Advanced Optimization of Biological Nutrient Removal Plants Using Feedforward and Feedback Control-Case Studies

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Abstract
This paper deals with specific examples of feedforward and feedback control of nitrogen and/or phosphorous removal plants using on line analysis and automated control. The plants had previously been optimized using traditional techniques utilizing lab samples and extensive experience. The data presented therefore indicates the potential, then quantifies the gains achievable when the restrictions of dealing with averages is removed. The improvement shown is a direct result of the increase in data available using on line analysis in conjunction with appropriate control algorithms.

Keywords
Feedforward control, F:M control, Inlet BOD Kg minus O2 Kg consumed

INTRODUCTION

The abstract for this paper deals with advanced optimization and this first needs some clarification. The definition of the word “Optimised” when applied to a WWTP has tended to mean that the plant meets license conditions or design specification.

Recent moves have been made in most countries to change accounting methods to reflect the real cost to the environment of all discharges from wastewater treatment plants. These costs are based on $ /Kg of ammonia/BOD/nitrate/toxin etc. This allows us to reconsider the standards by which we define when a plant has been optimized and in fact to keep re-evaluating it on a regular basis.

What has been discovered as a result of detailed on-line analysis is that the operational control philosophy used in most wastewater treatment plants is antiquated. Often it is based on text book assumptions with respect to the size and rate of influent quality changes and their effects on the internal nutrient removal process rather than the fluctuating reality actually occurring. The data presented in this paper highlight how these assumptions preclude the possibility of continuous effluent discharge at optimal levels on even new wastewater treatment plants. It also clearly indicates the potential to maximize instantaneous performance on an ongoing basis in a cost effective manner.

The following are specific examples of the achievable improvement and the methodologies to realize this potential in plants considered to be already optimized. By this we mean that prior to this work, they met discharge license conditions.

CASE STUDY 1

Simple Feedback Control
The first plant we will look at is an Intermittent Decant plant. It is of approximately 40,000 Person Equivalent and uses 3 aeration tanks each of which is continuously fed. The standard control philosophy is to have the 3 tanks operating in linked cycles so as to be out of step with each other by 1/3 of a cycle. The cycle times are fixed as are the aeration times in each cycle.
License limits allow an average of 2 mg/L of ammonia on a daily composite. This calculation requires a flow based composite.

The data in figure 1 shows one of the 3 aeration tanks prior to any higher level control. Zero tank level is the bottom of the decant (approximately 4.5 meters remaining depth). Dissolved oxygen levels and also the ammonia present as measured by a Stip Buoy ammonia analyzer are shown.

