Monitoring & Control for Cost Effective Nutrient Removal or Addition in Waste-Water Processes

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ABSTRACT

On line control of nutrient removal in biological processes, and addition of Phosphorous and Nitrogen to nutrient deficient biosystems, up to now, have not found widespread application. The reasons for this were lack of reliable “In situ” instrumentation together with process variants and physical structures which did not lend themselves easily to dynamic control. The advent of batch and semi batch biological processes, together with recent instrument advances, has potentially changed this.

These changes have now enabled an Ammonia measurement system to be installed and tested within a digester liquor treatment plant, operating in a semi draw and fill mode. This paper gives details of both Ammonia-N and orthophosphate in situ measurement devices, and describes the practical implementation of such devices on real plants. Effects on effluent quality control and treatment costs are considered.

INTRODUCTION

Development of wastewater processes and their control has been led by a variety of drivers including, aesthetics, public health, legislation and financial constraint. This has resulted in intensification, mechanisation and automation of what we now recognise as modern wastewater facilities. Development is still continuing, with Nutrient discharge legislation, regulatory charging constraints, and private sector profit generation, becoming very powerful drivers.

Most major facilities employ some form of activated sludge variant, all of which require measurement and control of certain key criteria: F: M ratio, oxygen supply, reaction time, nutrient addition or removal and final settlement. Plant loading varies with time; hence it is not possible to make optimum provision at all times merely by physical design. If we are to move forward we must design in variable treatment provision controlled by real time measurement of the important variable parameters. This may be done in many ways, however which ever method is chosen there are two inescapable pre requisites: (a) An initial plant design which builds in the capability for variation and (b) availability of reliable, affordable instrumentation,

Table 1 is an attempt to summarise the major areas in which future development may be advantageous.

Table 1 **Current and possible future control strategies**

Criteria	**Measurements**	**Current strategy**	**Future Strategy?**
F:M Ratio	BOD, SS or VSS, Respiration rate	Controlled @ design stage. Usually no dynamic control except manual wastage	On line BOD + on line endogenous respiration measurement. Used for :load balancing, variable aeration capacity control, variable sludge return rates
Oxygen supply	Dissolved oxygen, air flow, main pressure	To maintain a fixed dissolved oxygen concentration	Floating DO set point according to either on line BOD, or NH3-N measurement
Reaction time	Time, BOD, NH3-N, NO3-N, PO4-P	Controlled at design stage. No dynamic control	Use at front end for feed forward control or in process to determine treatment directly
Nutrient addition	PO4-P, NH3-N	Dosage usually manually set and then dosed flow proportionally	Measure load on line + nutrient analysis and dynamically control
Effluent quality	BOD, NH3-N, NO3-N,PO4-P, SS	Usually spot or composite sample + lab analysis. No possibility of dynamic feed back	On line analysis + feed back

For the purposes of this study we will confine further discussion primarily to that of Ammonia, removal or control. In situ Phosphate measurement will also be briefly described.

PROCESS CONSIDERATIONS FOR NITRIFYING ACTIVATED SLUDGES

Most effluent quality consents issued for discharge to inland watercourses now include NH3-N limitation. Consequently the majority of Activated sludge plants, irrespective of their particular variant, are designed to fully nitrify. A natural consequence of this is the production of Nitrate, which, itself may pose both problems in the receiving water body and in the stable operation of the activated sludge plant itself. Consequently provision for anoxic treatment to reduce the Nitrate concentrations is normally made.

The obvious implication of the above is that the operator should at very least know how the Ammonia and Nitrate concentrations vary and preferably be able to alter process conditions in order to control the aerobic and anoxic treatment stages.

