# IMPROVED EFFLUENT AT LOWER OPERATIONAL COST BY IMPROVISING DISSOLVED OXYGEN CONTROL


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# IMPROVED EFFLUENT AT LOWER OPERATIONAL COST BY IMPROVISING DISSOLVED OXYGEN CONTROL

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Many plants suffer from poor DO control even though they have continuous DO monitoring and direct control of aerators to a preset DO level. Poor control is usually the result of problems with 3 or 4 aspects of the process of measurement and control. The overlap of these problems results in greater difficulty in isolating specific causes and effects.

This paper focuses on data showing symptoms and identifies causes in addition to showing how various parameters such as ammonia and nitrate relate to the inlet BOD Kg load and the DO control system.

## 1.0 TERMS

**BOD Kg:** This is the kilo's of biologically degradable material entering the plant and requiring removal by the consumption of the same number of kilo's of oxygen by the biomass.

**O2 Kg:** The kilo's of oxygen utilized by the biomass calculated from aerator or blower speeds/pumped air volume/transfer coefficients etc.

**OUR:** Oxygen Uptake Rate being the instantaneous O2 Kg being taken up by the biomass per unit time or BOD Kg being consumed per unit time.

## 2.0 POOR DO CONTROL

Poor and inappropriate DO control often plays a major part in changing effluent quality and biomass type through the year. Often poor settling issues such as floc size and type, denitrification in clarifiers, filamentous growth etc are blamed on temperature change, loading variability, rain etc. This may seem to be valid, however if we think about it, these variations are simply the reality that the plant was meant to be designed to deal with. If it is not dealing with it, then either the design is inadequate or it is being operated incorrectly.

A combination of the two is normally the reality with the nett result being an overall failure to adequately compensate for real time changes on a short and long time basis. The result is changing biological conditions and effluent quality.

## 3.0 ISSUES

The issues we need to look at are many and come from a number of sources including:

**Inaccurate sensors**

The method most people use to calibrate sensors hides the error that was present. Check for this in saturated raw effluent before cleaning and after cleaning to quantify the shift.

- Thin fat layers develop quickly on even slippery membranes if temp is below 35° C;
- Biomass growth on the fat layer and on any minute abrasions present;
- Air interference.

**Sensor positioning.**

The assumption is often made that the aeration tank is fully mixed for DO. This is totally untrue in all applications. DO varies continuously at all points in a tank and across the floc itself. Check your aeration zone by doing some profiling at maximum and minimum loading periods.

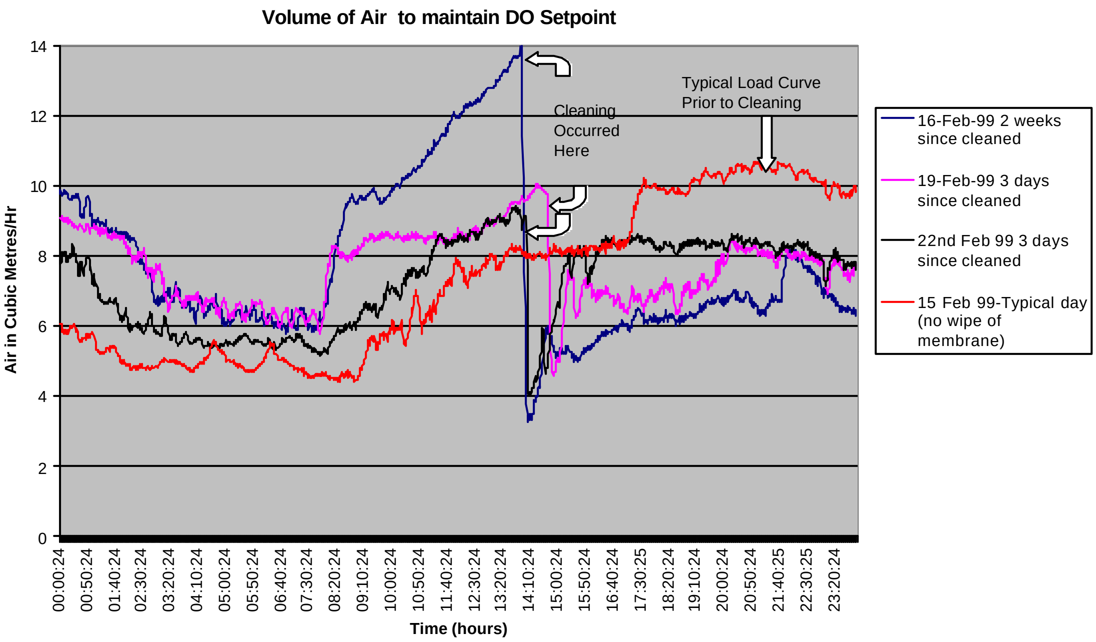
**Hardware.**
How flexible is the aerator speed control? How does changing aerator speed change other factors? Are diffusers in good condition?

