DISSOLVED OXYGEN CONTROL IN THE ACTIVATED SLUDGE PROCESS

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ABSTRACT
The increased cost of energy and the need for biological removal of plant nutrients resulted in a renewed interest in dissolved oxygen control in the activated sludge process. Back-up systems are required to prevent overaeration during the night which may be detrimental to the nutrient removal process. Full-scale experience with both fine bubble and surface aerators are described.

KEYWORDS
Dissolved oxygen, blowers, surface aerators, fine bubble systems, nitrates, phosphates, nutrient removal, automation, back-up.

INTRODUCTION
The energy crises and the worldwide rise in energy cost has caused a review of dissolved oxygen control as a tool in the optimization of plant operating costs. Furthermore, the interest in biological removal of plant nutrients has enhanced the importance of dissolved oxygen (DO) control as a means of achieving consistent results. Excess aeration will result in dissolved oxygen being returned to the anoxic zones designated for denitrification such that incomplete denitrification takes place and nitrates appear in the effluent. Such nitrate may then be recycled with the Return Activated Sludge (RAS) to the anaerobic zone where conditioning for phosphate removal would then be impaired. The paper reviews the experience with DO control systems in South Africa.

In South Africa, the tendency is to use surface aeration for smaller plants and fine bubble diffused air aeration for the larger plants. It was assumed that the fine bubble system would be more energy efficient and since larger plants could be constructed in modular form, there would be sufficient modules to be able to remove one for maintenance during periods of low flow.

Dissolved oxygen control for surface aerators consisted mostly of an adjustable overflow weir controlling the depth of immersion of the aerators. By lowering the weir, the depth of immersion is reduced and less oxygen is transferred to the liquid. The opposite can be achieved by raising the weir. Alternatively, the aerators could be switched on and off in a certain sequence, depending on the oxygen demand as determined by dissolved oxygen (DO) probes. As a back-up system one could use timer switches on the aerators to activate them for predetermined periods.
A central blower system is normally used for a multiple basin fine bubble diffused air aeration (FBDAAS) system. A means must therefore be established by which one could control the flow of air to the basins but ensure that every section of every basin receives the correct air flow for that time of day. Blower control by a combination of blower switch on/off and inlet vane control is favoured, together with some means of ensuring the correct distribution. A back-up system is also required to prevent substantial over or underaeration at certain times.

DIURNAL VARIATION OF COD AND TKN LOAD AND THEIR EFFECT ON OXYGEN DEMAND

The diurnal variation of COD and TKN load will be more intense, the closer the plant is to the source of waste. Fig. 1 shows the diurnal variations for a plant that is not more than 2 km away from the main source of sewage. Fig. 2 shows a simulation of the diurnal oxygen demand for the inputs in Fig. 1, using a computer model developed by the University of Capetown. The model takes into account the saving of oxygen when employing internal denitrification. Note that the carbonaceous oxygen demand lags behind that for converting ammonia to nitrate.

![Figure 1](https://iwaponline.com/wst/article-pdf/20/4-5/93/99466/93.pdf)

**Fig. 1.** Diurnal variation of COD and TKN load

![Figure 2](https://iwaponline.com/wst/article-pdf/20/4-5/93/99466/93.pdf)

**Fig. 2.** Simulated demand for oxygen

NUTRIENT REMOVAL SYSTEMS

The majority of plants now being constructed in South Africa is based on the Bardenpho system for nitrogen and phosphate removal. The most recent development of this process is embodied in the flow diagram in Fig. 3. The basic theory is that nitrogen could be removed by allowing the ammonia to pass through several anaerobic and anoxic stages, to the aeration stage where conditions are optimized for nitrate formation. The mixed liquor from this basin is recycled at rates between 4 and 10 times the influent flow rate to an
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Anoxic zone preceding the aeration basin where no intentional aeration takes place. Nitrates are used as alternative electron acceptor by anaerobic respiration of the heterotrophic organisms and are reduced to nitrogen gas which escapes to the atmosphere. The nitrates in the effluent and in the return activated sludge (RAS) are reduced to very low concentrations. When little or no nitrates are returned with the RAS to an anaerobic basin, certain organisms use stored polyphosphate to uptake short chain fatty acids in the feed. These fatty acids supply the energy for the organisms to uptake excess phosphates in the aeration zone. However, since some nitrates may at times be present in the RAS, the first zone is used for removing the remaining nitrates before contact with the bulk of the short chain fatty acids in the following anaerobic basin.

