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AN OTE PROTOTYPE TO OPTIMIZE MAINTENANCE AND AIR CONSUMPTION: FULL SCALE ANALYSES AT CITY OF LOS ANGELES' WASTEWATER TREATMENT PLANTS

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ABSTRACT

These are the results of the oxygen mass transfer curve (MTC) in two aeration grids of Tank 15 at the Tillman Water Reclamation Plant of the LA's Bureau of Sanitation. The purpose of these measurements was to measure the effect of changing the valve settings so that the response of the system to changing loads could be predicted better, and to obtain more realistic estimates of the maximum allowable valve settings under the process conditions at the plant.

The manufacturer of the ceramic diffusers provided a range of allowable air flows. In general, the minimum is the flow needed to prevent water seepage through the diffusers into the air system, and hence there is no question that compliance with this limit is necessary. However, the manufacturer's upper limit is to prevent the diffusers and gaskets from damage by the pressure of the air, and may be above the flow that is acceptable for efficient oxygen transfer. Before the experiment, there was no way to know how the peak that theory predicts for the MTC would compare to the feasible range of air flows that is defined by the capacity of the blower and pipe system and

the manufacturer's limits.

Now that these pioneering measurements have been carried out, we see that peaks not only appear in these data, but also are found at or below the midpoints of the observed ranges of air flows. Hence, it is clear that in these grids there is only a narrow range of usable air flows between the lower limit determined by the manufacturer and the peak of the MTC. The downward slope of the MTC at air flows above the peak means that increasing the air flow in this range decreases the amount of oxygen transferred, and thus is both counterproductive and a waste of energy. This limits the ability of the tank to respond to changing loads, and probably is the result of fouling of the diffusers.

However, measurements of other tanks will be needed to obtain a reasonably comprehensive view of the prevalence of this situation in the Bureau's plants. Also, it is desirable for the additional measurements to include clean diffusers, to determine the extent to which cleaning increases the usable range of air flows. This provides insight into the dynamic behavior of a plant in a way that is not provided by measurements at a single air flow, even if such measurements show increased efficiency after cleaning.

As the measurements made in determining the MTC include local dissolved oxygen measurements, they also provide a basis for assessing the need for additional DO sensors in the tanks. Presently, most tanks only have one DO sensor in the whole tank for the control system, or pairs of tanks are controlled using the readings from a DO sensor in one of them. These results indicate that at the minimum knowing the DO in each grid would be desirable for increasing the efficiency of air use. Results of air flows using four DO sensors in two tanks (three grids per tank, one DO sensor per grid in two grids per tank) versus the usual practice of one DO sensor controlling two tanks with the associated blower air costs will also be presented.

Meanwhile, these results, preliminary as they are, show that the MTC can be determined under process conditions, and offer an example that can be followed by people at other activated sludge wastewater treatment plants to set a maximum air flow and define a usable range.

KEYWORDS

mass transfer curve, air optimization, oxygen transfer efficiency, activated sludge, aeration, offgas

INTRODUCTION

Control of aeration basins in wastewater treatment plants is ordinarily based on the assumption that blowing more air through the process water will transfer more oxygen into it. Hence, sensors mounted in the tanks monitor the dissolved oxygen (DO) concentration. If the DO falls below the desired value then automatic systems or the operators increase the air flow; likewise, a rise above the desired DO value prompts an air flow reduction. The experiments in this report are to optimize the air flow in the aeration tanks which is the mostly costly process in an activated sludge plant.

Basic physical considerations imply that oxygen transfer efficiency (OTE) tends to decrease with increasing air flow: larger air flows tend to produce larger bubbles, which have smaller surface-to-volume ratios and rise faster, and hence transfer less of their oxygen into the water. This is exemplified in manufacturers' standardized OTE data for their ceramic diffusers, in which measurements in clean water are typically fitted with straight lines that slope down, or with downward-sloping segments of parabolas with small quadratic terms, so that over the interval of feasible air flows the segment is nearly straight.

It is less common to make such measurements under operating conditions. There is a study by Allbaugh, et al. (1985), in which such measurements were made, and their Figure 8 includes downward-sloping straight lines that summarize two other studies apparently done similarly, but little other information appears to be available.

This is understandable, since to perform such a study it is necessary to set the air flow in a tank or a portion of a tank to known values while the OTE measurements are being done. Such measurements are time-consuming and laborious, especially with the instruments for offgas measurements of OTE that have been available until recently. Also, adjusting tank air flows to suit a measurement session is likely to be inconvenient for operators, and may even run a risk of causing a violation of discharge standards.

Hence, aeration control is usually conducted now with no knowledge of the actual change of OTE caused by an air flow change. The limitations of this approach become clear on considering that it is not always true that increasing air flows transfer more oxygen. At high enough flows a further flow increase decreases oxygen transfer, because the reduction in OTE counteracts the effect of additional oxygen availability in the higher 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_2mass 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_2mass flow in the air is proportional to air flux, the O_2mass transfer rate into the water as a function of air flux is approximately an inverted parabola, with one region that has a positive slope and another with a negative slope.

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 in the water. Evidently, if air flow rises high enough that it reaches the side of the MTC that has a negative slope, then two things happen: (i) control procedures that assume a positive slope produce results opposite to what is expected; (ii) energy is wasted in blowing a large flow of air that transfers no more oxygen than a smaller flow at the corresponding point on the positive slope of the MTC.

It seems likely that it is unusual for the air flux in a tank to be so high that oxygen transfer starts to decrease for the tank as a whole, but that nonuniform fouling may lead to this condition in the most fouled areas; in any case, the only way to know whether these guesses are true is to make controlled OTE measurements on some operating tanks and compute the actual MTCs.

This paper reports the first results from a program of such measurements that were carried out at one of the plants operated by the Los Angeles Bureau of Sanitation. This has built on work by many other authors, dating back to Redmon, Boyle, and Ewing (1983), the developers of the modern offgas test. The work has also been influenced by the reports (Stenstrom, 1991-1994) on tests at the Los Angeles plants that have provided extremely valuable comparisons with the more recent work (Iranpour, et al, 1997-1999), which has included remeasurements on the tanks in these reports. Stenstrom and Masutani (1989) has also provided perspective on plant operations in Southern California, including an example of serious system deterioration at Whittier Narrows. Babcock and Stenstrom's (1989) analysis of the effect of errors in the measurement process has improved our confidence in the quality of results that can be obtained.

