, the average efficiency of Tank 5 declined from around 10% on March 27 to around 5% on April 27. Unlike the one percentage point decline in the estimated efficiency of Tank 15, from around 13% on October 16 to around 12% on March 4, the declines in the efficiencies of Tanks 4 and 5 are greater than the estimated standard deviations derived from the averaging calculation, and thus appear statistically significant.

These conclusions are supported by the detailed measurements in Figures 5. On February 12, all but one of the *aSOTE* measurements in Tank 4 were near 20%, and the corresponding air flux measurements were all near 0.2 scfm/ft^2, except for the point with 11.5%, which had a flux of 0.4 scfm/ft^2. On April 13, most of Grids A and C of Tank 4 had efficiencies below 10%, with air fluxes above 0.3 scfm/ft^2, and Grid A had fluxes above 0.4. In all three grids, peak fluxes occur at the locations of the main air pipes (50, 150, and 250 feet from the influent end), suggesting leaks in these pipes. Similar results, not shown in figures, were obtained on April 27, with fluxes in Grid A peaking above 0.6 scfm/ft^2, and corresponding efficiencies around 5%, although the efficiencies in Grid C were back to near 20%, with fluxes below 0.2 scfm/ft^2.

The Tank 5 measurements on March 27 varied much more along the length of the tank than the February 12 measurements in Tank 4, but only a few were above 0.3 scfm/ft^2. By April 27, the fluxes in Grid A peaked above 0.7 scfm/ft^2, and the corresponding efficiencies were below 5%. On both days, both Grid A and Grid B had flux peaks near the main air pipe locations. These results indicate that both Tanks 4 and 5 need repair to their air systems, and that significant damage occurred in March or April.

Evidence of the potential for improvement by cleaning, and the performance of new diffusers at this plant, is provided by Table 1b. The most direct comparison between the recent results and the 1991-1993 results is provided by calculating area-weighted averages of the recent data that omit [illegible]

[illegible]

between the second and third testing sessions conducted by the L.A. Sanitation and UCLA collab[illegible] Tanks 6 and 7, diffusers were cleaned in both tanks, and between the third and fourth sessions the diffusers in Tank 6 were replaced and the diffusers in Tank 7 were cleaned with liquid acid. The liquid acid cleaning improved the efficiency of Tank 7 to approximately the same values as observed in tanks 15 and 16 in 1991, but not to the level achieved with new diffusers in Tank 6. At present the results suggest that tanks 14 through 16 may be due for cleaning again, but additional analysis is needed to determine the efficiency improvements that would be needed to justify the expenses of the different possible cleaning operations (gas cleaning, water hosing, or acid wash).

Efficiency Peaks

High efficiencies were seen in Tank 16 (Figure 2a) near the influent end, lower efficiencies in Grid A, especially high efficiency at the beginning of Grid B and a repetition of this general pattern of lower efficiencies in the interiors of the grids and a higher efficiency at the very beginning of Grid C. A general trend toward higher efficiencies appears as one goes from grid A to Grid C, although it is very noisy and is interrupted by the peaks at the beginnings of Grids B and C. Similar results are seen in Figures 3a and 4a for the two sides of Tank 14, and results from other tanks and other measurement sessions show similar patterns.

One possible reason for higher efficiencies at the boundaries of the grids, is differential fouling of the diffusers. Observations in dewatered tanks show that diffusers in the middles of the lateral pipes tend to be more fouled than those near the main manifold or near the ends of laterals. Hence, a portion of the enhanced oxygen deficiency could be attributed to this phenomenon.

Another possible interpretation is provided by considering that the flow of the wastewater through the aeration basin causes the bubbles to follow diagonal trajectories from the diffusers to the surface. Thus, a hood location at the leading edge of a grid is likely to collect little air from the diffusers in that grid.

On the other hand, as diffusers produce a distribution of bubbles of different sizes, there is a corresponding distribution of speeds of rise, with smaller bubbles rising more slowly, and hence following trajectories with less steep slopes. Thus, air collected above the leading edges of grids B and C may have come primarily from the smallest bubbles from grids A and B, respectively, which provide higher transfer efficiencies than larger bubbles not only by their higher surface to volume ratios but by their longer residence time in the water.

This explanation is not available for the high efficiencies derived from the measurements made at the influent end, at the beginning of grid A. Gas observed at the beginning of the tank presumably comes from several sources, possibly including air entrained during primary treatment, and aerated water from the basin if the flow of secondary influent (primary effluent) and RAS into the basin (through large pipes that discharge against baffles) causes departures from plug flow. However, the main source is probably the aeration performed in the distribution channel to keep solids from settling on their way from primary treatment.

DISCUSSION

These results indicate the value of a program of regular OTE measurements of the kind that we are trying to develop. It is clear that substantial undesirable changes occurred in Tanks 4 and 5 in only two months. It appears likely that this is the result of damage to the piping system that is independent of the diffuser fouling that has previously been discussed as a major concern of this study, and that repair or replacement of this system, rather than diffuser cleaning, would be the appropriate response.