**Control Strategy and Software.**
Why do you use the setpoint value you do? What are you achieving with it and why? The profiling may tell you a few things which allows you to rethink these setpoints. Is the software flexible enough to deal with your varying oxygen uptake requirements?

It is important to work through the above issues in a logical manner, evaluating the cost of fixing and of not fixing any that do not come up to the required standard. Less than optimal systems suffer from higher than needed aeration power costs, excessive aerator wear and tear, higher chemical usage levels and lower effluent quality that is achievable, not to mention added maintenance cost and time by the operator.

Identification and quantification of the issues and costs involved in these issues simply takes a little time and an appropriate methodology. For example - sensor accuracy is usually a function of a number of factors like fat and grit levels, temperature, digestibility of the waste, mounting position and cleaning regime. Testing for the effects and the costs of sensor inaccuracy helps make decisions on the type and position of sensors and the best cleaning interval.

**Figure 1:** ***Volume of Air to Maintain DO Setpoint***




The above graph shows the considerable error which can occur within hours let alone days of cleaning and recalibrating. An appropriate control strategy to achieve the biological conditions you want at each and every loading condition the plant sees can only be determined with accurate data on DO levels.
The sensor placement decision involves deciding what the data is intended to show while the control strategy is then based on what you want to do about it.

If we break aeration systems into two broad categories of point and diffused air transfer systems we can develop some simple guidelines. Note that all systems actually fit into a continuum between these two.

## 4.1 Point Aeration

Point aeration systems can include surface aeration such as brush and rotating blade aerators. In plants using these types of aerators, there is an approximation of an instantaneous rise in the DO level at the aerator which then drops back the further from the aerator the waste travels due to oxygen uptake by the biomass.

**Carousel Plants:**
In Carousel style plants with brush aerators this occurs along the length of the rapidly flowing ditch. At some point between aerators, the DO level needs to drop to a figure low enough to result in anoxic conditions. Denitrification will then begin to occur.

The question is - at what point will this happen under different loading conditions and how much aerobic and anoxic area is needed to minimize both ammonia and nitrate levels at both peak and low load?

The answer is that at high load, denitrification is rapid. Generally we need more area for aerobic activity to maximize ammonia removal. At low load, we need a very large anoxic zone and a small aerobic one since there is little ammonia to convert and denitrification is slower. Lower temperature will affect both the rate of nitrification and denitrification as will biomass health. If we are to change aerator speed or immersion to create the best possible conditions, we must have sensors in appropriate positions and a control strategy which uses this data to maximum effect.

The data in Figure 2 shows a Carousel Plant which does this, and also shows the limitation still present. This limitation can only be removed by using feed-forward control which is currently being implemented from a BOD analyzer.