Our attention to the potential economic significance of this work has also been guided both by the early Stenstrom, Vazirinejad, and Ng (1984) paper on the economic evaluation of upgrading aeration systems to fine-pore diffusers, and by the Currie and Stenstrom (1994) discussion of replacing ceramic diffusers with membrane devices. These papers provide concise summaries of the potential benefits of the high efficiencies attainable when fine-pore devices are working well, although for a more thorough analysis for design purposes the EPA manual (1989) is the essential reference.

Additional very recent excellent references that will have an impact on the theory and practice of aeration are: a) Newbry (1998) that in the course of presenting the energy intensity parameter provide a detailed derivation of formulas describing the physics of oxygen transfer in a way that can be applied to other studies of the behavior of aeration tanks; b) Fisher and Boyle (1999) that performed a very careful study of oxygen transfer in systems with and without selectors and found essentially identical results in both types of tanks, contrary to their expectations from the conventional explanation of the loss of efficiency that is seen in dirty water; and c) the Semmens, et al. (1999) paper which is the latest from this group's research program on using microporous membranes in oxygen transfer instead of the present types of ceramic diffusers. The relationship of the work of these authors to our field oxygen transfer studies and future research are briefly discussed in Iranpour et al. (1998, 1999 a, and 1999 b) and will be further discussed in more detail in later reports.

EXPERIMENTAL SETUP

The experiment team and the plant operators collaborated in setting the airflow to known values during the measurements. Combining the airflows with the OTEs determined during the sessions provided both of the quantities needed to determine the mass of oxygen transferred under the experimental conditions.

The study was carried out in Tank 15 at the Tillman Water Reclamation Plant, which is located in the San Fernando Valley. The tank is a rectangular aeration basin, 30 feet wide, 300 feet long, and 15 feet deep, equipped with Aercor ceramic dome diffusers. Although the diffusers have not been cleaned since 1996, which may result in less favorable results than would be obtained elsewhere, this tank was used because it has been equipped with an independent valve and DO sensor for each grid. This makes it possible to establish a fixed airflow for one grid that does not affect the operation of the rest of the tank.

Grid A was chosen for the first set of measurements in the hope that if the study included setting the aeration there to insufficient levels, the aeration of the subsequent grids could be adjusted to compensate. Also, Tank 15 is only one of approximately a dozen aeration basins that are in operation at Tillman at any time, so that variations in treatment effectiveness in this one tank would be diluted among the effluent of the rest of the tanks, and hence there would be little risk of violating the plant discharge standards.

The established method of offgas OTE measurements was used (Ewing 1993, Redmon 1983, Campbell 1982): offgas is collected by a hood floating on the surface of the tank, and after removal of $O_2$and water vapor from the sample stream, the O_2partial pressure is measured by a fuel cell. The depletion of O_2relative to the ambient air is then computed, from which one derives the raw OTE. Correcting for departures of ambient conditions from the standard atmospheric pressure and temperature, and for nonzero DO in the wastewater, gives the standardized parameter commonly denoted a ðSOTE, which provides the most uniform basis for comparing aeration efficiencies observed at different times and places.

EXPERIMENTAL PROCEDURE

Measurements were conducted in Grid A of Tank 15 on April 13 and 14, 1999, at the four locations shown in Figure 1. Likewise, measurements were conducted at corresponding locations in Grid B on April 19, 1999. These locations were chosen to provide the most uniform sampling that could be achieved with a relatively short measurement time that would allow repetition at all locations at each of several airflow settings within one working day.

The same procedure was followed at each valve setting on each day. The team leader adjusted the valve and recorded its position and the airflow indicated by the control room gauge. During the following period, approximately one hour, the experiment team then measured the OTEs, first at the upstream two locations along the tank length at Y=28 and then at the downstream locations at Y=80. This was repeated for four or five valve settings.

Only a relatively narrow range of the possible valve openings was used, from about 18% to approximately 40%. This was dictated by equipment limitations. Aercor recommends a minimum airflow of 0.5 scfm per diffuser, which for the 1522 diffusers in Grid A gives 761 scfm as the minimum flow to the grid. This corresponds to a valve opening around 18%. The 40% limit was used because the offgas instrument's pressure gauge for its oxygen sensor gave erroneous readings for openings above 40%.

RESULTS

Figure 2 shows the efficiencies and the mass transferred into the water as functions of the air flow. These flows are extrapolated from the local air flow measurements made in the course of the OTE measurements. It is possible that they may be influenced by local fouling, which would explain why they sometimes differ by 20%-30% from the flows to the whole grid recorded from the control room flow gauge.

It is evident from Figure 2 that the largest valve openings used were sufficient to reduce the efficiency well below 1%, so that there would have been little value in making measurements at openings above 40%, even if the offgas instrument's pressure gauge had made this possible.

The OTE data from most of the locations show substantial scatter, instead of forming the expected smooth downward-sloping straight or nearly straight line, so this scatter carried over into the mass transfer values. Nevertheless, the primary conclusion from Figure 1 is that over most of the observed range of airflows, at each of the four measurement locations, the mass transferred was decreasing with increasing airflow. Only in the lower half of the range of airflows did the mass transferred increase or stay approximately stable with increasing airflow.

Figure 3 show the corresponding values for the April 14 session. Most of the valve settings used on this day differed only slightly from those used on April 13, and comparing Figure 3 with Figure 2 shows that similar valve settings usually, but not always, produced similar results.

In particular, the results at the 40% setting at point A, which is 25 feet from the right side as viewed from the influent end and 28 feet downstream of the influent end (hence assigned coordinates X=25, Y=28) are nearly identical, and the reading at the 18% setting on April 14 agrees well with the reading at 20% on April 13. On the other hand, the respective OTE readings at 20% on April 13 and 18% on April 14 at point B (X=25, Y=80) differ by a factor of almost 2, and this is reflected in the corresponding mass transfer values. Additional measurements would be required to determine whether this is a genuine large change in only one day, or whether the difference results from some measurement mistake. Making all allowances for the uncertainties implied by the scatter in these data, and the differences from the April 13 measurements, it is clear that, as on April 13, the OTEs decrease so rapidly, and reach such low levels, that the mass transfer values decrease with increasing air flows over most of the interval observed.

Figure 4 shows the results from the April 19, 1999 measurements on Grid B. They were carried out over a narrower range of valve settings (25%-40%) than the Grid A measurements, but show the same characteristic of a mass transfer function that peaks at or before the middle of the range of air flows.

COMBINING THE RESULTS

Figure 5 shows plots that combine the April 13 and 14 data for each location in Grid A, along with visually estimated parabolas that appear to fit the scattered data reasonably well. Each of these parabolas peaks around 1000 cubic ft/min. The ones for Points A and B peak a little above 1000 and the ones for Points C and D peak a little below 1000, but the results are too uncertain to draw any conclusions from this apparent difference.