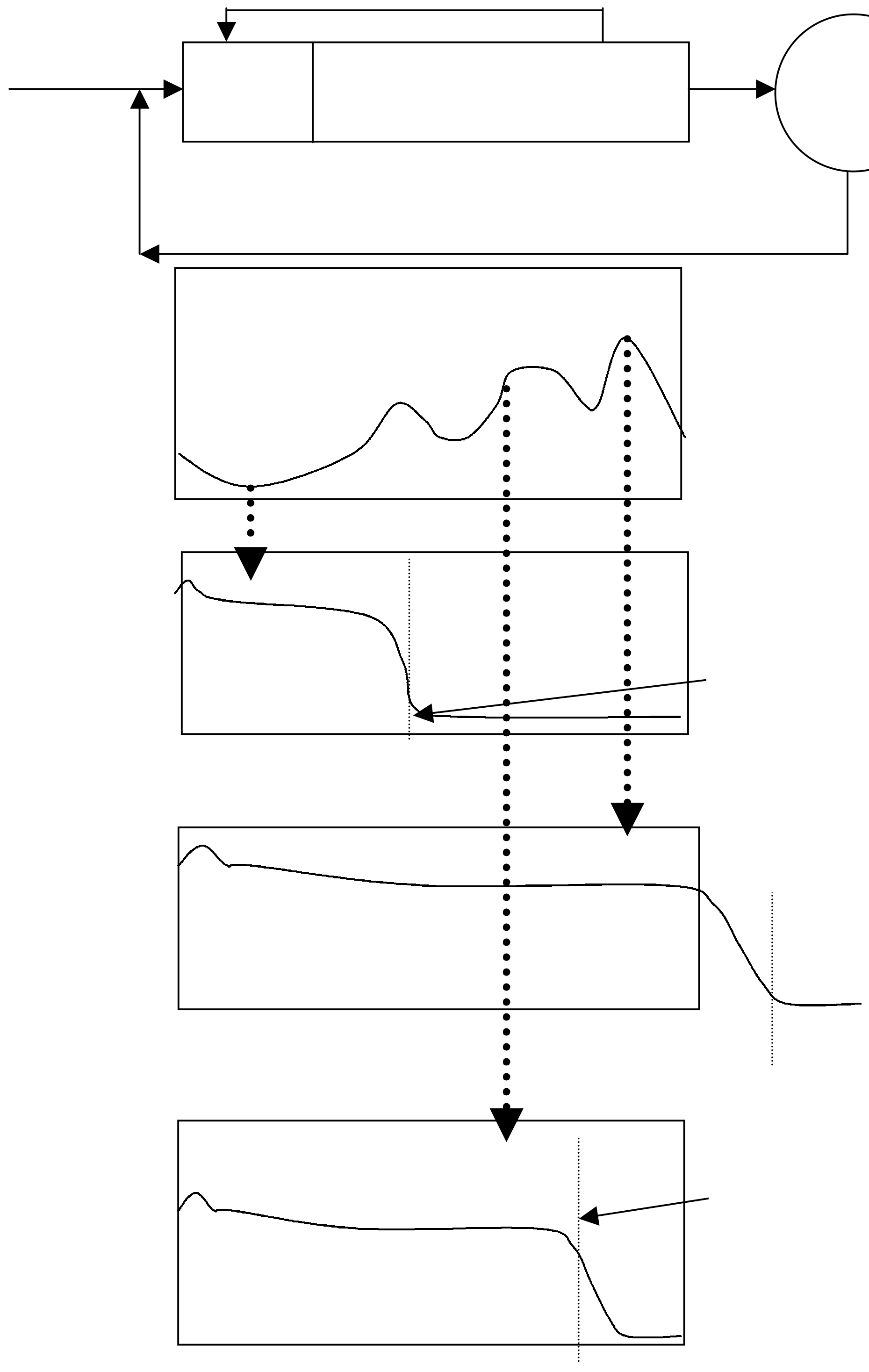
For the purpose of illustration two process variants will be considered further:

(a) Plug flow, extended aeration + anoxic zones and (b) Sequencing Batch Reactors

PLUG FLOW SYSTEM

Fig 1 shows a process schematic for a typical plug flow nitrifying activated sludge plant. A, B, and C illustrate idealised treatment curves corresponding to three different loading rates shown in the typical daily load curve.

FIG 1 Idealised treatment curves



The shape of the treatment curve or respirogram is made up of 4 components: (a) the initial blip which represents easily degradable organic material, (b) the long gentle plateau which comprises of less readily degradable organic material + Ammonia and (c) The long low tail which is the endogenous respiration of the sludge [1].

Transition between “a” and “b” is well defined. The reason for this is that the Nitrification process approximates to zero order in respect of Ammonia concentration. Hence the rate stays almost constant until there is virtually no Ammonia present and then suddenly drops when there is full Nitrification, i.e. at the point of “full treatment”.

The time taken to reach full treatment or in the case of a plugflow system, the distance down the bay, will be a function of the imposed substrate load. In the case of treatment curve A, which corresponds to times of low loading, full treatment is reached a long way before the end of the bay. Where loading is high, curve “B”, full treatment is never reached within the confines of the physical structure. Hence there is a breakthrough of Ammonia into the final effluent. Hopefully, operation normally lies at a loading rate as shown in C, such that full treatment is achieved just before the liquid leaves the aeration tank.

Where situations arise as in A and B, consents are exceeded or money wasted due to aeration of completely treated sludge. To improve this situation, a means is required to both vary the aerobic treatment time to meet the load and also a means to increase the treatment rate. Also sensing systems are needed to indicate when these variations may be required.

MECHANISMS FOR MANIPULATING TREATMENT TIME IN PLUG FLOW PLANTS

There are various ways to manipulate the treatment time required to match the treatment time available. We will consider just two based on Nitrification control:

(i) Decrease oxygen concentration to limit nitrification

(ii) Employ variable anoxic zones thus enabling changes in aeration time.