### 4.2 Using DO Differential

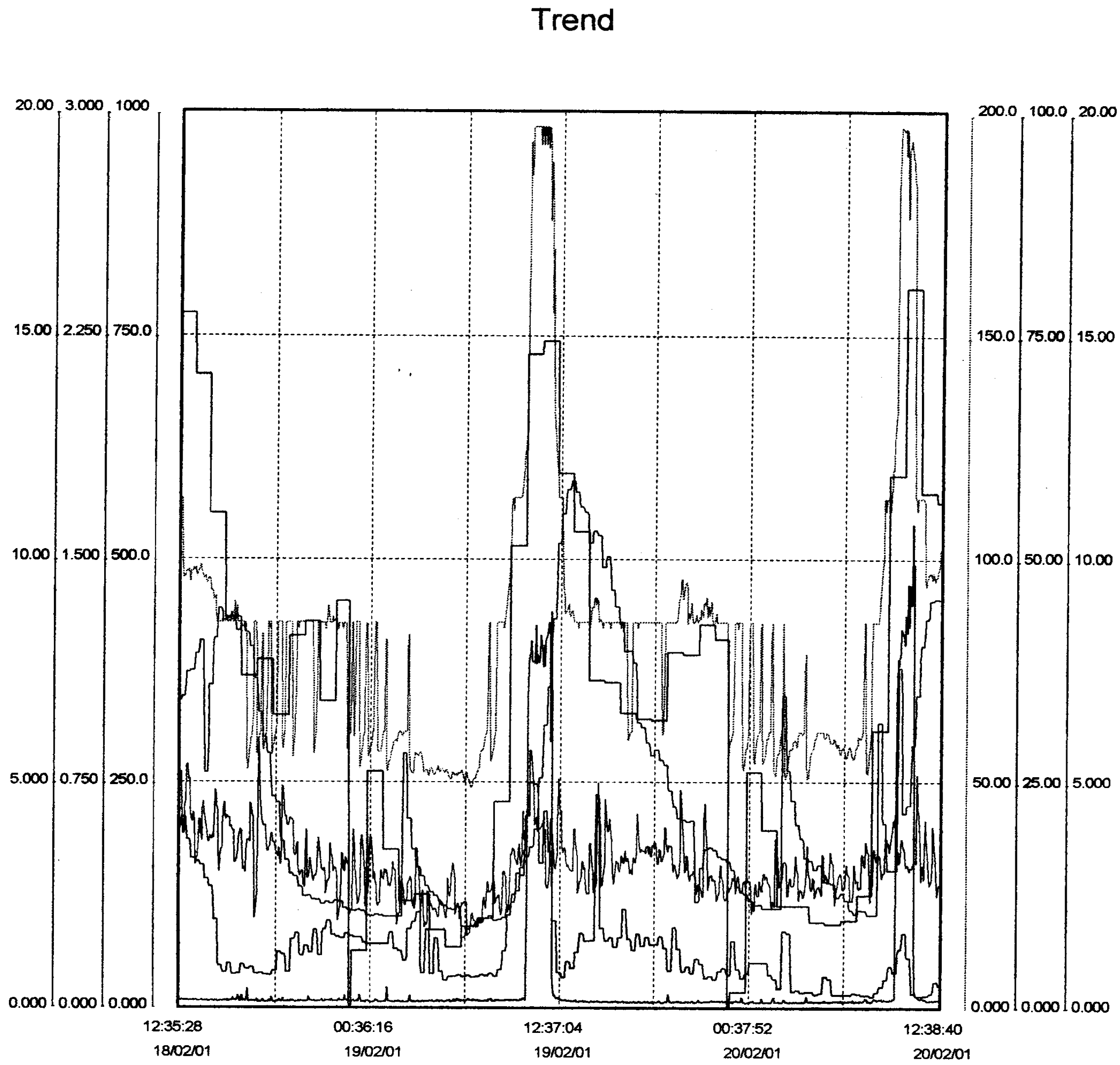
DO 1 and DO 2 sensors are positioned just after the aerator and a further 30 metres downstream of the aerator respectively. The difference between the probes in effect, is an approximate prediction of the point at which anoxic conditions will occur. Three sensors is an ideal situation, with each carefully spaced along the flowpath between aerators.

Note: It is important to study flow patterns under different aerator speed and immersion conditions to evaluate best sensor position.