Such repairs also may help reduce air-side fouling of the diffusers, which is not affected by external cleaning processes. As the air supply to the diffusers is in part derived from the headworks and other areas that otherwise would produce unacceptable odors, it is filtered before it is distributed to the tanks, and so the air-side fouling may result from deposition of substances evaporated from small amounts of process water that have leaked into air distribution system through such imperfection. (Compression heats the air to 75 °C or more, so that both water and volatile organics are rapidly vaporized.) This may occur during normal operation, because of the unsteady air flow through leaks, but it is much more likely to occur during power failures which in recent years have occurred at TWRP about once a month.

The results obtained so far have suggested that it might be valuable to gain increased understanding of the response of a tank to changing biological loads by measuring the oxygen mass transfer curve (MTC) (Allbaugh, et al., 1985) for a grid, which probably will be done on tank 15 or 16 because each of the grids on these tanks is independently controlled by feedback from a DO sensor. In this way, when the air flow to one grid is set manually during the MTC test, the rest of the tank will have a better chance of compensating to maintain effluent quality from that tank.

CONCLUSIONS

Successful OTE measurements have been made at TWRP. Six tanks have been measured in the past few months, and two more were measured in earlier years. More comprehensive sampling has been done than in the past, and a new sampling pattern has been tried that separates the results from the left and right sides of a tank and allows faster coverage of a whole tank. Measurements with fixed hood positions provide insight into temporal variability.

Results from several tanks show similar patterns, including enhanced efficiencies at the upstream and downstream edges of the aeration grids and in measurements over the gaps between grids, which have not been observed before on these tanks. These variations are believed to result from a combination of differences in diffuser fouling along the lateral pipes, such as has been observed in dewatered tanks, and fluid dynamic effects as the bubbles rise and the process water flows.

Efficiencies in several tanks are less than the highest values observed in the past, but for many tanks it is not yet clear how much of this is irreversible deterioration of the diffusers and how much is fouling that could be removed by suitable cleaning, or other damage to gaskets and pipes that would be detected if the tanks were dewatered. On the other hand, two tanks show strong evidence of rapid recent deterioration of their air distribution systems.

Prospective future work includes additional measurements on these and other tanks in Los Angeles sewage treatment plants, and a more systematic assessment of the economic factors in decisions to clean or replace diffusers.

Many other large municipal sewage treatment plants have similar equipment, so that these results are relevant beyond boundaries of the Los Angeles sewer system. In particular improved aeration efficiencies have the potential to save millions of dollars nationwide, and there would be a further benefit if cleaning, replacement, and repair decisions were systematized. The present successful OTE measurement are a prototype of the relatively intense monitoring of oxygen transfer in present and future types of aeration basins that will be needed to turn these possibilities into realities.

ACKNOWLEDGMENTS

The authors would like to acknowledge contributions and reviews by: TWRP manager, R. Birk, and his staff, D. Balster, J. Cervantes, and V. Kwok; WESD management, K. Ludwig, and his staff, A. Liu, B. Straub, K. Kharaghani, R.Simon, R. Mayer and M. Starr; TITP managers, C. Mansell and Y.J. Shao; Professors J.J. Lee and D. Miller; and WEFTEC'98 Research Review Comittee, Drs. C.R. Baillod, H. Melcer, and J.B. Neethling.

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Table 1 - Summary of Experimental Parameters and OTEs

Date	Tank No.	Partitions	Pattern	Efficiencies: Grid Interiors OTE	Grid Interiors aSOTE	Overall OTE	Overall aSOTE
				average ± standard deviation			
04/05/91	15	6	transverse	15.20 ± 0.95	16.70 ± 1.06	*not available*	
04/05/91	16	6	transverse	15.30 ± 1.94	17.10 ± 2.43	*not available*	
07/01/92	15	6	transverse	12.70 ± 1.25	15.10 ± 2.59	*not available*	
07/01/92	16	6	transverse	13.00 ± 2.95	15.90 ± 4.13	*not available*	
07/22/93	15	6	transverse	9.60 ± 2.22	10.20 ± 2.68	*not available*	
07/22/93	16	6	transverse	10.80 ± 1.76	11.80 ± 2.21	*not available*	
10/16/97	15	10	transverse	10.35 ± 2.56	12.74 ± 2.74	11.04 ± 2.86	13.74 ± 3.35
10/22/97	16	15	transverse	10.20 ± 1.28	12.36 ± 1.35	11.03 ± 2.21	13.24 ± 2.40
10/23/97	14	20	transverse	9.08 ± 1.47	11.25 ± 1.57	9.18 ± 1.40	11.43 ± 1.55
11/05/97	14R+L*	36	longitudinal	10.07 ± 1.98	12.59 ± 2.55	10.12 ± 1.93	12.69 ± 2.52
11/05/97	14R*	16	longitudinal	10.88 ± 2.28	13.68 ± 2.56	10.92 ± 2.08	13.83 ± 2.41
11/05/97	14L*	20	longitudinal	9.48 ± 1.50	11.69 ± 2.31	9.45 ± 1.48	11.69 ± 2.28
02/10/98	11	17	transverse	13.09 ± 1.94	16.56 ± 2.38	13.36 ± 2.06	16.99 ± 2.69
03/04/98	15	18	transverse	9.22 ± 3.24	11.72 ± 3.84	9.72 ± 3.42	12.46 ± 4.30

* R means right side along the tank; L means left side along the tank.