Fig. 3. Flow diagram - Bardenpho Process

The process can also function with channel-type systems for the removal of nitrates. Whatever system is used, DO control is essential to ensure that the nitrates in the RAS is reduced to a minimum. For good nitrogen removal it is first of all necessary to maintain the DO at a level sufficient to ensure total conversion of ammonia to nitrate, but not allow overaeration since DO returned to the anoxic zone at the high recycle rates required will be used preferentially at the cost of reducing nitrates. In most instances, the carbonaceous compounds available are only just sufficient for reducing the nitrates formed and recycling excessive DO will reduce the capacity of the plant to remove nitrates.

Phosphate uptake is also dependent on a sufficient DO level in the aeration basin and the DO of the mixed liquor being discharged to the final clarifiers must be sufficient for ensuring that no release of phosphates from the sludge to the liquid will take place.

Thus the need for DO control in nutrient removal plants could be summarized as necessary for:

Sufficiency to ensure nitrification at all times and thus a low effluent ammonia.

Minimizing the DO return via the recycles to the anoxic basins or zones or to the anaerobic zone.

Sufficiency to ensure the uptake of phosphates and prevent release in the final clarifiers.

Energy saving which will flow naturally from the above.

**DO CONTROL IN FINE BUBBLE AERATION SYSTEMS**

In bubble aeration plants there is an almost direct relationship between the DO in the aeration basin and the SVI. While DO in the aeration basin of about 0.8 mg/l would mostly be sufficient, keeping the DO above a level of about 3 mg/l would result in a dense sludge and indirectly enhance the capacity of the plant. Here then the ideal situation is to keep the DO high in most of the aeration basin but taper the DO towards the recycle pumps such that it is optimally at about 0.5 mg/l at the recycling pumps or at the point of passage to the second anoxic basin where such is used. Then raise the DO again in the final aeration stage to ensure that sufficient DO will be available in the final clarifiers. A lay-out of typical nutrient removal plant using fine bubble aeration is shown in Fig. 4 with the ideal DO profile.
In a multi-basin system, the division of airflow to the various units must be arranged such that every zone gets its correct share of the airflow even though the airflow to the entire system varies with the oxygen demand.

Setting butterfly valves in fixed positions may give the correct distribution for one specific airflow but the distribution pattern may then change when the airflow has to be increased or decreased. Compounding the problem is that underaerating a zone for a couple of days may result in permanent damage to the diffusers in that bacterial growth will tend to cover the stones. Some of the other valves must then be closed somewhat more to ensure that the affected zone gets a sufficient share of the airflow.

These problems were solved at the new Rooiwal plant of the City of Pretoria in the following way:

There are presently six modules but the air headers make provision for an eventual eight modules. In the interim the future connecting pipes have been sealed off and provided with valves for easy connection in the future without a break in air supply.

There are three centrifugal blowers with inlet vane control connected in parallel. Provision was made for a fourth unit, again with the possibility of adding on without interfering with plant operation.

Motorized butterfly valves have been installed on the main feed pipe to each module. These valves can be controlled from the plant computer from where it is also possible to have a read-out of the valve position.

The air flows passing through the main control valves are being monitored in the control room.

Four DO probes are installed in each of the modules. Two probes were installed near the recycle pumps, another in the main aeration basin and a fourth in the final aeration basin. The readings of all the probes near the recycle pumps in each of the six modules are averaged by computer, i.e. 12 in all are being averaged to obtain the signal sent to the blower house for air flow control. There being safety in numbers, a breakdown of up to three probes will not affect the average value markedly and replacing zero values for disabled probes can only result in a somewhat higher airflow than is optimal. The averaged signal is automatically compared with the range setpoints and if more (or less) air is required, a signal is sent to the blower room for increasing (or decreasing) the air flow. This process is repeated and it is possible to maintain the average DO within the narrow band that is required.

The DO values registered by the probes are displayed on the screen of the monitor as shown in Fig. 5. This mode of display has the advantage that the operator can compare readings on the similarly positioned probes in the various modules by looking down one of the columns on the display. It is therefore possible for him to change the settings of the main control valves from the key board to obtain a better distribution of air to the operating modules.
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Initially, outputs from three probes in each of the modules were used for automatic balancing of the airflows between the modules. The computer averaged the read-out from three probes in each module and compared this average with that of the other modules and changed the settings to ensure an even distribution of air. The number of probes unfortunately proved to be too small and since the probes were not sufficiently reliable, unbalanced airflows were being experienced. The computer program was therefore changed to monitor the various airflows instead of the DO so as to ensure even distribution, or if required a preselected distribution ratio.