On the other hand, it may be more significant that the mass transfer values from the upstream side of the grid, at Y=28, are lower than those from the downstream side, at

Y=80. This is consistent with past measurements, both by this research group (Iranpour et al., 1997, 1998) and by many others (e.g., Fisher and Boyle, 1999, and references cited therein) showing that OTEs rise as treatment progresses.

Figure 6 shows OTE profiles recorded along Tank 15 in previous measurement sessions during which the airflow was under the control of the plant's automatic feedback system. The variations over long periods reflect fouling development and cleaning events during the years since the diffusers were installed, but the more closely spaced measurements in the past two years are a little more consistent with each other. In particular, the profiles from October 16, 1997 and March 4, 1998 show efficiencies at points near Y=28 and Y=80 that are similar to those observed for low air flows at those locations on April 13 and 14, 1999. The efficiencies at these locations are a little lower in March, 1998 than in October, 1997, probably reflecting a modest degree of fouling during the lapse of four and a half months.

Figure 7 presents the control room air flow measurements from the 1997 and 1998 sessions, showing that on both days the air flows were usually close to those at the peaks of the 1999 MTC curve, or were in the region of positive slope. Comparing Figures 6 and 7 also shows evidence of the expected anticorrelation between air flow and OTE, but since the measurements are made at different positions, and hence are probably influenced by local variations in the degree of fouling, as well as by changing air flows, it is not possible to derive from these older data the kind of quantitative relationship provided by the measurements with fixed air flows made for this study.

CONCLUSIONS

1. We have observed an aeration system in which, over a wide range of air valve settings, OTE decreases so rapidly with increasing airflow that providing more air actually decreases the amount of oxygen transferred into the process water.

2. These observations required setting the air flows to known values for while the OTEs were being measured, instead of the previous approach of observing the plant in undisturbed operation.

3. Control procedures that assume increasing mass transfer with increasing air flow are useless or counterproductive when the assumption is invalid.

4. From preliminary optimization, the maximum allowable air flow to grid A according to these measurements is approximately 1350 scfm, corresponding to a valve opening around 25%.

5. These results are preliminary and additional experiments to develop MTCs, to optimize the airflow, are being planned.

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Figure 1. Plan view of an aeration tank: MTC measurement locations in Grid A