(a) Phase II, Multiple hood positions

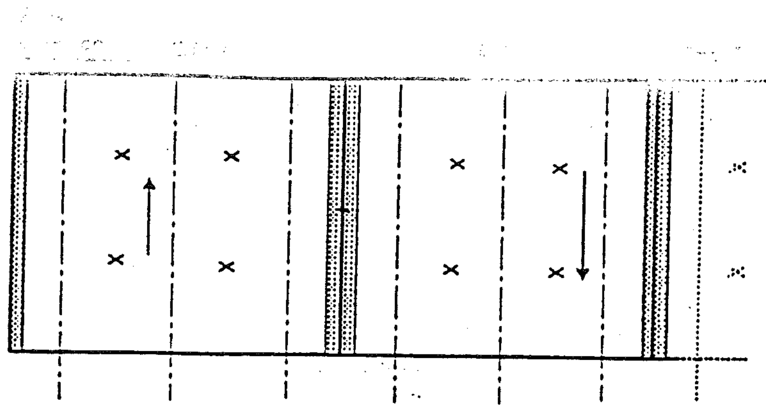
Date	Tank No.	Partitions	Pattern	Efficiencies: Grid Interiors OTE	Grid Interiors aSOTE	Overall OTE	Overall aSOTE
				average ± standard deviation			
02/24/92	6	6	transverse	9.21 ± 2.73	9.91 ± 2.62	*not available*	
02/24/92	7	6	transverse	8.45 ± 1.39	9.01 ± 1.76	*not available*	
06/29/92	6	6	transverse	6.29 ± 1.46	7.31 ± 1.41	*not available*	
06/29/92	7	6	transverse	7.26 ± 1.36	7.74 ± 1.41	*not available*	
12/10/93	6	6	transverse	11.60 ± 2.45	13.40 ± 3.85	*not available*	
12/10/93	7	6	transverse	9.95 ± 1.57	10.79 ± 1.96	*not available*	
07/11/94	6	6	transverse	15.57 ± 1.97	19.63 ± 2.90	*not available*	
07/11/94	7	6	transverse	14.02 ± 1.13	16.87 ± 0.65	*not available*	
02/12/98	4	18	transverse	15.37 ± 1.94	18.93 ± 3.31	15.37 ± 1.93	19.06 ± 3.46
03/27/98	5	26	transverse	7.83 ± 2.16	9.85 ± 2.60	7.97 ± 2.46	9.92 ± 2.76
04/01/98	5	8	transverse	7.62 ± 2.20	8.70 ± 2.41	8.13 ± 2.69	9.25 ± 2.84
04/13/98	4	16	transverse	5.04 ± 3.70	7.47 ± 5.47	5.68 ± 3.73	8.36 ± 5.59
04/27/98	4	14	transverse	5.66 ± 3.36	8.97 ± 6.11	6.28 ± 3.33	9.69 ± 5.88
04/27/98	5	11	transverse	4.40 ± 3.01	4.66 ± 3.10	5.15 ± 3.05	5.42 ± 3.14

(b) Phase I, Multiple hood positions

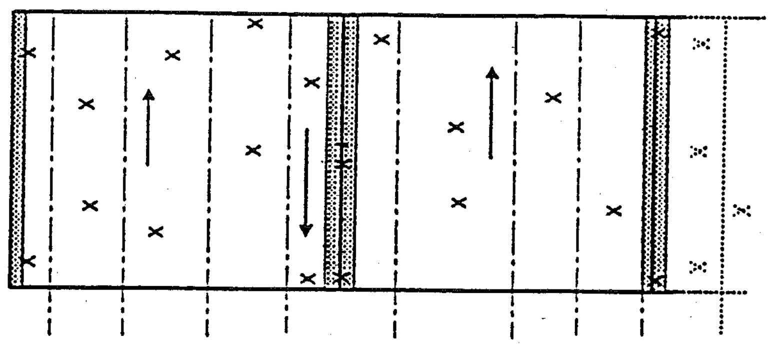
Date	Location	Partitions	Pattern	Efficiencies: OTE	aSOTE
				average ± standard deviation	
Tank No. 15					
02/18/98	Grid A; center	1	fixed	4.10 ± 1.91	4.73 ± 2.26
02/19/98	Grid B; center	1	fixed	12.25 ± 1.25	15.51 ± 1.68
02/25/98	Grid C; center	1	fixed	12.36 ± 1.14	15.90 ± 1.63
Tank No. 16					
03/03/98	Grid A; leading left edg	1	fixed	3.95 ± 1.40	4.07 ± 1.46
03/11/98	Grid B; right, center	1	fixed	14.57 ± 0.96	18.50 ± 1.94
03/12/98	Grid C; trailing left edge	1	fixed	11.90 ± 1.71	13.55 ± 2.05