The need for changing setpoints for DO under different loading conditions becomes immediately apparent if we look at the nutrient levels. Simple DO control from one position on the Carousel cannot adequately reflect the Oxygen Uptake Rate (OUR) occurring, resulting in excess air at low load and insufficient air at high load. The result of this being high nitrate alternating with high ammonia and filamentous growth. We can avoid this by simply reacting adequately to the reality of the changing load.

If using two sensors the last DO probe should read approx 0.5 DO under high load conditions.

**Figure 2:** ***The Potential Gains Of Feed-forward Control***




| Legend | Trend Name | Comment | Min. | Max. | Avg. | Min. Scale | Max. Scale | Eng. Units |
|---|---|---|---|---|---|---|---|---|
| ________ | BOD | BOD EFFLUENT QUALITY | 78.59 | 300.3 | 157.1 | 0.000 | 1000 | |
| ________ | AOTR_kgO2 | KgO2 Aeration Rate/Hour | 48.99 | 196.9 | 83.76 | 0.000 | 200.0 | |
| ________ | DO_PROBE1 | DISSOLVED OXYGEN 1 | 0.010 | 1.619 | 0.086 | 0.000 | 3.000 | |
| ________ | kgBODP | Kg BOD iPERIODIC | 0.000 | 80.41 | 33.60 | 0.000 | 100.0 | |
| ________ | AMMONIA | DISSOLVED AMONIA | 0.203 | 4.996 | 1.264 | 0.000 | 20.00 | |
| ________ | NITRATE | DISSOLVED NITRATE | 1.538 | 11.76 | 4.637 | 0.000 | 20.00 | |

## 4.3 Surface Aerators

In an IDEA type plant with surface aerators, the flow path is out from the aerator, down to the bottom, along and back up into the aerator. The length of the flow path being determined by many factors such as depth, aerator speed, temp, MLSS etc.

The level of DO achieved during the early stages of aeration depends on the position of the sensor on the flowpath. The sensor needs to be located at a position which is around 0.5 mg/L DO or less at the beginning of the aeration cycle. By doing this we can see clearly when the waste has been degraded and when the biomass has consumed the influent BOD Kg.

The patterns seen here are for a fixed aeration period with fixed aerators either all on or all off. The DO levels clearly indicate that at times the DO never rises during the aeration cycle while at other times, the DO is very high quite early in the cycle. This is logical as the BOD Kg to be treated in any particular cycle varies diurnally and with holiday periods including weekends. What is not logical is to run the plant this way.

The O2 Kg put into the system should relate directly to the BOD Kg to be removed. If the DO did not rise by the end of aeration, the waste was not fully treated and high ammonia levels can be expected. Ie The BOD Kg present – the O2 Kg applied left a positive number so some waste must be left untreated. In cycles where the DO rose early in the cycle, aeration continued long after the BOD Kg present was all consumed and it is likely that high nitrate levels will be present. Ie the BOD Kg –O2 Kg applied is a large negative number indicating wasted power in aeration.

The best situation is to have a small negative number at the end of aeration indicating we removed all the BOD Kg present but minimized over aeration.

Assuming correct probe position and accurate sensors, we can use a variety of methods to determine the best aeration cycle length.

The following 2 methods depend on what we are trying to achieve.

- If we simply want to maximize removal without excessive O2 usage, then we can just control aeration time by using the rise in the DO level at the end of BOD removal. Ie watching for the drop off in OUR
  This method will work well on the majority of plants, particularly where levels of nutrients remaining are not critical.

- If levels of nutrients such as ammonia must be guaranteed to low levels such as below 2 mg/L on every cycle, a strategy using on line ammonia analysis may provide better results.

### 4.4 Variable Aeration Time Control

The difference between aeration on times is in the ratio of at least 10 to 1. The cycle with high ammonia at discharge occurred due to a default on level, which prevented overflow of the tank during a period of extended aeration. Note that if the BOD Kg at the inlet had been known, the previous cycle could have been shortened to allow a longer aeration time on the high load cycle.
If you have an oxidation pond system with surface aerators only and the DO sensor mounted from the side of the pond, it is likely that you are wasting your time even measuring DO. The system must be investigated to discover how the DO profile varies and the sensors repositioned to reflect this. A single sensor in a large pond is an insult to the concept of control.