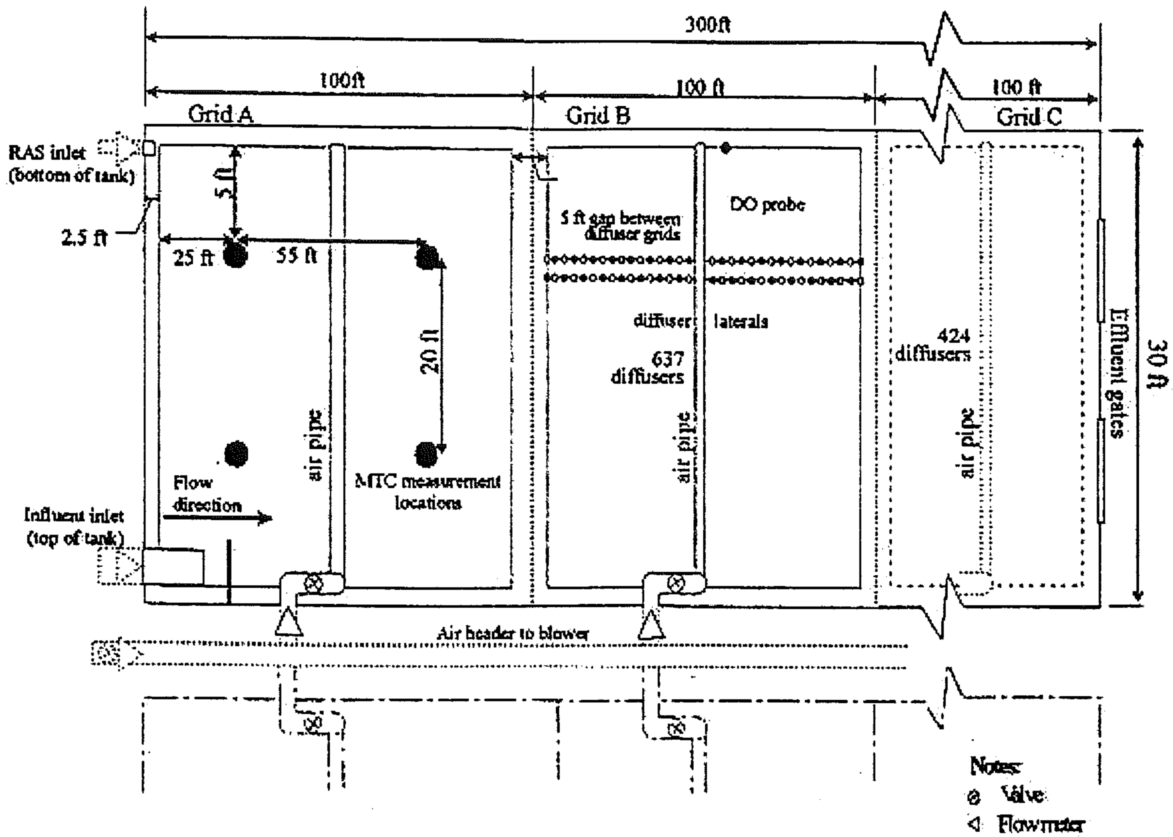
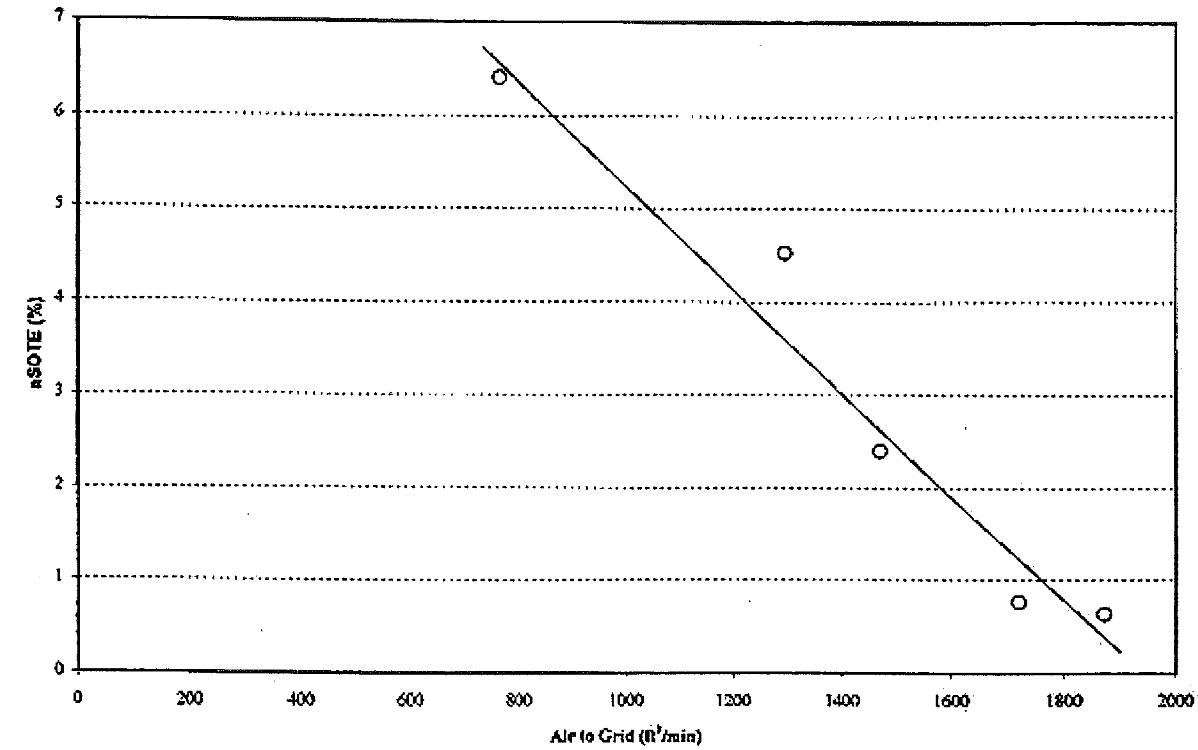
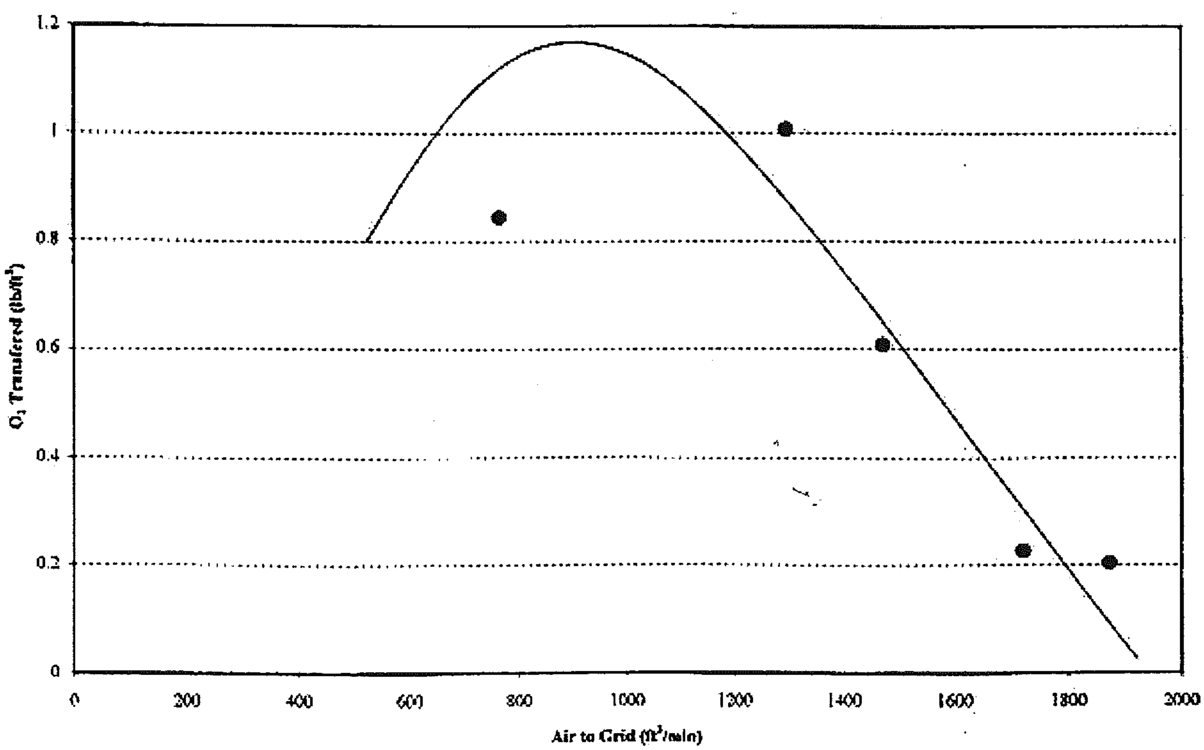


Figure 2. Offgas anlysis for Grid A, Tank 15 at TWRP, 04/13/99.