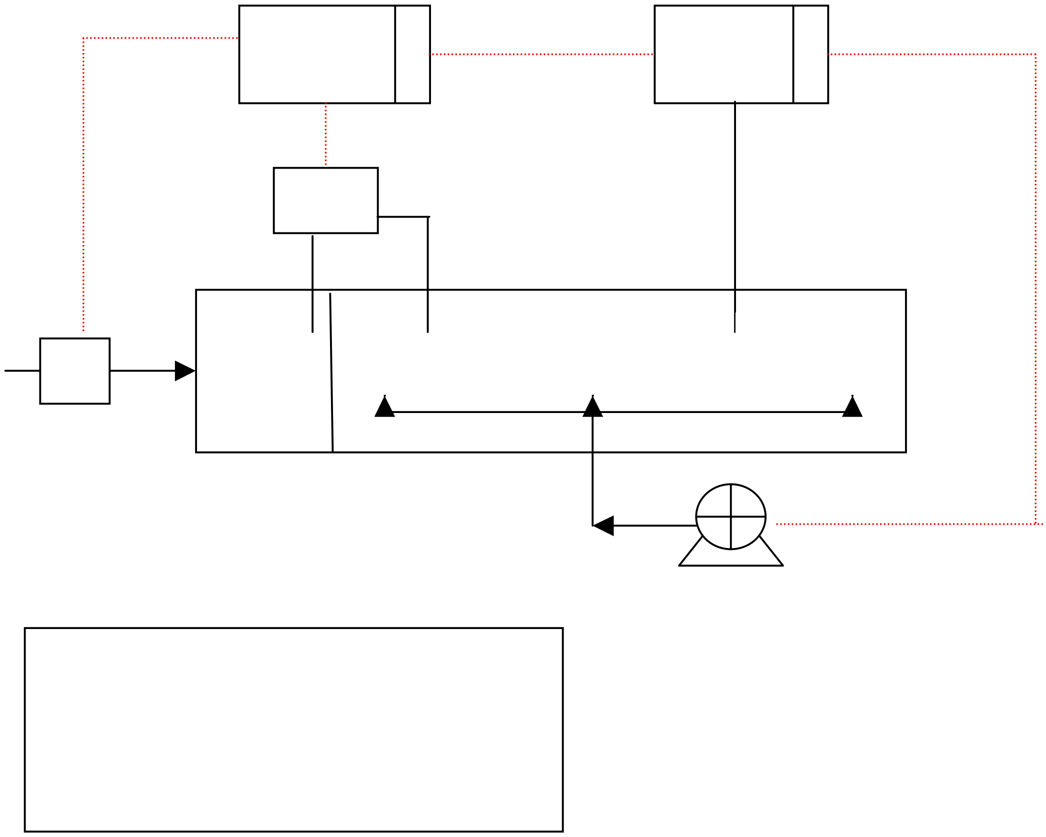
Suggested schematics for both possibilities are shown in figs 2 and 3. These are illustrative only, many variations on this theme being possible.

Potential control logic for feed forward system:

Ammonia measurements could be made in the fixed anoxic zone and a little way down the first aerobic zone. In addition the flow into the bay, would be measured. This would provide the inlet Ammonia concentration, required nitrification rate (dNr) and the actual nitrification rate (dNa). The difference in these rates should be zero. A change of DO set point relating to the size of nitrification rate differences could be fed forward to the blower controller. This would optimise the nitrification rate such that air use is minimised whilst maintaining satisfactory effluent quality.

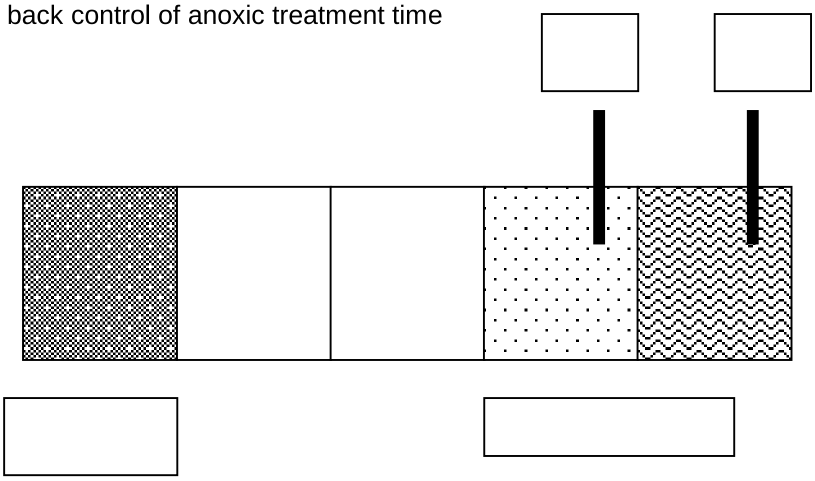
The success or failure of such a system would depend on the sensitivity of the nitrification rate to DO concentration and the ability of the DO measuring and control system to adequately control between small DO concentration differences.