### 4.5 Diffused Aeration

The concept of totally even aeration does not exist yet and probably never will. Modern diffusers produce relatively even bubble patterns in a small area above the diffuser however there is significant variability in the rate of oxygen transfer and DO level both through out the vertical water column of a treatment plant and laterally. The oxygen transfer rate is affected by many things with some of the main ones being the pressure, bubble size, diffusion, gradient and cross flow velocities. Since the rising bubbles draw liquid up with them, which then flows back down through gaps in the bubble stream, DO gradients must be present. All that is needed here is to remember that assumptions of full mixing for DO may not be valid and therefore DO sensor position is important.

Profiling of the vertical water column will usually yield a DO profile which shows a maximum DO level which is about 80% of the way to the bottom at high load and about 50% of the way to the bottom at low load, other than in intermittent decant or SBR type plants. These style of plants can have maximum DO at the end of an aeration cycle at the surface, particularly if over aeration is occurring as indicated earlier in this paper.

A good control strategy will never allow this to happen since this high surface DO condition indicates we are literally starving our biomass and it's health will therefore be poor. The best installation position is generally between 70% and 80% of the way to the bottom.

Continuous Activated Sludge with Diffused Aeration

Assuming we are looking at a continuous activated sludge plant we need to relate the issues discussed above to the conditions present in such a plant.

If we are removing at least nitrogen, then we will again have aerobic and anoxic zones.
The size of these zones from a theory perspective may have little to do with reality if we have large fluctuations in inlet BOD Kg/Hr loading. DO control becomes a critical issue if we are to run these plants effectively. Since the mixed liquor is recycled at a rate typically ratio'd to the actual or average inlet flow at around 6 to 1 we must be careful to consider the effects of using a constant DO setpoint under different inlet loading conditions.

During the tail end of high load periods, nitrate levels at the end of the aeration zone will be high. This is no problem if it is being recycled back into the inlet stream while the load there is still high, however this is not the case as the evening peak drops off. In some of the data above the inlet BOD Kg changes can exceed a 3:1 ratio every evening in a 2 hour period with much larger changes during rain events which also bring in extra oxygen.

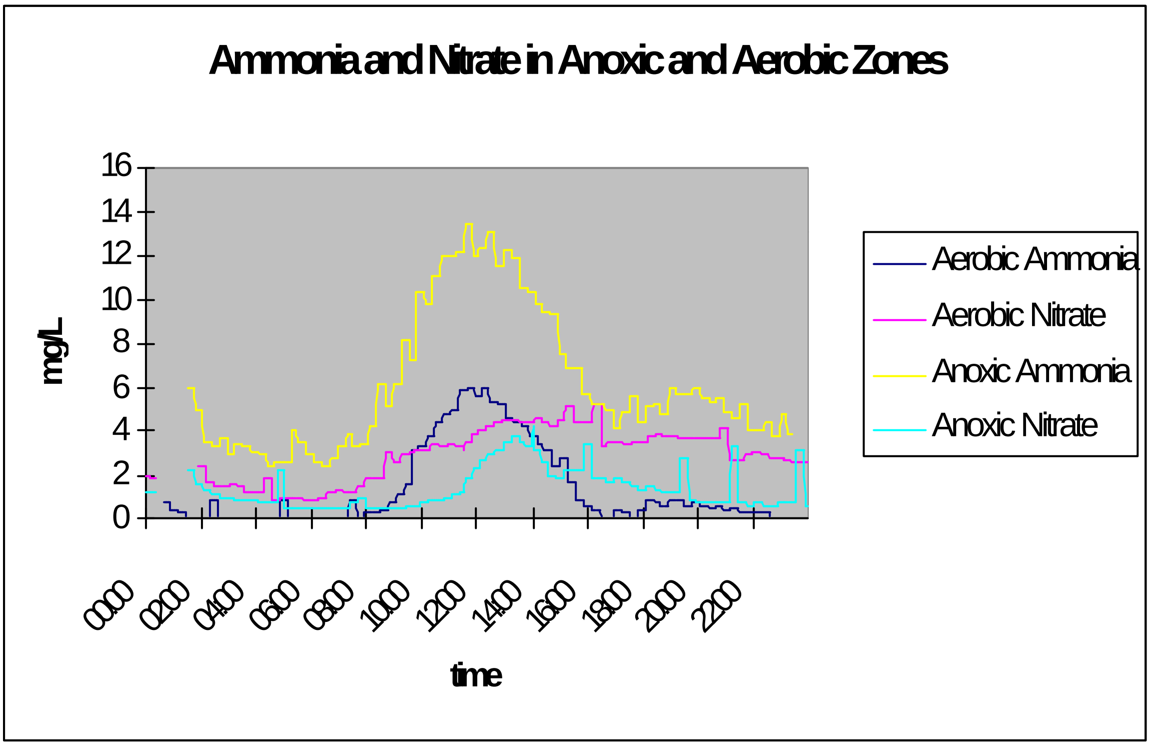
The result may be that between high nitrate levels in the recycle and lower BOD Kg load at the inlet the anoxic zone becomes largely aerobic.