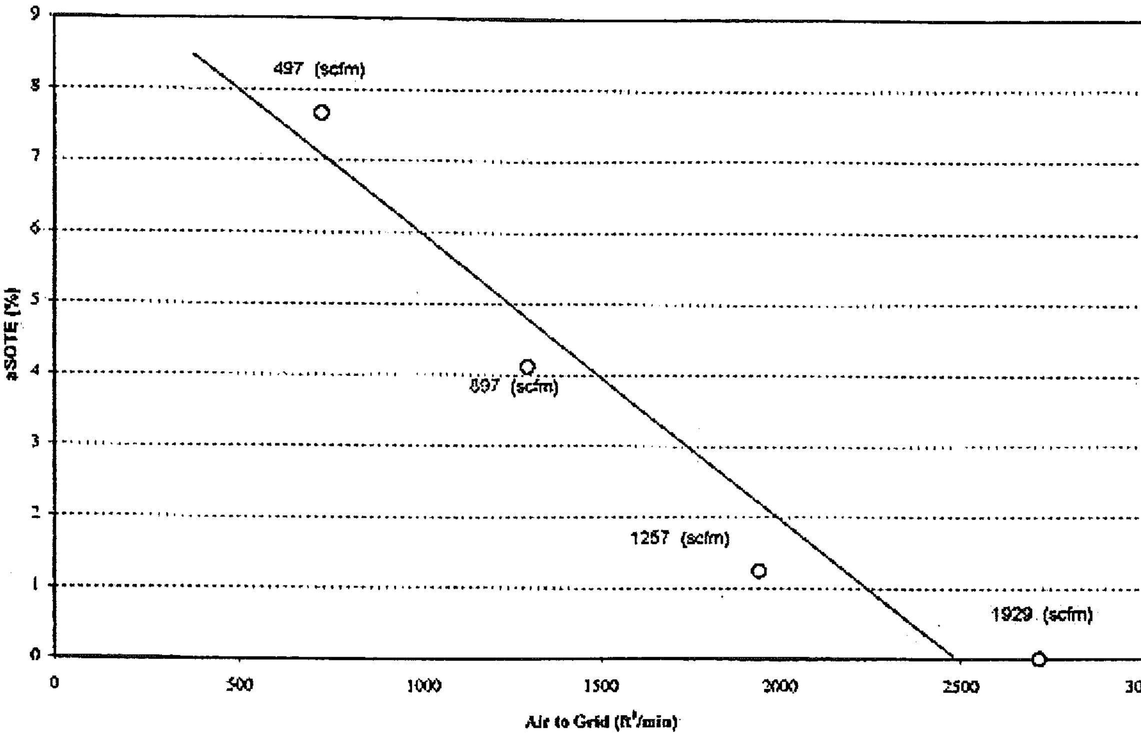


(a) Efficiency vs. air flow

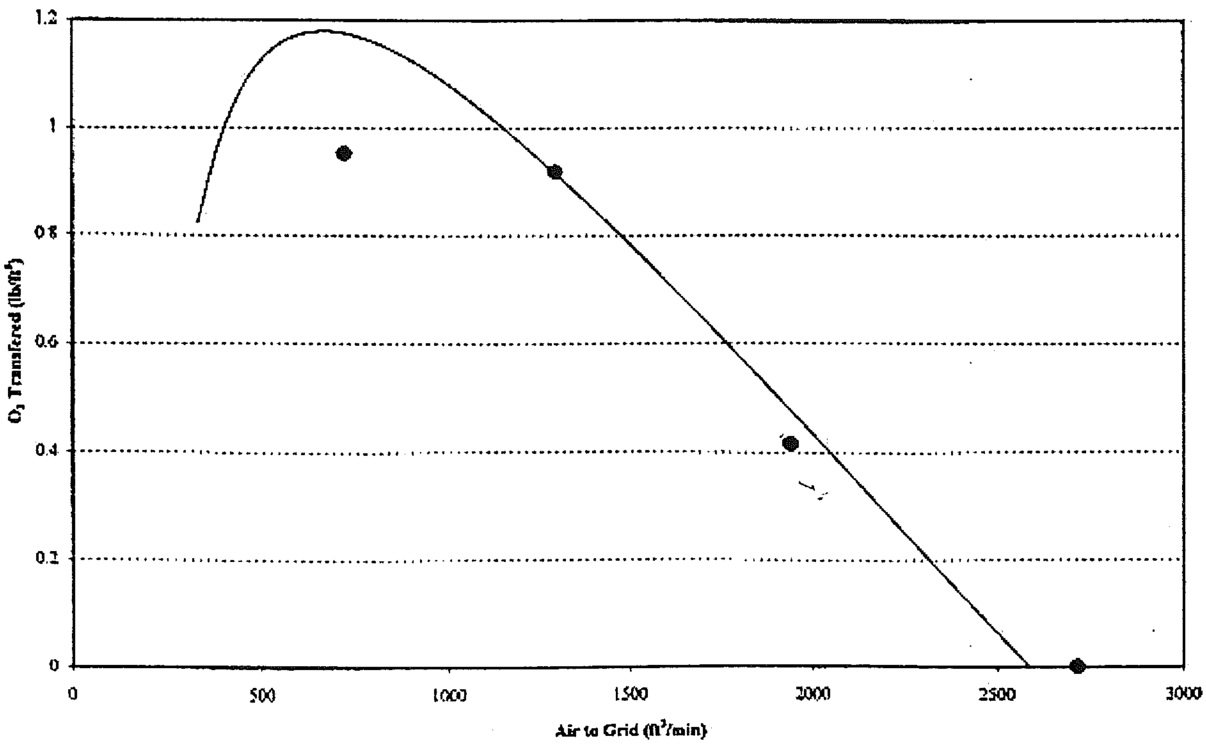


(b) Mass transfer curve

Figure 3. Offgas anlysis for Grid A, Tank 15 at TWRP, 04/14/99.