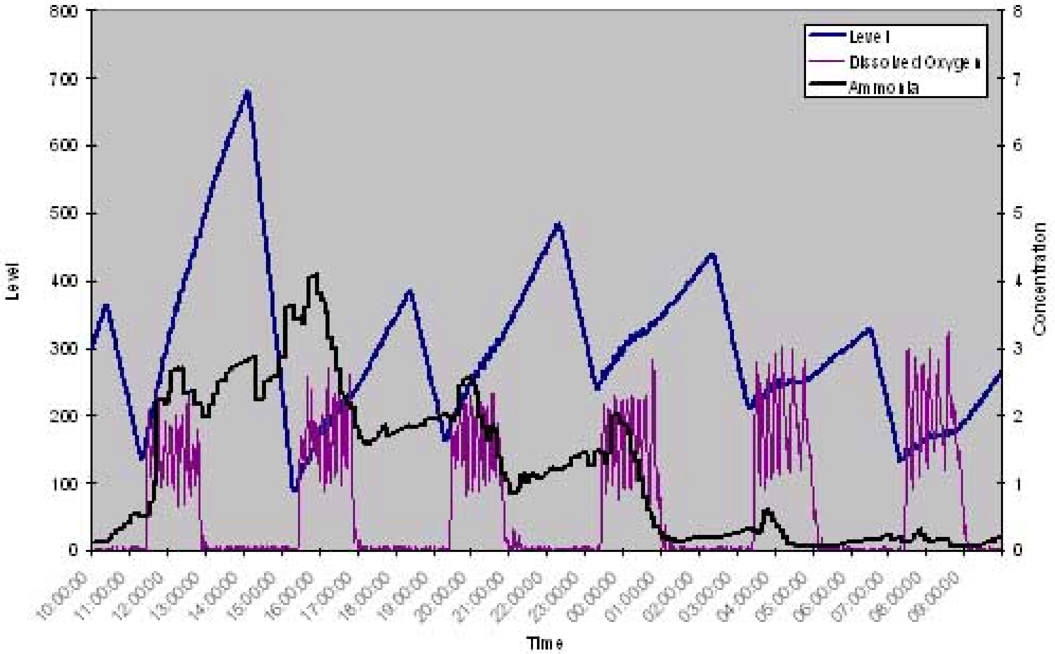

Fig. 1: Ammonium removal before using the Feedback Control

The decant part of the cycle is represented by falling tank level and it is during this time that the ammonia level represents that being discharged. Note that during first 2 cycles shown, the level of ammonia exceeds the license limit and these also constitute the largest volumetric discharges. Discharge levels during the later half of the first decant are between 3 and 4 mg/L. The plant meets ammonia specification due to the extremely low ammonia levels discharged during the last 3 cycles shown on the chart which correspond to low load periods.

Figure 2 shows the same tank being run under a very basic feedback control system where the ammonia analyzer determines the aeration time. The aeration continues until the ammonia levels drop below 1.5 mg/L with a level default set on rate of rise to prevent overflow of the tank. This can be seen operating in the first cycle.

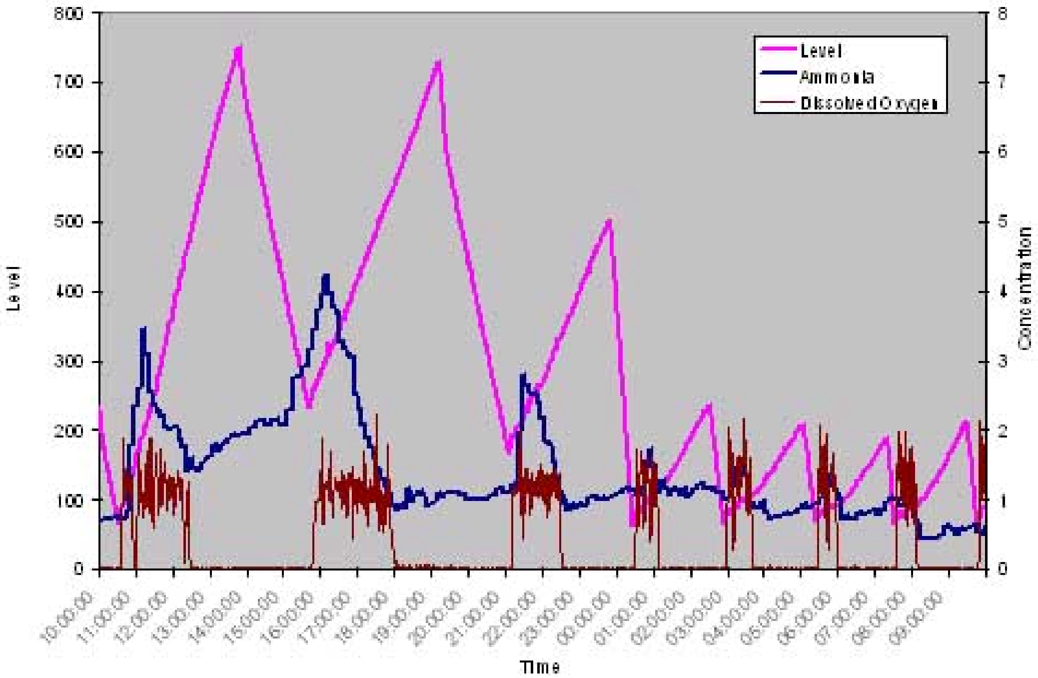

Fig. 2: Ammonium removal using the feedback control

Despite the fact that peak ammonia loadings during the first aeration cycle of figure 2 were approximately 1.5 mg/L higher than during the first cycle in Figure 1 and the fact that hydraulic limitations demanded premature stopping of the aeration, the decant from the first cycle was almost exactly 2 mg/L with all other decants of the day easily bettering this target. The nett result was a reduction of the Kg of ammonia discharged with lower overall aeration usage.
Payback times for the equipment and software to do this were well within financial criteria required.