High nitrate levels are likely to continue throughout the low load period if the DO setpoint and profile across the aeration zone are kept the same during low load periods as at other times.

When the morning load surge comes in, the high nitrate level drops rapidly in the anoxic zone but the higher ammonia level means that it is high again at the end of the aerobic zone. The ammonia levels at the outlet may now rise to unacceptable levels for a short time due to a lack of aerobic area, biomass and or retention time.

The following data shows levels of ammonia and nitrate in the anoxic and aerobic zones of a modern BNR plant considered to be under excellent control

**Figure 3:** ***Ammonia and Nitrate in Anoxic and Aerobic Zones***




Discharge ammonia and nitrate levels on a daily average basis are around 1 mg/L and 2.5 mg/L respectively. DO levels are maintained at a constant setpoint at all times.

Note that several alternatives to constant DO setpoint control are possible and these would allow better adjustment of conditions in the plant to reflect the changing load conditions.

The ultimate option would be to measure BOD Kg at the inlet, ammonia and nitrate near the end of the aeration zone and have individually auto controlled air valves feeding separate diffuser banks down the length of the aeration zone. These would be linked to accurate appropriately placed DO sensors. The inlet BOD Kg measurement would then allow the DO setpoint to be ramped up and down to suit the conditions, allowing an increase in the size of the anoxic zone during low load periods by closing down normally aerobic sections of the plant. Lower DO levels in the remainder of the aeration zone will stimulate simultaneous denitrification, resulting in lower nitrate levels in the recycle. Recycle rate and RAS can also be adjusted to ensure biological conditions are appropriate.

Most plants are lucky if they have individual auto adjusting air valves down the aeration zone let alone the rest of the equipment. In every plant something can be done and if an operator does some DO profiling along the aeration zone under different loading conditions and some testing for the regularity of the inlet patterns, significant improvements can still be made.
The SCADA can be programmed to adjust the DO setpoint, RAS and recycle to the pattern of varying loading.

The costs of the changes may or may not be justified financially or environmentally, however the work needs to be done to allow this to be clarified. Many of you may be now asking yourself why the plant design and the SCADA programming does not already take these issues into consideration. The question is very valid, with the answer usually being that the data used to design it was inadequate, resulting in an inadequate solution being provided.

## 5.0 CONCLUSION

DO control has a major effect on the quality and cost of waste treatment. Effluent quality can be greatly improved in most plants with a reduction in running costs via simple changes to sensors, maintenance, position and control strategy.
The operator is the only one likely to see the effects of poor control and be in a position to investigate the potential for improvement.

Note: DCM Process Control can provide additional information on methodologies for investigating issues raised in this paper. These can be obtained by emailing Dianne on dcm@ausnetwork.com.au or rob@dcmprocesscontrol.com