(c) Fixed hood positions

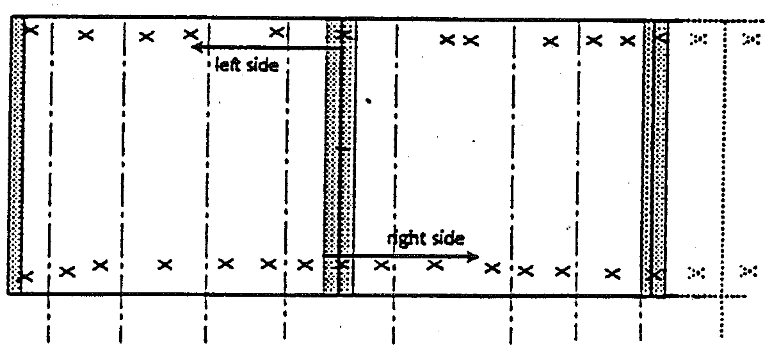
Figure 1 - Sampling layouts.



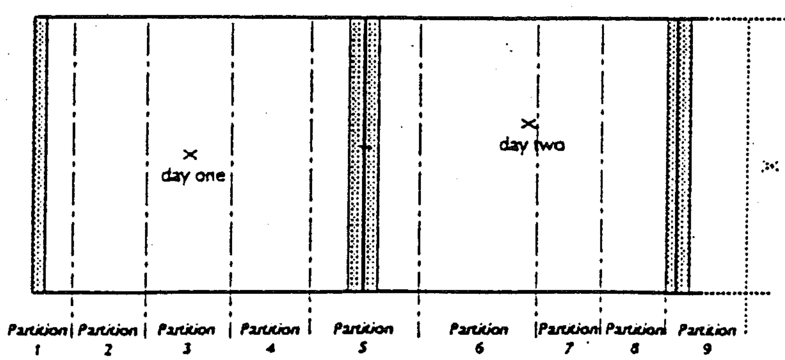
(a) transverse sampling (1991-1994)



(b) transverse sampling (1997-1998)

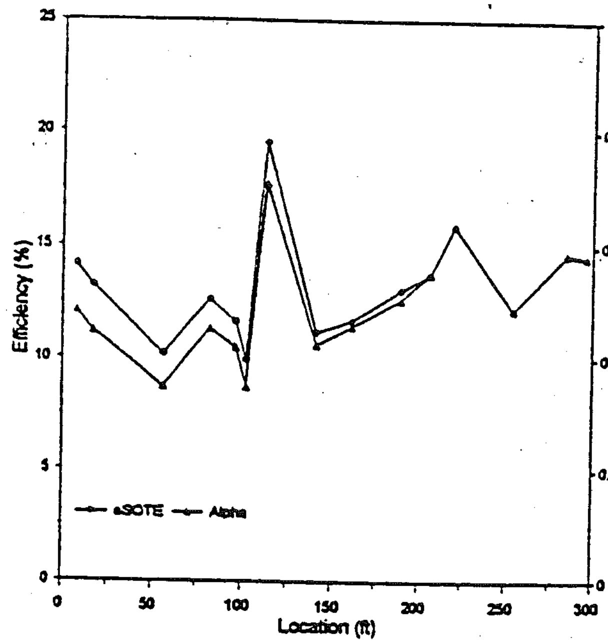


(c) longitudinal sampling (1997-1998)

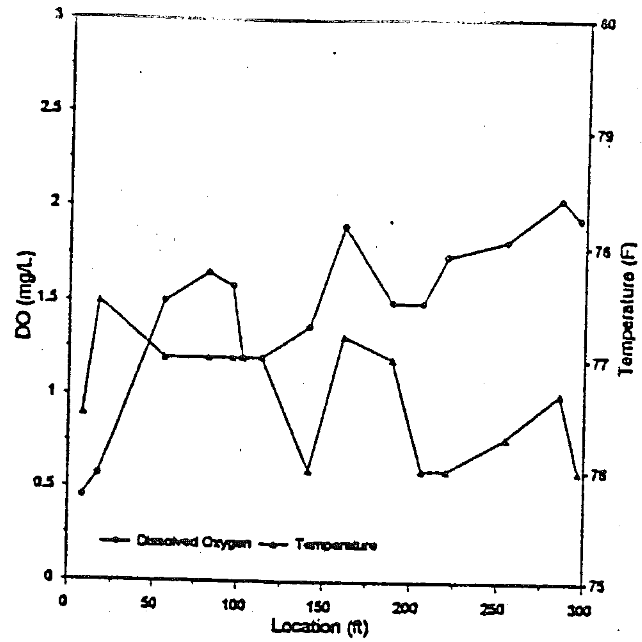


(d) stationary sampling (1997-1998)