Thus after each change of airflows brought about by the DO probes the airflow rates are compared by a separate control loop and if there is a variance from the predetermined ratios to the modules, the control values are automatically adjusted to correct the flow division.

Thus it is still possible to run one module at an elevated DO by simply programming this module to receive a higher share of the airflow. This action is completely independent of the averaged DO signal being conveyed to the blowers for overall air supply control.

It was necessary to ensure that the balancing of the airflow as described in the previous paragraph will not lead to a gradual closing of the main control valves and a secondary loop has therefore been installed to check that at least one of the valves is fully open at all times.

This control system still required that the air flow to the individual zones of each module be adjusted by hand and as this is tiresome, consideration is given to a third nest of loops to control the gates in each module to give an even distribution of airflow to each of the zones of each module independently from the other modules. The different tiers of control function independently and do not rely on the somewhat unreliable DO probes. However, the total number of probes in all the zones ensures a sufficient back-up system for controlling the overall air supply while the display of the outputs on the screen allows the operator to preset the flow distribution to each module and each zone in each module by using air flow meters which have proved to be more reliable.

Even without the third nest of automatic flow control, excellent results are being obtained in this way.

A further innovation at this plant is the recording of DO data. Since analytical results normally become available only after a few days, one may want to find out what the reasons were for a particular malfunction, e.g. the results may indicate high nitrates associated with high phosphates in the effluent. One could then recall to a graph on the screen, the 24 hour output of a particular probe to see if the DO control functioned properly on that day. This saves a lot of paperwork.

Average DO and flow information is logged daily but the full graphs are stored for 40 days and then automatically dumped.
SURFACE AERATION PLANTS

DO control in surface aeration plants is different in that there can be no uniform distribution of oxygen through the aeration basin. For nutrient removal plants the arrangement of the various anaerobic/anoxic and aeration zones could be similar to that shown in Fig. 4 with all the aerators in a formally divided aeration zone, or the anoxic and aeration basins may be combined or linked together most economically as shown in Fig. 6. The advantages of the arrangement in Fig. 6 is that mixed liquor is recycled to the anoxic zones through the pumping action of the aerators and no separate mixed liquor recycle pumps are required. (The aerators should preferably work in conjunction with draught tubes.) The oxygen input could be controlled either by an automatically adjustable weir responding to a DO signal for regulating the immersion depth of the aerators, or by switching aerators on and off. The larger the aerators the greater the strain to the gearboxes caused by switching on and off. It is preferred to run the aerators full-time, except when stopped for maintenance. Control of the adjustable weir by the DO signal therefore becomes a prerequisite.

When controlling such a 'combined' plant with surface aerators for nutrient removal, an oxygen gradient across the aeration basin is not only unavoidable, but can be used to great advantage. There will be an oxygen gradient in reverse from high at the outlet of the aeration basin to low at the aerators near the anoxic zone, to zero in the anoxic zone. There will also be a gradient from the surface down into the aeration basin as shown in Fig. 6.

Mixed liquor will be recycled:

(a) horizontally from the aerated section of the aeration basin to the inlet of the anoxic zone where contact with the incoming sewage will take place;

(b) vertically down from the surface of the aeration basin to levels where there is an oxygen deficit and denitrification can take place. Thus the aerated zone is as indicated in Fig. 6 but it is evident that the transition level will vary with the oxygen requirements of the mixed liquor. When the oxygen demand increases, the transition level will move up, reducing the aerobic volume and this may result in ammonia appearing in the effluent. However, as the DO near the surface will be reduced, the matter can be rectified by sensing the DO and by adjusting the weir and thereby the immersion depth of the aerators.

This system of induced horizontal and vertical currents has the advantage that the incoming carbon is used optimally for the reduction of the nitrates and it has been found that with this type of plant total nitrogen removal could be obtained at ratios of COD:TKN as low as 6. Not only are newly formed nitrates recycled to the anoxic basin for denitrification using the incoming carbon but it had been exposed to oxygen but also, the continuous downwards recycling exposes the nitrates to organisms that a moment before adsorbed carbon which provides the energy source for a higher denitrification rate than would be possible under purely endogenous conditions in a second anoxic zone.
The dissolved oxygen concentration near the anoxic zone is generally low and the variation small, making this location unsuitable for control purposes. In addition, when the oxygen demand is low one might need to switch off the aerators nearest to the anoxic zone. The ideal location for the probes is therefore between the last two aerators, since these would operate continuously, except when stopped for maintenance. Even when operating the aerators on the stop/start principle this location would be preferred since the first aerators to be switched out would be near the anoxic zone.