FIG 2 Feed Forward DO set point control



The difficulties and potential for instability using such an approach, with multiple nested control loops, are quite high. It would be much easier to merely control the length of time the liquor is subjected to aerobic treatment. This may be achieved in a feed forward manner, using the same logic as described above, but merely controlling the number of anoxic zones employed, or using a feed back system as shown in fig 3.

Fig 3 Feed back control of anoxic treatment time



Potential feed back control logic

The aeration bay would be subdivided into controllable sectors. Each sector having the capability to be aerobic or anoxic.

By installing two Ammonia probes it is then possible to sense whether the point of full treatment is occurring significantly before the end of the aeration bay.

If Probe “a” is low and Probe “b” is high then it is known that full treatment is only occurring in the last sector, hence there is no possibility to reduce the aerobic capacity without exceeding ones consent.

If probe “a” is low and probe “b” is low then it is known that there is at least one sector capacity for reduction of aeration. When this is the case the aeration in the end sector would be reduced to a minimum (or stopped altogether if a mixer was available). If probe “b” remains low for at least one sector retention time, then there may be capacity to reduce aeration in the next sector up the bay. This could be done until such time that probe “b” starts to go high.

This system has the advantages of being extremely simple, with no need for three term controllers. It also maximises the denitrification capacity of the plant thereby reducing energy costs and increasing settleability of the sludge.

The disadvantage is that it operates in a retrospective sense. This disadvantage may be negated to a certain extent if the sector sizes are kept fairly small.

At the time of writing neither of these strategies has been put into operation, nor are they the only available strategies.

An evaluation project to assess plug flow ASP control strategies, using NH3-N measurement, is to be carried out in the near future.

SEQUENCING BATCH REACTOR

Sequencing batch reactors are easier to control than plug flow systems. The reason for this is that one effectively has captured a slug of liquor in a tank and is then treating it for a period of time under your control. Most existing systems merely use a fixed time aeration period. This implies therefore that one MUST set the time sufficient to treat the highest load that the system will see, otherwise there will be periods where full treatment is not achieved. By the same token however there will be significant periods of time where full treatment has been achieved but aeration is continuing thus wasting money.

It should be a comparatively simple task to measure the Ammonia concentration in the aeration tank and stop the cycle at the desired level of treatment.

This system is currently under test at an existing treatment site. Further details are given in a later section.

SENSING SYSTEMS

From the previous discussions it is clear that in theory one should be able to use either in situ respiration rate measurement as an indirect measurement of complete nitrification OR use in situ Ammonia measurement as a direct measurement of the parameter in question. The advantages and disadvantages of each system are listed below:

Table 2

SENSOR TYPE	ADVANTAGES	DISADVANTAGES
Respirometer	Simple, no reagents, low maintenance	Higher cost, Only detects when Nitrification is complete. Hence can't use to control partial nitrification. Can't be used in feed forward mode
Insitu Ammonia Measurement	Lower capital cost, can be used for partial nitrification control, can be used for feed forward mode, low maintenance	Requires reagents

It is apparent that the insitu Ammonia measurement system is more flexible for this purpose, hence respirometry will not be considered further here.

FIG 4 Isco-STIP process buoy for In-situ Ammonia-N measurement

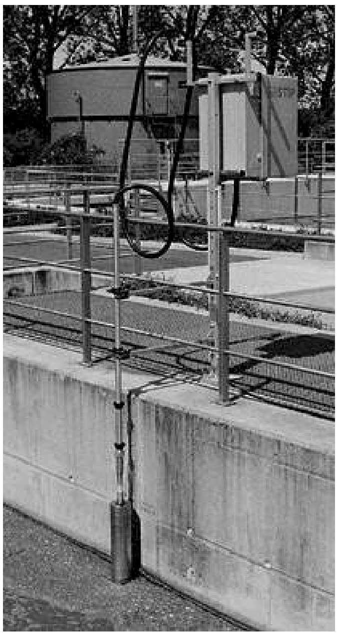
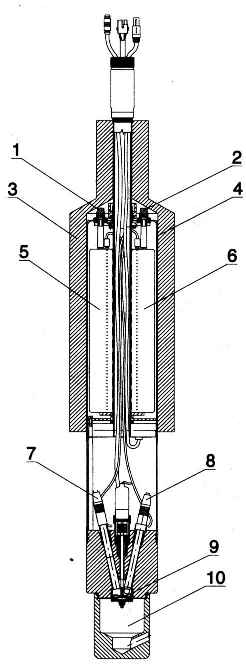


FIG 5 Component schematic for Isco STIP process buoy



The Isco-Stip Ammonia process buoy uses a standard gas sensing electrode to measure the NH3-N in the aqueous phase, however it has been designed not to require any housings, pumps, pretreatment or large quantities of reagent, thus allowing direct deployment in the process liquor. The operating logic, data storage, communications facility and local display are all housed in the small weather proof enclosure, whilst the wet end sensor houses reagent and standard containers, liquor settlement chamber, sensor chamber, gas sensing NH3-N electrode, temperature sensor and pH sensor.