Further optimization by changing the programming of the cycles to allow 2 tanks to decant shortly prior to the main morning surge of flow and we assume load, will allow further improvement in performance with almost no additional cost. Once the morning surge is over, cycles can move back to the normal staggered pattern.

Feedback control as shown here relies on measuring what is already present and then attempting to deal with it as best we can. This is similar to waiting until the engine of a large heavy vehicle is already labouring on a hill before trying to change down a gear to maintain speed. This is better than not changing gear at all however it is not necessarily the best solution. Any experienced heavy vehicle driver takes pre-emptive action when changing conditions occur on the road and this philosophy is just as applicable to wastewater treatment. The critical factor is having the necessary information to pre-empt a load change.

CASE STUDY 2

Feedforward Control
This example shows how a strategy utilizing information on the instantaneous inlet BOD Kg allows greater operational versatility, information on biomass health and better resultant nutrient removal

performance. This information allows us to make decisions and take action to ensure the optimal conditions in the aeration and anoxic zones. We call this Feed forward Control.

The data below is from an Australian wastewater treatment plant of modern design that is designed to remove C and N. The plant is an approximately 20,000 Person Equivalent plant using course screening followed by a preselector tank and a modified carousel system (Pasveer/Oxidation Ditch) and clarification. The modification involves a diffused air grid of approx. 10 meters of linear length in front of one of the standard brush aerators. Returned activated sludge (RAS) flow rate has traditionally been run at a constant rate.

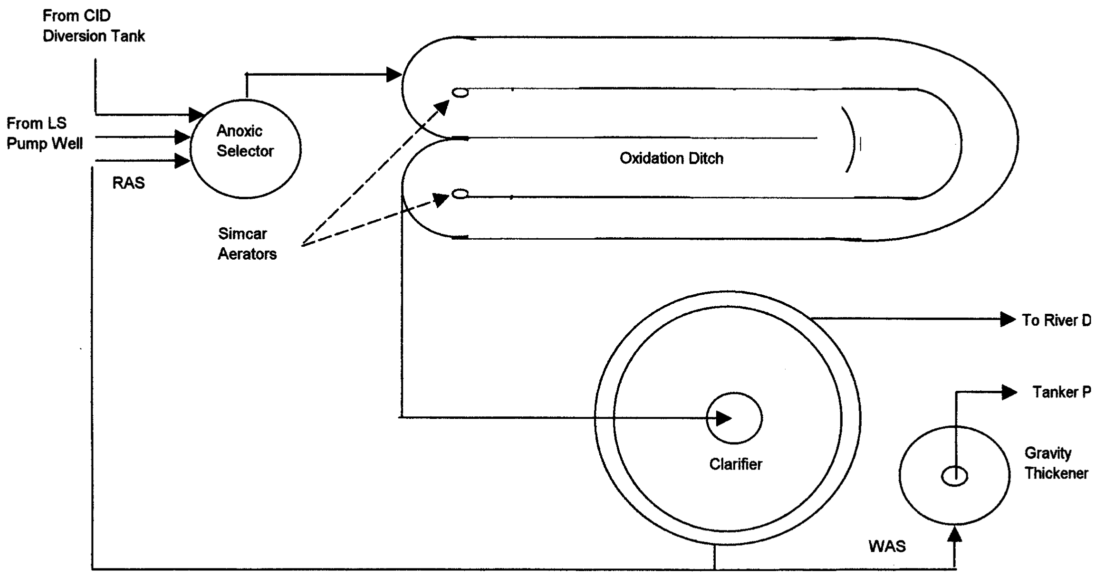

Fig. 3: Schematic view of the wastewater treatment plant using Feedforward Control

The plant meets it's license limit of an average of 2 mg/L of ammonia easily and usually maintains nitrate levels at values well below 6 mg/L on composite samples.

An on-line BOD analyzer (Stip Biox 1010) is continuously sampling from the screened inlet prior to the preselector and is linked with inlet flow to give instantaneous BOD Kg.

Computation of dissolved oxygen (DO Kg) being consumed by the biomass is calculated from blower/brush aerator speeds and appropriate approximations for oxygen transfer factors.