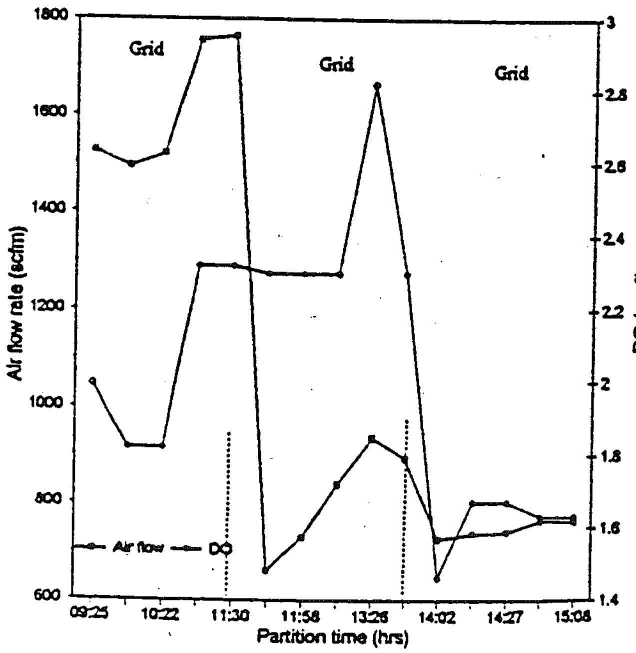
Figure 2 - Offgas analysis of Tank 16 at TWRP, 10/22/1997