The operational sequence is as follows:

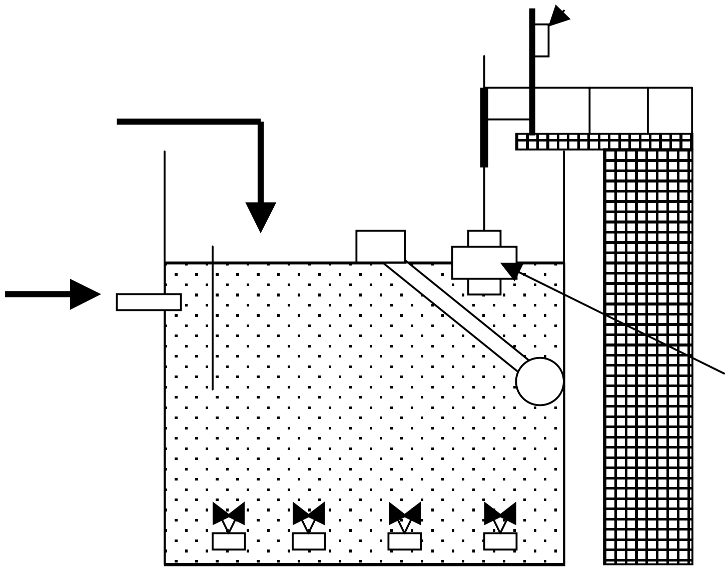
Sample is purged from chambers (9 &10), by air from a compressor. The vessels are then vented to atmosphere allowing the hydrostatic head to force new sample into the settling chamber (10) up to a level sensing electrode in the chamber. The sample is retained for a programmed time to allow solids to settle. Chambers 9 and 10 are again vented allowing the clarified supernate within the settlement vessel to enter the measuring chamber (9). A low voltage mixer in the measuring chamber is then switched on and the pH of the liquid is attenuated to pH11.5 by addition of an EDTA/NaOH mixture from the reagent vessel (6). This is achieved with minimum chemical usage by maintaining constant pressure in the reagent vessel and pulsing a solenoid valve leading to a machined orifice. Each pulse will deliver the same quantity of reagent and the resulting pH is monitored by the pH probe (7), further additions being controlled by a feed back control loop. After pH correction the signal from the NH3-N probe (8) is amplified and logged. The cycle then normally repeats itself, except when a calibration is called for.

Calibration: Probe calibration is done at pre selectable intervals. When calibration is due the above measuring procedure is performed, at the end of which the sample is NOT purged out but kept within the measuring chamber such that a standard addition procedure may be performed. This is achieved in a similar manner to that of adding reagent, i.e. by pulsing a solenoid valve. One pulse of standard from the standard vessel (5) is admitted to the chamber and a measurement made. Another eight pulses are then added and a measurement made, thus allowing the slope of response and actual values to be calculated. Once calibration is complete the measuring and settlement chambers are purged in the normal manner and the measuring sequences recommenced.

PRACTICAL APPLICATION, OF NH3-N MEASUREMENT AND CONTROL, ON AN SBR TREATING DIGESTED SLUDGE CENTRATE LIQUORS.

Anaerobically digested sludge is centrifuged, the centrate being pumped into a balancing tank. This liquor requires at least partial treatment to reduce the Ammonia concentration to acceptable levels, before going onto further aerobic treatment in admixture with settled sewage. An SBR type system is used for this purpose. Currently the fill and draw cycle is controlled on a timer, and aeration control is based on a timer-controlled variable D.O. set point.

Fig 6 Schematic of an SBR Centrate Treatment Plant



Current operational practice lies part way between true batch treatment and continuous treatment, since aeration starts immediately the centrate feed starts and continues for a considerable time through the aeration cycle. When the aeration period finishes the blowers are turned off and the mixed liquor allowed to settle. After a given period the draw off mechanism is lowered such that supernate flows over a weir in the draw off box. The level of this box is automatically controlled to give a constant head over the effluent weir, until such time that it reaches a preset low point. The draw off arm is then wound back up to its original position, and the cycle reinitiated.