Where there is a formal division between the anoxic and the aeration basin, the best location would be near the intake of the recycle pumps as for the diffused air plant. At one particular plant probes in this position controlled the DO excellently such that with all the aerators running the ammonia and nitrates in the effluent were consistently below 1 mg/l.

**CHANNEL TYPE SYSTEMS**

Channel systems present problems in that the recycle rate is so high that the complete mixing is achieved. The change from anoxic to aerobic conditions is so rapid that very low DO concentrations are registered in the mixed liquor at any point. The range is not sufficient for control by DO metering. The system favoured here is that developed by Usrael (1977) for measuring the respiration rate of the biomass and using this information for control of the oxygen input.

**SOPHISTICATION IN AUTOMATION**

The key factor in effective DO control is the performance of the DO probe. No degree of sophistication in automation of DO control can compensate for unsatisfactory probe performance. Not to use the most reliable probe possible, would amount to a false economy. A satisfactory maintenance program is an essential requirement.

**BACK-UP FACILITIES**

There are superior DO control systems that have operated for periods of up to five years without interruption provided that the probes and the equipment were maintained properly. Nonetheless, we believe now that it is essential to provide for some back-up facilities in the event of a breakdown. When using surface aerators, the obvious choice in this regard is for timer switches on the aerators which could be brought in when required by the increased oxygen demand.

Timer switches as the only control device, are reasonably acceptable for smaller plants but it has the drawback that during storm flows, the pattern of oxygen demand may change and with that the residual DO in the aeration basin. Also, regular adjustment from one day to another may be necessary.

The only feasible back-up system for a FBDAAS consists of a device that simulates a preselected signal from a DO control system. One such system scans a graph of the expected oxygen demand for the day. The graph must be prepared beforehand and mounted on a circular drum to form a continuous line. Also electronic systems are available in which one could enter such a graph digitally. Such system is preferred to the analog technique. An improvement would be for the logic system to store the diurnal oxygen demand and apply the information directly in case of failure of the DO system. Such a back-up system could also be used to control the adjustable weir of a surface aeration plant.

Continuous determinations monitoring the ammonia and the nitrates in the effluent could be used to evaluate the standby control system in nutrient removal plants. If the timer switches or the graph control system administers too little or too much aeration at any time, this would be evident by a rise in either the ammonia or the nitrates in the effluent. By doing a few diurnal determinations one can get a reliable pattern for the DO demand curve. If subsequently the curve needs readjustment, one could base it on the ammonia and nitrate concentration of a composite sample and adjust the form curve up or down. In some plants this form of control is used exclusively due to the lack of reliable DO metering systems.
SUMMARY

1. The performance of nutrient removal plants depends largely on the effectiveness and the reliability of the DO control equipment, especially where high standards are demanded for both nitrogen and phosphate level in the effluent.

2. The record of performance of such equipment in South Africa is dismal and efforts are being made in trying to improve the situation.

3. In fine bubble diffused air aeration plants with multiple basins and a central blower house, the division of the airflow to the various models has presented problems. Averaging the readout from probes in all the modules gave a reliable signal for control of the total airflow even when some of the probes malfunction. Monitoring of the air flows and secondary loops for balancing the airflow to each module after each change in airflow from the blowers proved to be the best method of ensuring the correct airflow to each module.

4. The best position for the probes in FBDAAS plants or surface aeration plants having formal anoxic zones with mixed liquor recycle pumps is just ahead of the recycle pumps. For "combined" anoxic/aeration plants with a combined reactor, the best position was found to be between the last two aerators.

5. Channel systems present a problem in that the variations in the DO are too small for proper control and one must resort to other control systems such as that developed by Usrael(1977) using respiration techniques.

6. Proper back-up systems are necessary for nutrient removal plants. These may consist of timer switches for surface aeration plants or digital or analog signals representing the diurnal oxygen demand which may supplant the DO derived signal during failure of the control system.

7. Nitrate and ammonia concentrations in the effluent could serve to reflect the effectiveness of the DO control system.

REFERENCE