On-line ammonia and nitrate analysis (Stip Buoy analysers) in the aeration zone provide information on the effectiveness of treatment. The results are displayed on a screen (fig. 4). The control system automatically adjusts conditions in the oxidation ditch as inlet load and outlet ammonia/nitrate levels vary.

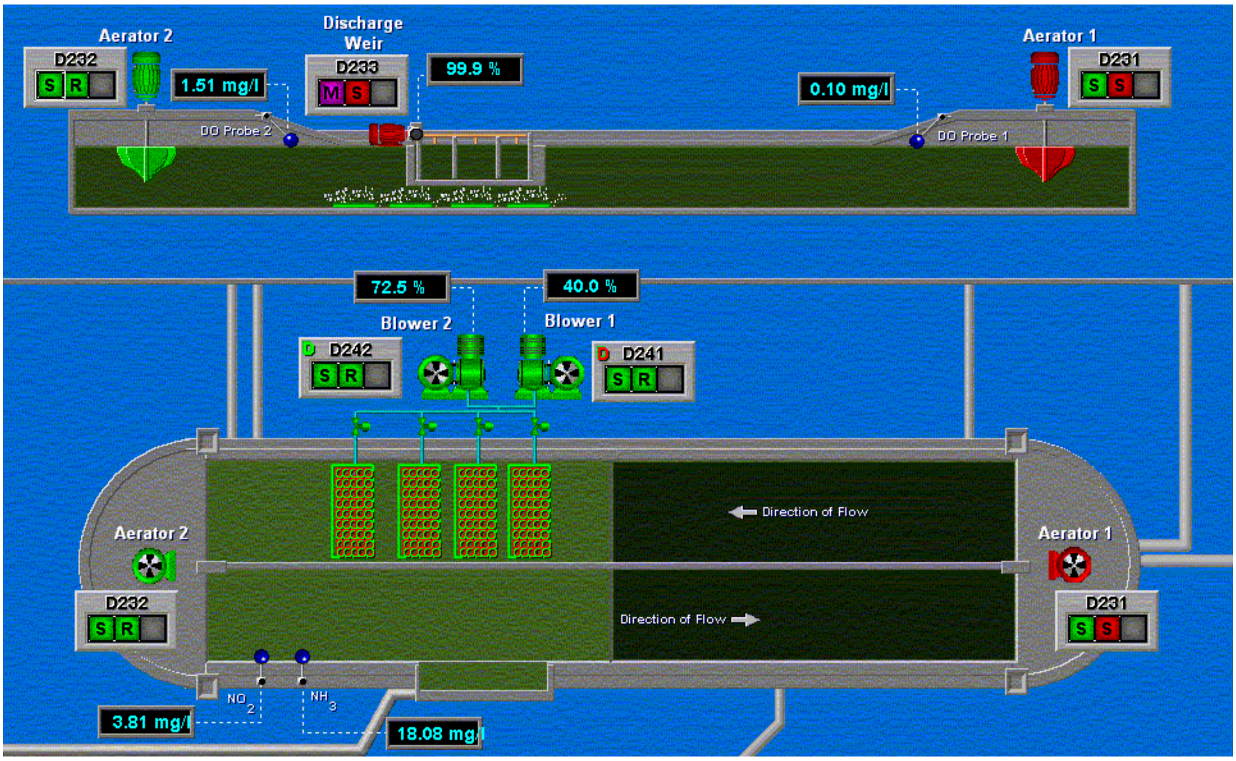

Fig. 4: Operator's screen of the oxidation ditch

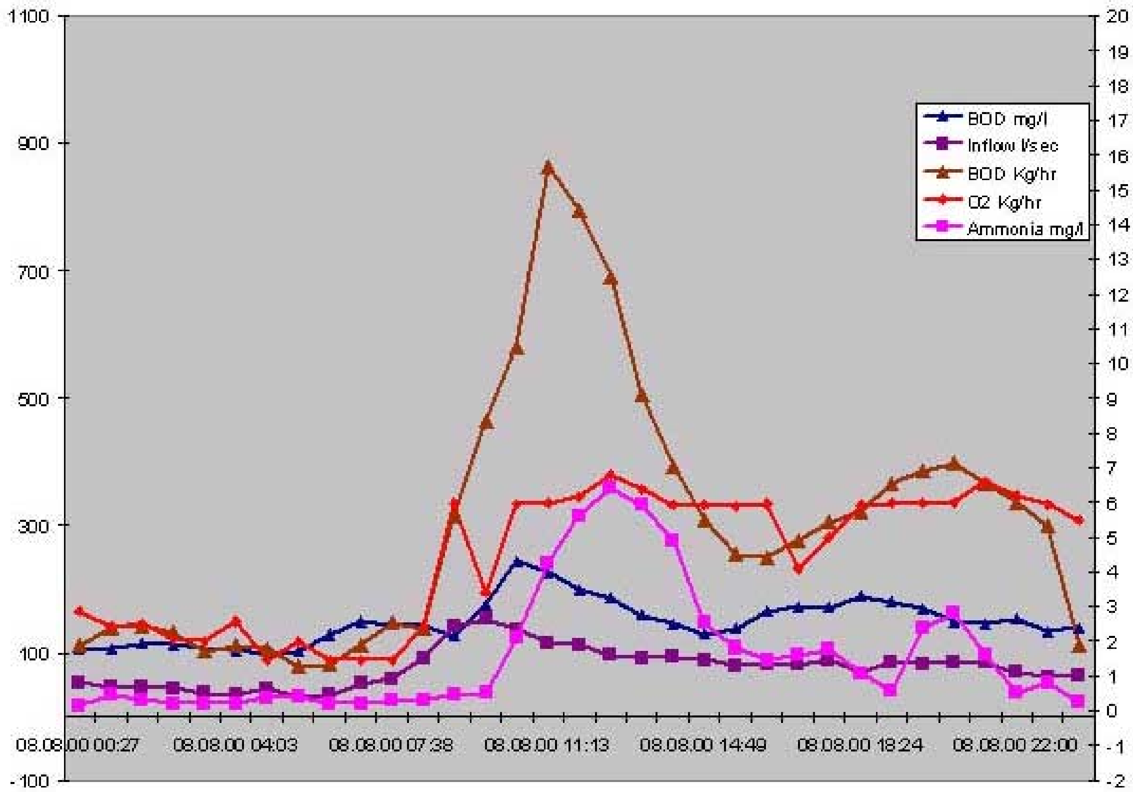

Fig. 5: Daily trend of various parameters in the plant without using feedforward control

This daily trend show the real time response of the plant to changing inlet load with no feedforward control action taken. As can be seen, ammonia at the outlet of the oxidation ditch rises whenever the inlet BOD Kg exceeds the O2 Kg utilized to remove it. Since ammonia is one of the major components of the raw waste, it's presence is a good indicator of untreated waste leaving the plant. The ammonia curve is directly predictable from the BOD Kg at the inlet minus the O2 Kg used in the aeration zone. If more waste is entering the plant than is being removed, then levels of ammonia and other primary nutrients must rise in the outfall.

The indications from the normal daily trends are that there is either insufficient biomass present to treat the peaks in BOD Kg or there is insufficient aerobic proportion in the oxidation ditch to allow sufficient processing time. A balance is required: Too much aerobic area results in a high nitrate concentration and subsequent settling problems in the clarifiers. Assumptions that this will be shown by the DO sensors is false. Many factors affect the DO at the point of measurement. This plant uses a second downstream DO probe to determine the presence of anoxic conditions. This helps to correct some of the limitations of simple control of dissolved oxygen. This however is not enough as can be seen from the surge in ammonia level each day.

Increased information from the inlet BOD Kg calculation has allowed the control system to be modified to allow the set point on the dissolved oxygen control system to be increased as inlet BOD Kg increased. The result being a larger proportion of the oxidation ditch under aerobic conditions without over aeration and high resultant nitrate levels. At times of low inlet BOD Kg, the plant uses less air than under identical circumstances prior to feedforward control resulting in lower power usage and reduced nitrate levels. The result of this is shown in figure 6.