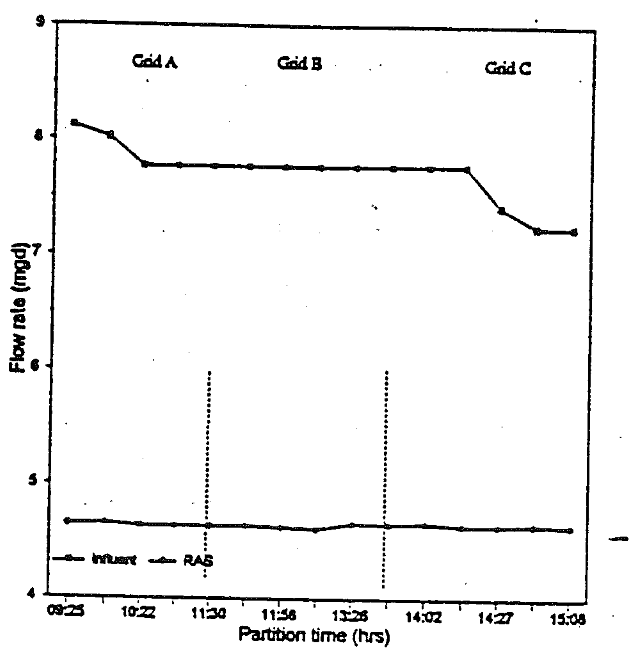
(a) aSOTE and alpha factor



(b) DO and temperature

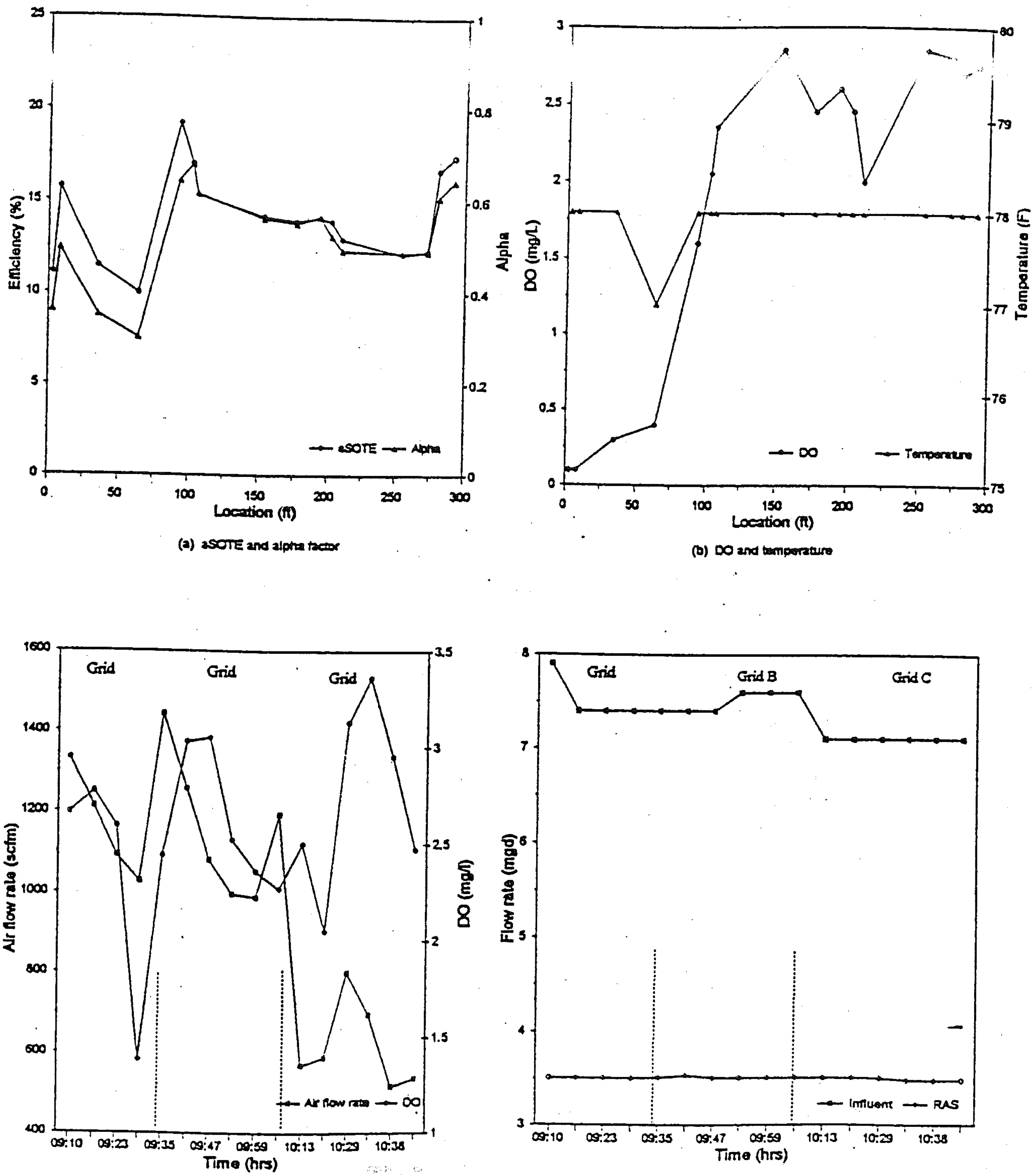


(c) Air flow rate and DO, control room data averaged over partitions



(d) Influent flow and RAS, control room data averaged over partitions

Figure 3 - Offgas analysis of Tank 14 at TWRP, 11/ 05 / 1997, longitudinal sampling, right side



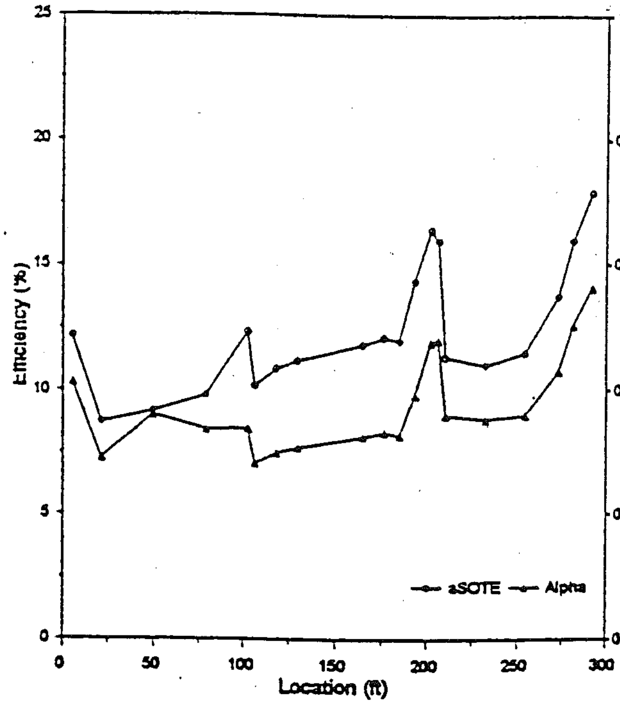
(a) aSOTE and alpha factor

(b) DO and temperature

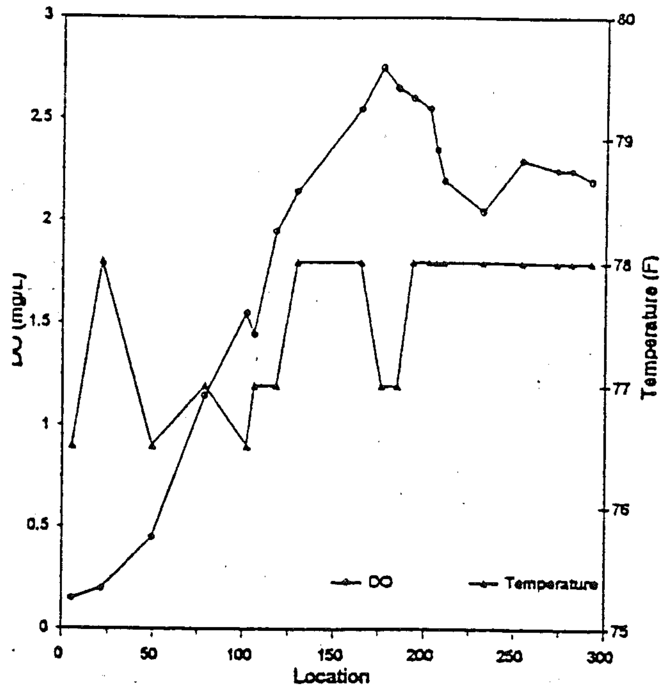
(c) Air flow rate and DO, control room data averaged over partitions