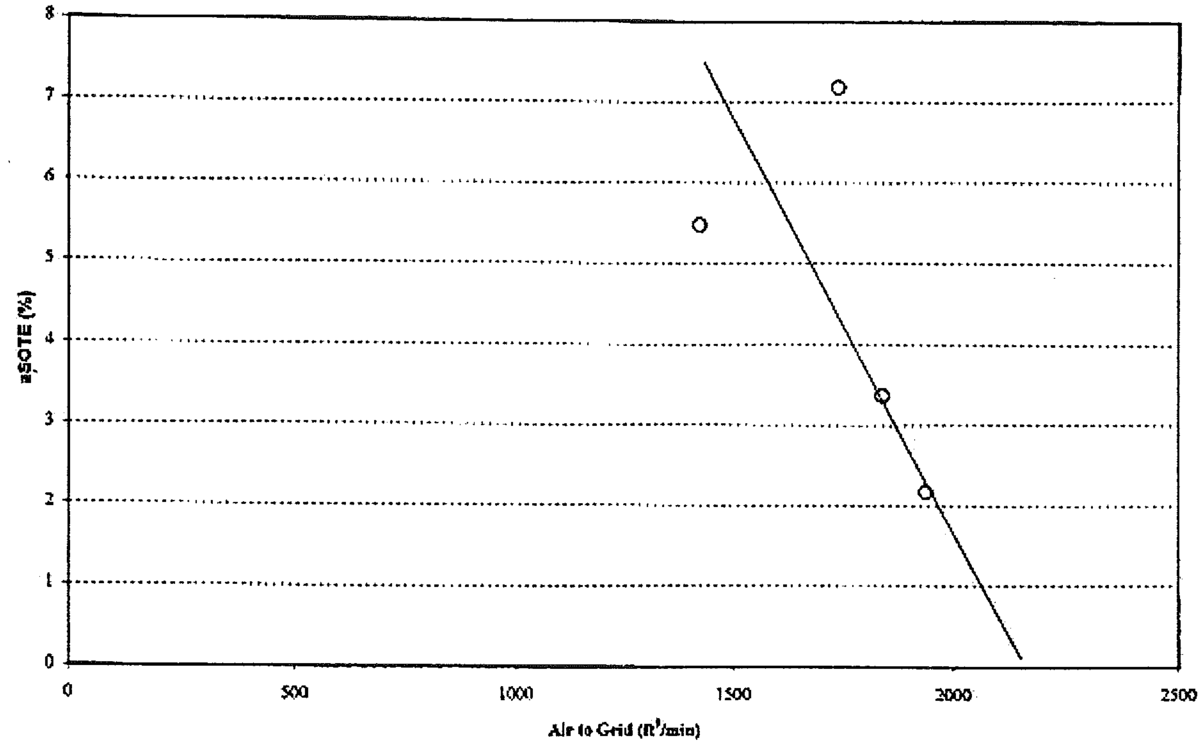


(a) Efficiency vs. air flow

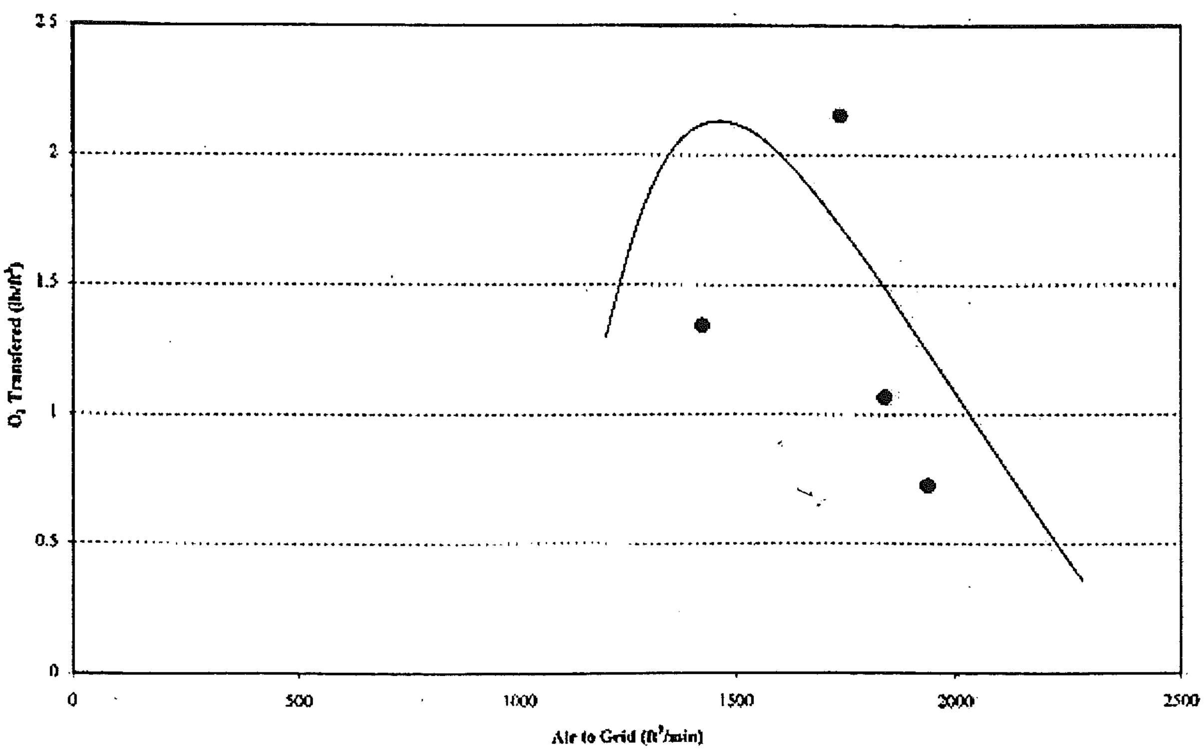


(b) Mass transfer curve

Figure 4. Offgas anlysis for Grid B, Tank 15 at TWRP, 04/19/99.