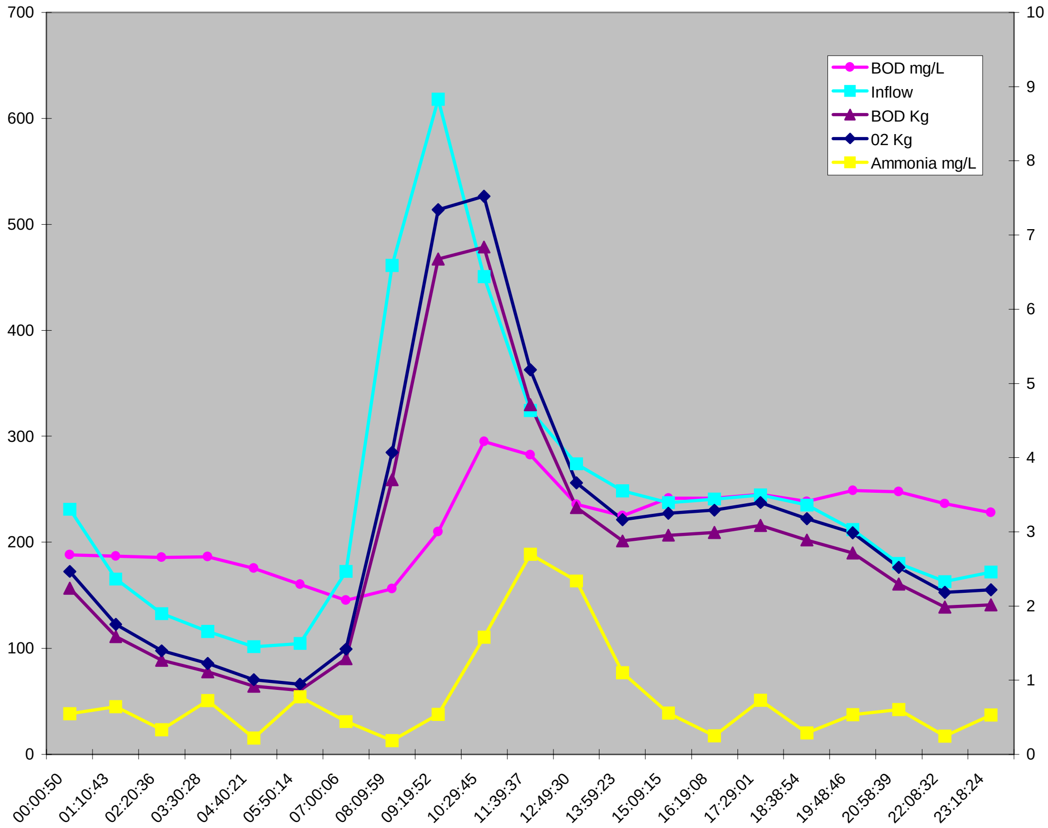

Fig. 6: Daily trend of various parameters in the plant using feedforward control

Further gains can be achieved in applications where the plant becomes biomass limited as the BOD Kg measurement can be used to increase the RAS flow also. Use of a small storage tank drawn from the bottom of the clarifier during low load conditions allows sudden large shifts in RAS flows for short times to leave clarification almost unaffected. An appropriate ratio of food:biomass can be adjusted easily. The cost of this is very small compared to large volume tanks needed to provide balancing of the entire inlet flow and although best included in the design stage, it can easily be retrofitted to existing plants.

Operations and engineering now have proof of performance of the plant for almost every moment in time plus direct cause and effect information to justify any additional capital expenditure on plant hardware. This eliminates the current difficulties in quantification of gains for future plant modifications. It also produces direct proof and quantification of the financial and quality gains achieved by the expenditure.

CONCLUSIONS

The performance of a wastewater treatment plant can be improved quite easily. Using on-line analyzers, insight into the real situation in the plant is possible. Using advanced process control techniques, the reality can be handled in order to improve the processes and to decrease the concentration of discharged components.

Both strategies presented in this paper resulted in the WWTP exceeding discharge license requirements by considerable margins at lower operational cost. Both strategies are useful to decrease sustainably the operational costs in waste water treatment plants, which are mainly based on the costs for discharge of ammonia/BOD/nitrate and electrical power for running the aerator motors. Nevertheless, feedforward control is the more advantageous and profitable method, because the plant operation is adjusted to the reality of the inlet loading conditions. Plant operators and engineers have to keep this into account. Until this is the case, excessive operational cost and capital expenditure will occur to raise the standards of nutrient removal to match ever tightening standards.

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