It had been suspected for some time that the aeration period could be better controlled. Measuring the Ammonia concentration directly and using this to control the cycle is the favoured option. Transferring a sample from the tank and pretreating it prior to analysis would be extremely difficult due to the very high content of fine shredded plastic material, which would pose a severe blockage problem. Consequently a prerequisite for improving control was the implementation of an insitu device for Ammonia measurement. The Stip process buoy is designed for this purpose, however due to the varying liquid level in the aeration tank, a floating platform to support the wet end was required.

Under normal operation the process buoy wet end is supported at a constant immersion depth by means of a floating collar. As the liquid in the aeration tank rises and falls so does the process buoy. The float is kept in place by means of a support extension, which passes through a vertical rigidly mounted guide. A winch cable is attached to the floating unit such that it may be lifted to walkway level for routine filling and maintenance purposes.

Fig 7 Floating Ammonia buoy support

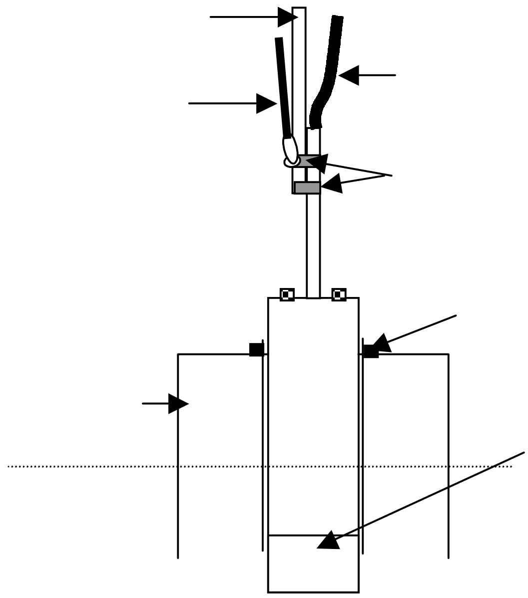


FIG 8 Buoy lifting and guidance system

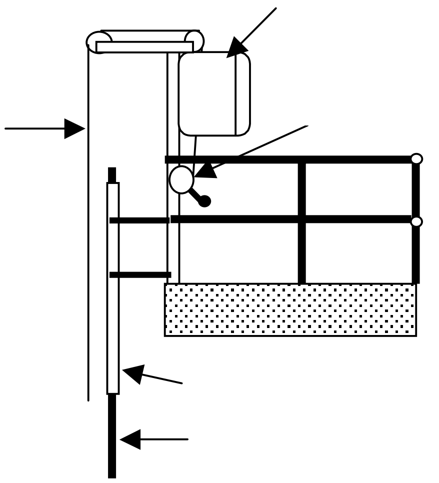


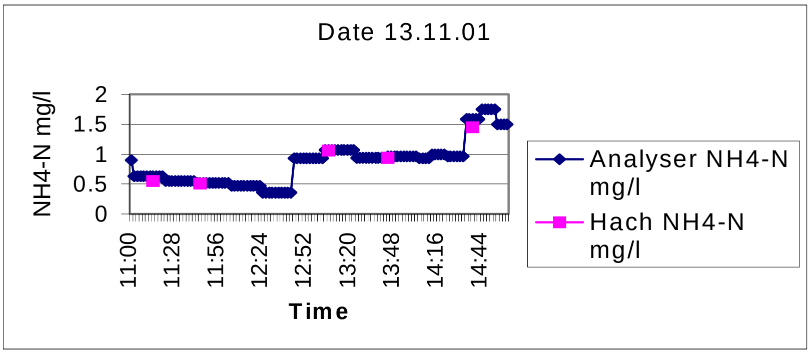
FIG 9   Floating Wet end

FIG 10 Transmitter/controller

RESULTS

AMMONIA BUOY PERFORMANCE

FIG 11 Comparative Ammonia analysis for 13/11/01



The validity of the Ammonia buoy results were proven by comparison with manual samples and colorimetric analysis using a Hach test kit, as shown in figs 11 and 13.