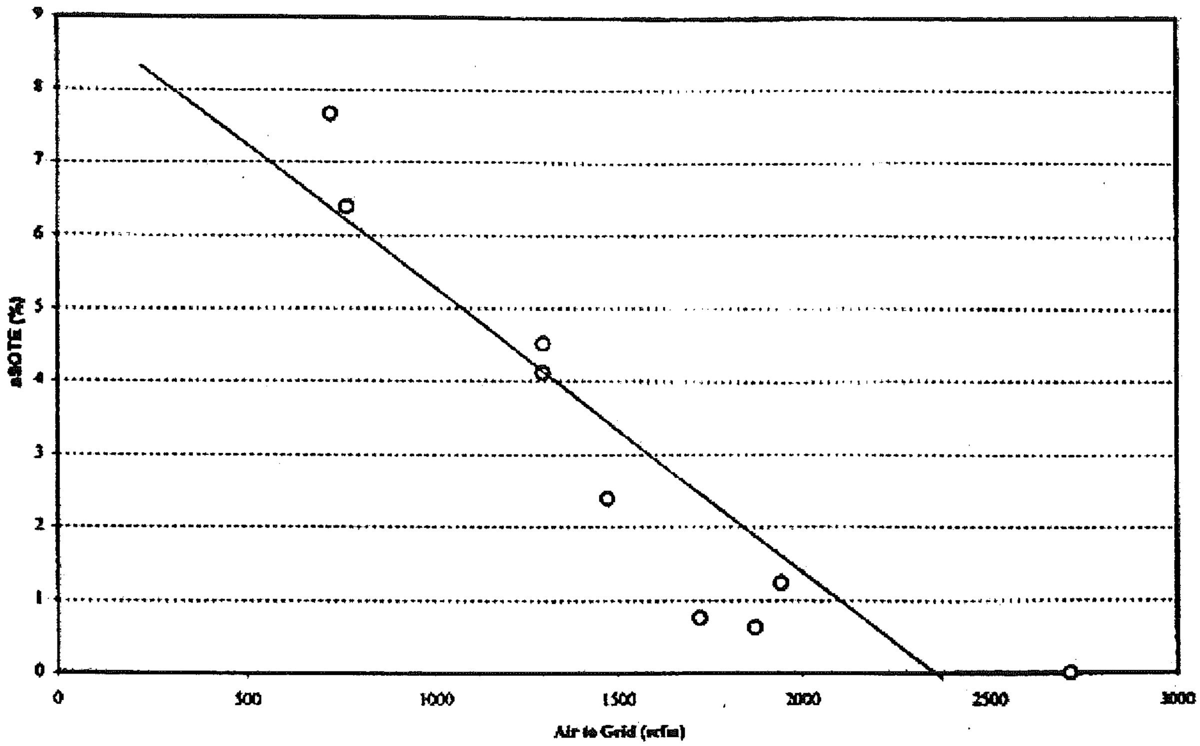


(a) Efficiency vs. air flow

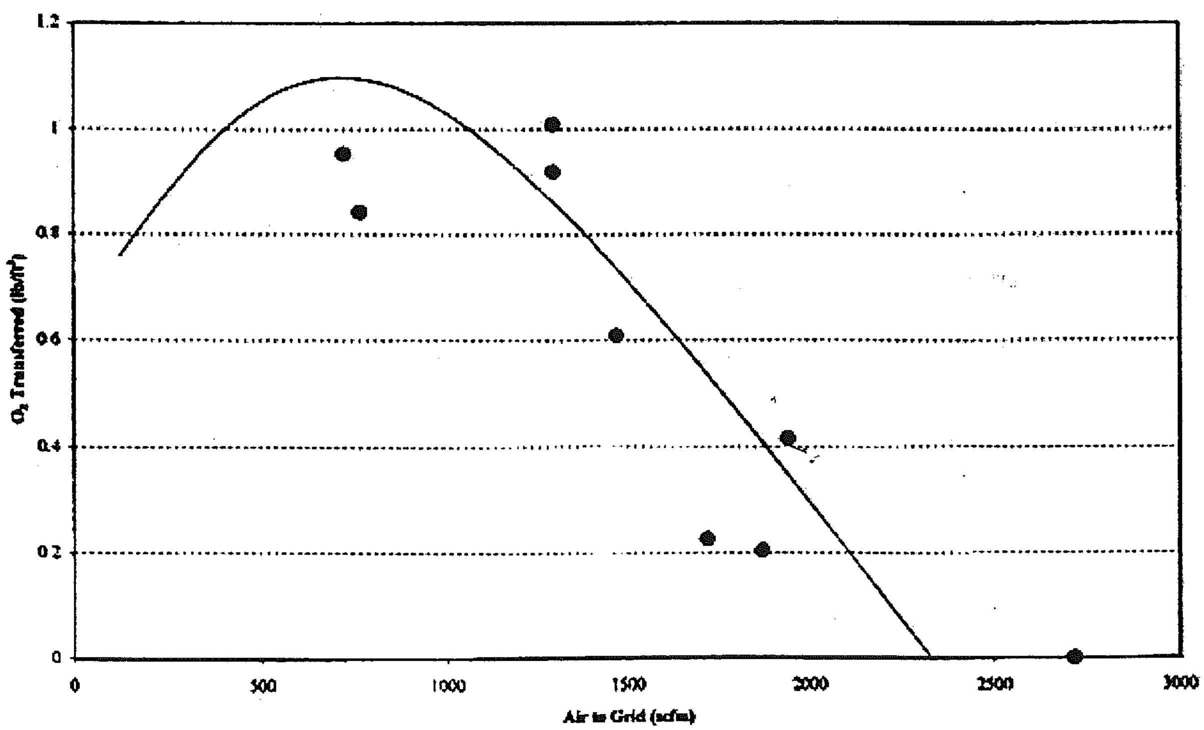


(b) Mass transfer curve

Figure 5. Offgas analysis for Grid A, Tank 15 at TWRP, combined data for 04/13 and 04/14/99.