(d) Influent flow and RAS, control room data averaged over partitions

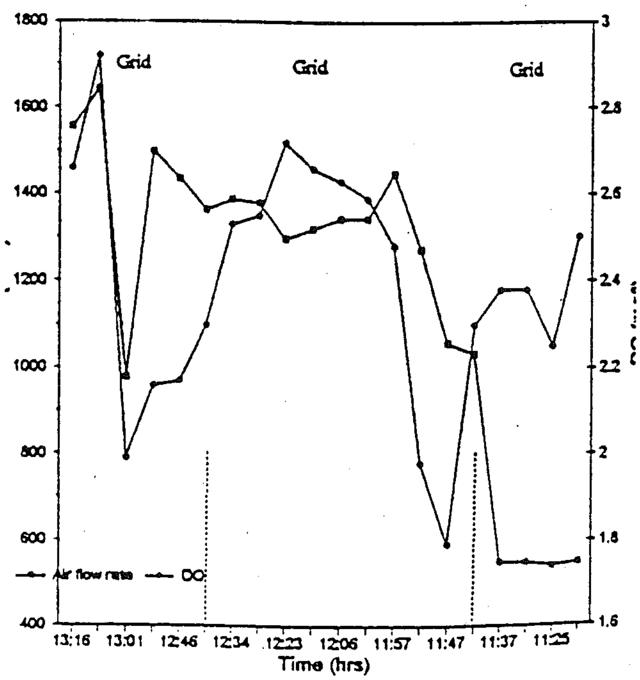
Figure 4 - Offgas analysis of Tank 14 at TWRP, 11/ 05/ 1997, longitudinal sampling, left side