PROCESS PERFORMANCE

FIG 12 Normal Plant Operation

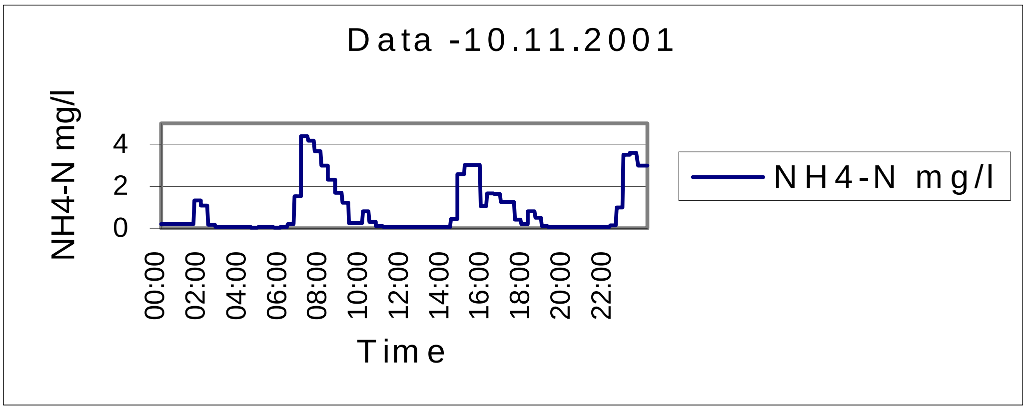


FIG 13 Process deterioration due to caustic failure

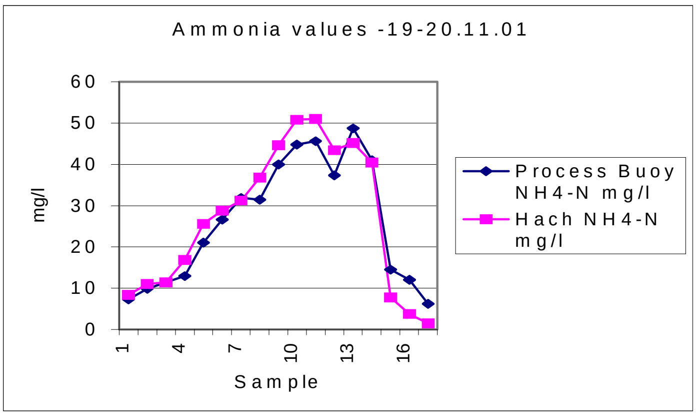
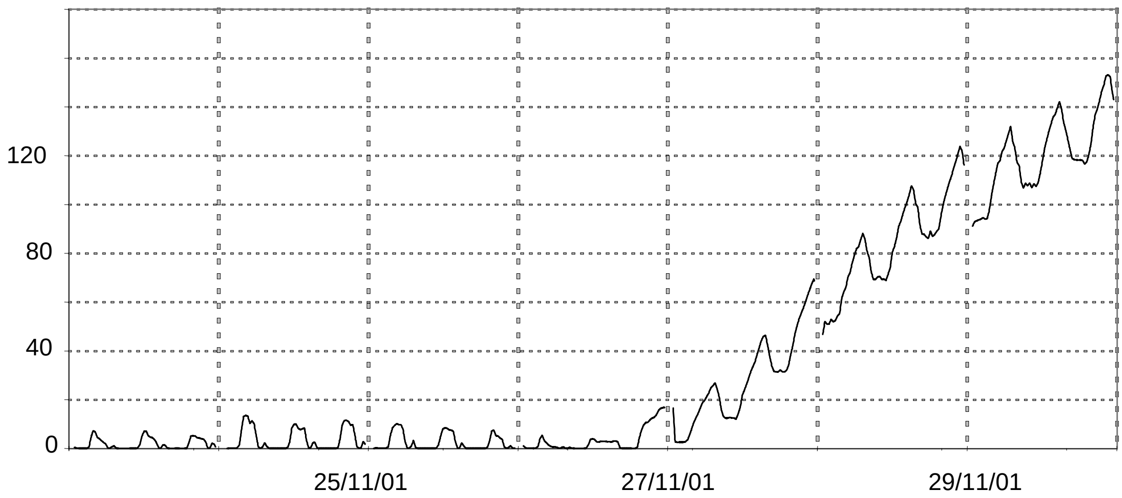


FIG 14   Process deterioration due to antifoam overdose



Under normal operating conditions it was found that the concentrations of Ammonia in the reactor tank were far less than expected or desired. This infers either that treatment is excessive or the loading on the plant could be increased considerably. In either case the efficiency could be improved, both giving improved operational costs and increased reliability of the Nitrifying filters due to the maintenance of a robust nitrifying population.

Two occasions were detected during monitoring trials, where the SBR nitrification was adversely affected. The first was due to failure of caustic addition, depression of pH and inhibition of Nitrification. When caustic dosing recommenced the recovery was almost immediate (fig 13). The second event was partially due to accidental overdose of antifoam, although it was suspected that other factors might also have had an effect. In this case there was a more severe effect and a much greater recovery time (fig 14).
In both cases, only the SBR effluent was affected, the treatment capacity of the Nitrifying filters providing sufficient extra NH3-N removal to prevent any excursion in the final effluent. The in-situ Ammonia buoy immediately detected process deterioration.

FURTHER WORK

NITRIFICATION CONTROL

1. It is hoped to implement automated aeration time control on an SBR plant, in order to increase its potential through put and to reduce the energy consumption per unit treated. In addition the tighter control will regularise the Ammonia concentrations going forward onto the Nitrifying filters, ensuring that sufficient load is imposed to maintain a healthy Nitrifying population, whilst at the same time not exceeding the treatment capacity of these filters.