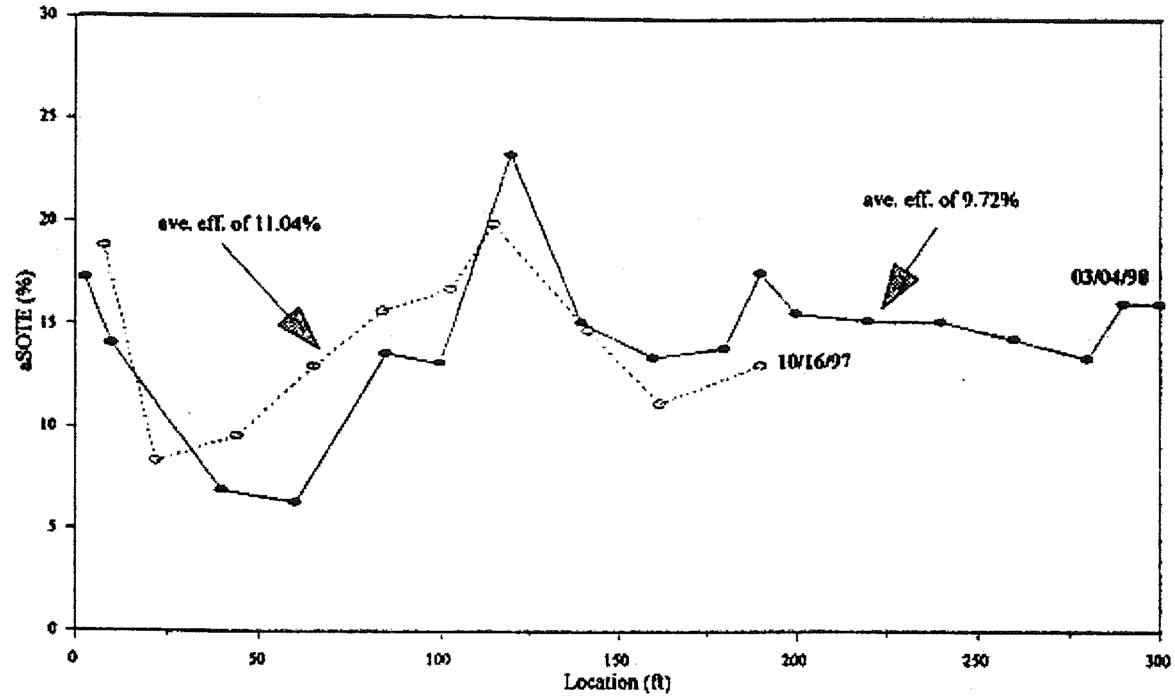


(a) Efficiency vs. air flow

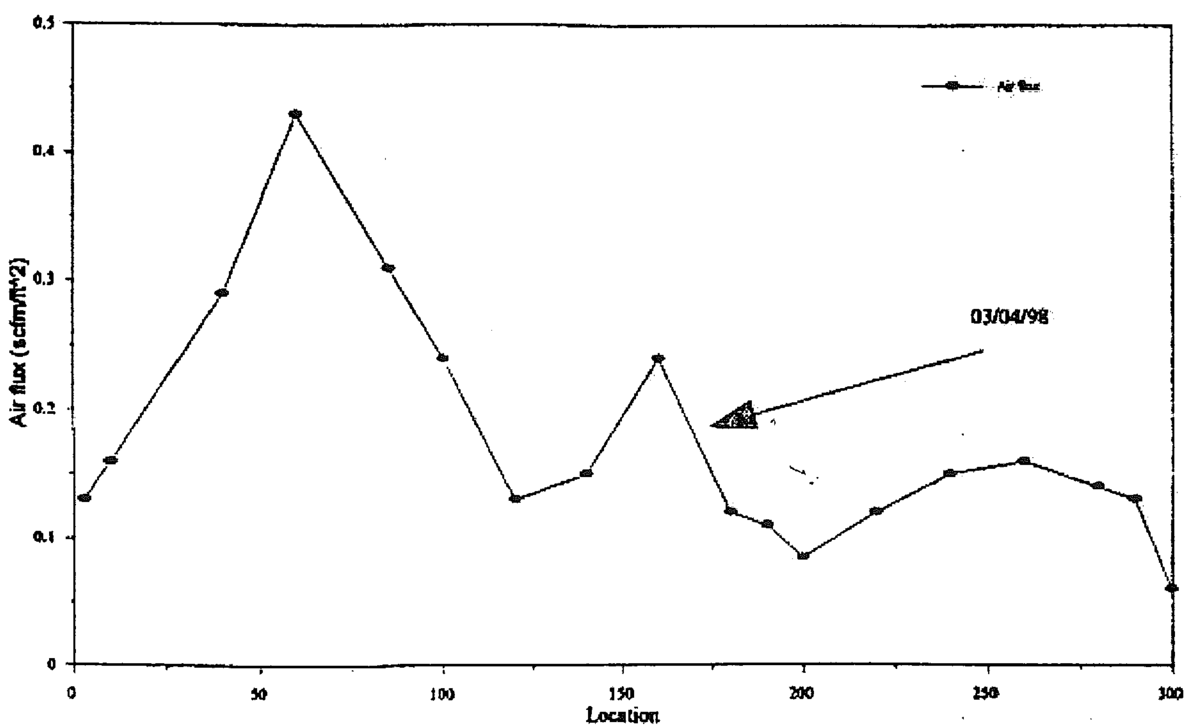


(b) Mass transfer curve

Figure 6. Offgas analysis of Tank 15 at TWRP for data on 10/16/97 and 03/04/98.

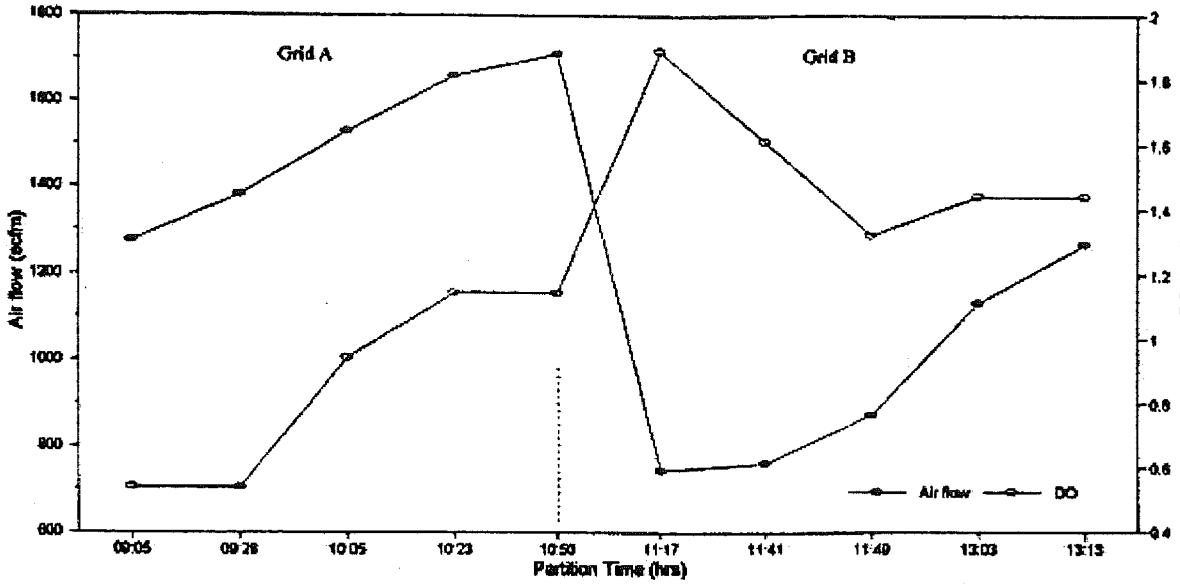


(a) Corrected oxygen transfer efficiency vs. location.

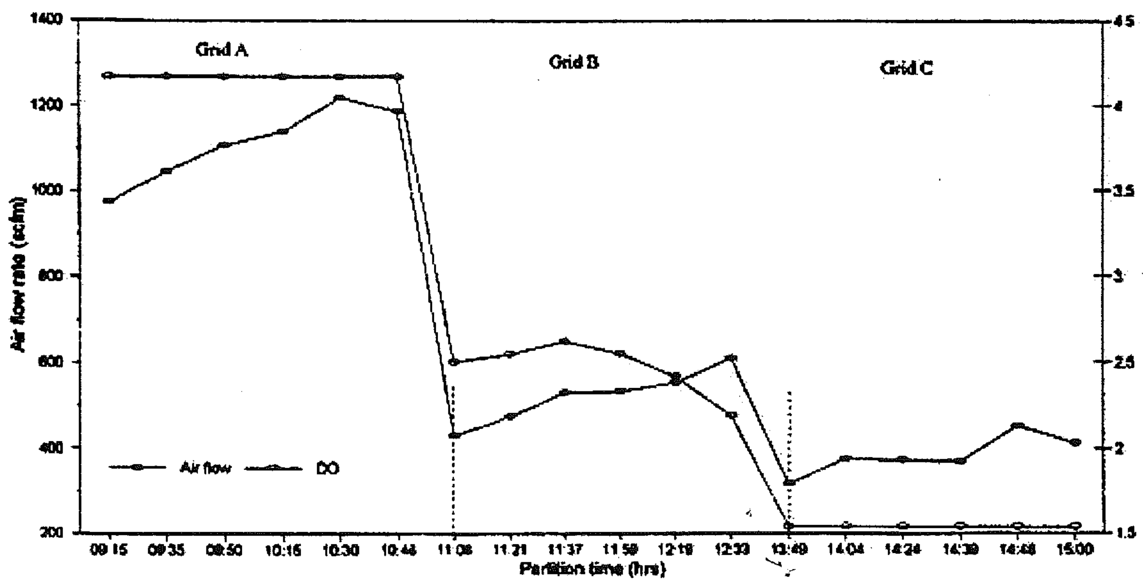


(b) Air flux vs. location.

Figure 7. TWRP Control Room Data nearest to sampling times for Tank 15.



(a) Air flow rate and DO vs. time, October 97.



(b) Air flow rate and DO vs. time, March 98.