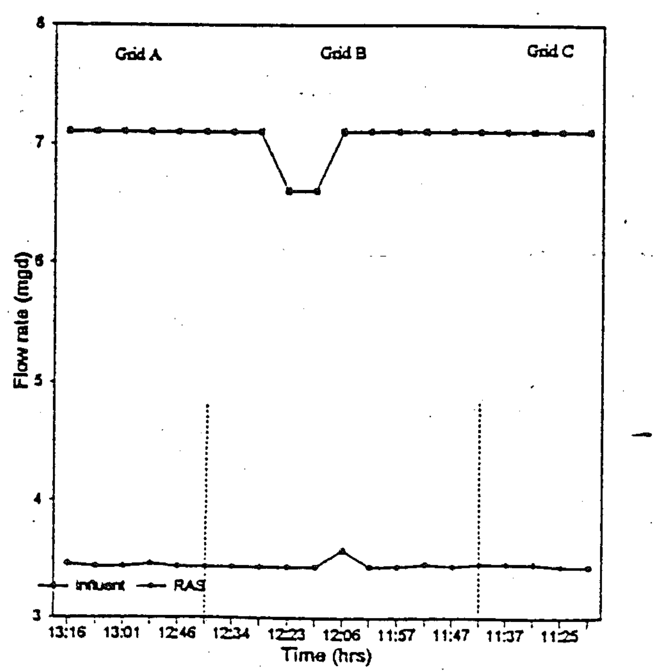
(a) aSOTE and alpha factor



(b) DO and temperature

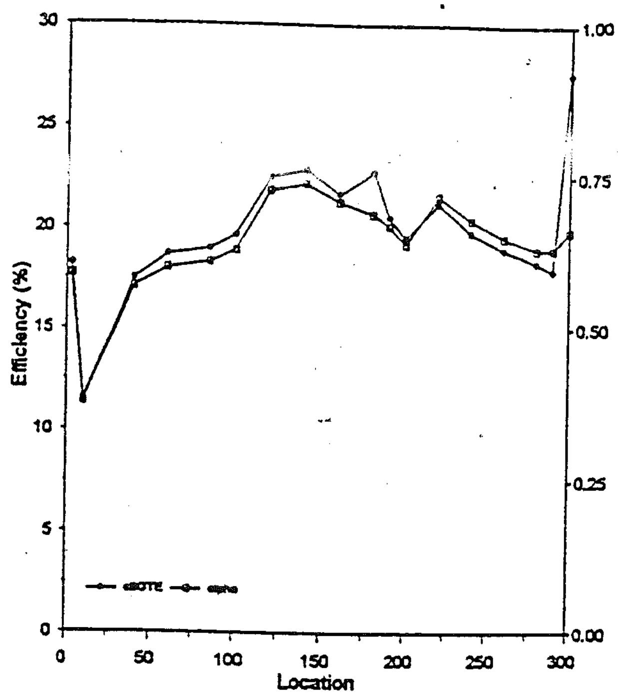


(c) Air flow rate and DO, control room data averaged over partitions

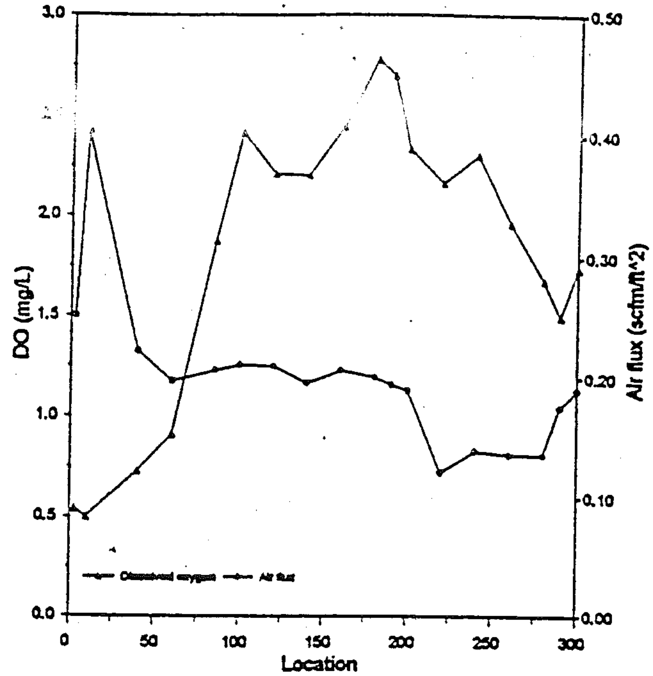


(d) Influent flow and RAS, control room data averaged over partititons

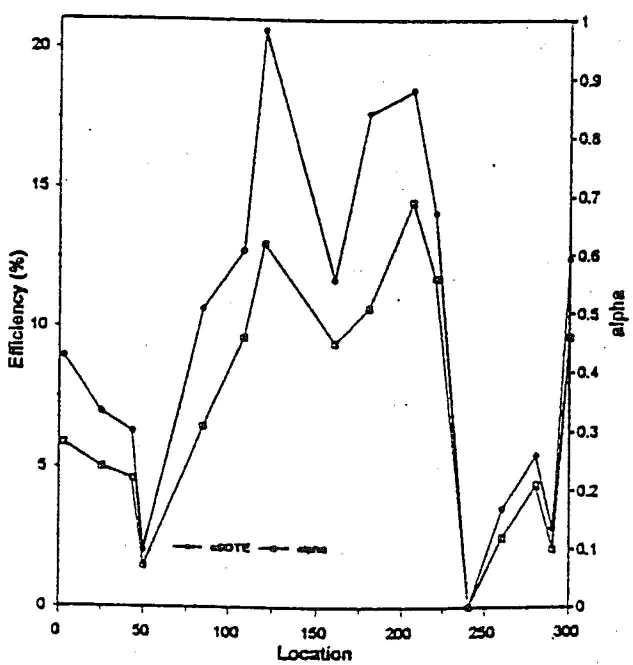
Figure 5 - Offgas analysis of Tank 4 at TWRP, 02/12/1998 and 04/13/1998



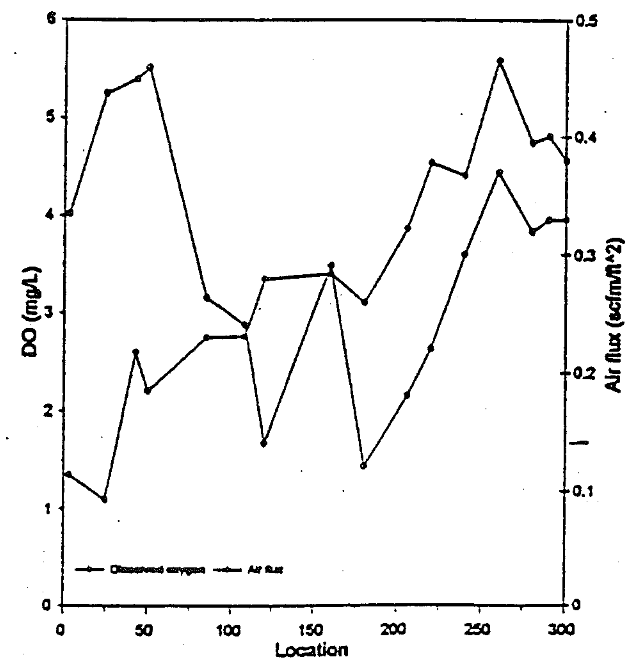
(a) aSOTE and alpha factor, 2/12/98



(b) DO and air flux, 2/12/98



(c) aSOTE and alpha factor, 4/13/98



(d) DO and air flux, 4/13/98