2. A Stip process buoy is to be deployed to measure Ammonia in the aeration basin of a plug flow plant. After performance verification, feasibility trials for variable DO set point control will be carried out.

POTENTIAL SAVINGS

In conventional nitrifying activated sludge plants, savings may accrue by four means: (a) not oxidising NH3-N beyond that required, (b) utilisation of NO3 oxygen for carbonaceous oxidation, (c) Increased aeration efficiency (approximately 20%) when operating near 0 mg/l D.O. concentration rather than 2 mg/l for optimum Nitrification rate [2], and (d) avoiding aerobic stabilisation of mixed liquor after full treatment has already been attained.

In the case of highly loaded liquor treatment activated sludge plants, extra savings may accrue due to a lower caustic demand. This is likely for two reasons: (1) unnecessary Nitrification would be eliminated, thus reducing the buffering capacity required, and (2) increased anoxic time effectively yields a "Caustic buy back dividend".

Estimates of the combined effect of (a) and (b), assuming the aeration efficiency = 2 KgO/Kw.hr, and energy cost is 5p/unit, may be obtained from the following equation:

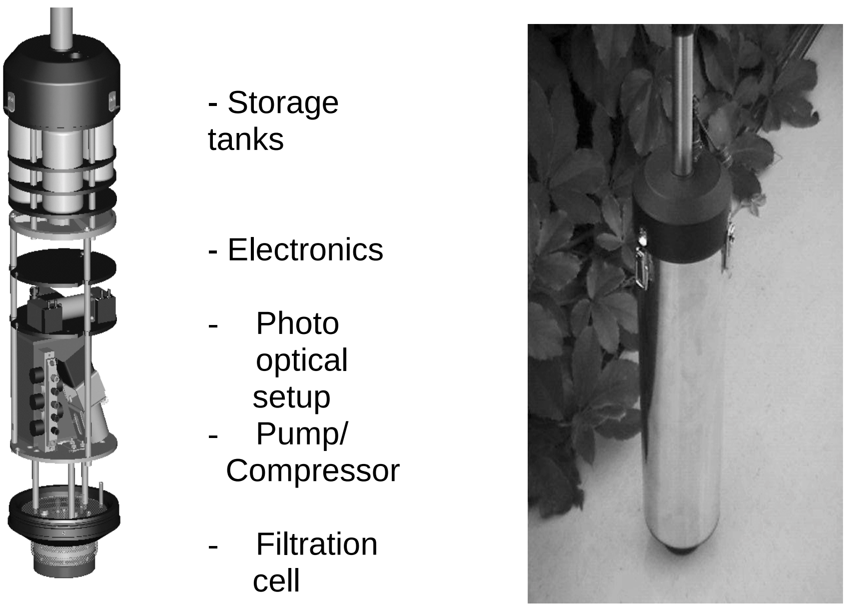
Cost saving = $V(11.25N + 3X)/10^5$ £/d,

Where V = sewage flow in m3/d, N = mg/l NH3-N unnecessarily oxidised, and X= % BOD load satisfied by NO3 oxygen.

PHOSPHATE MONITORING

Isco–Stip are to launch an In–Situ measuring system for the measurement of ortho-phosphate in March/April 2002. Performance trials will be executed on a paper mill waste treatment plant adjacent to an existing Ammonia buoy. The overall objective is to monitor and control the Nutrient additions more effectively. The pre release units are illustrated in fig15 below:

Fig 15



The end of the sensor assembly is immersed in the liquor to be monitored. Sample is admitted into the reaction vessel via a patented self-cleaning filter system. Reagents are added in accordance with the Molybdenum blue standard method [3], and the absorbance measured at two separate wavelengths. This permits accurate measurement over a wider range of concentrations than would normally be possible.
Both the Phosphate and Ammonia process buoys may be controlled from one transmitter/receiver, thereby offering a more cost-effective dual monitoring package for nutrient addition control or Phosphate and Ammonia removal.

CONCLUSIONS

1. The Isco-STIP ammonia Process Buoy operates satisfactorily when situated directly in the aeration basin of an activated sludge plant.
2. The process buoy has been successfully adapted to operate in a tank of varying liquid depth, such as a fill and draw system.
3. Dynamic monitoring of Ammonia removal in an activated sludge plant treating digested sludge centrate is feasible.
4. Control of variable aeration time using the output of the process buoy should be feasible.
5. Direct monitoring of the in tank Ammonia concentration and utilisation of limit alarm controls would help prevent treatment excursions due to unforeseen plant problems.
6. The Process buoy may be used to control the NH3-N concentration going forward to say Nitrifying filters, therby ensuring the Nitrifiers are neither starved nor overloaded.
7. Potential cost savings on medium to large works could be £15K/yr or more, depending on the situation.

ACKNOWLEDGEMENTS

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