SIMPLIFIED PROCESS MODELLING FOR WASTEWATER TREATMENT DIAGNOSIS

Dr. Jeremy Lumbers[*] and Dr. Mohamed Abdel-Razik[**]
[*] Chairman, Tynemarch Systems Engineering Ltd.
Abinger House, Dorking, Surrey RH4 1DF
[**]now Senior Lecturer, Ain Shams University, Cairo, Eygpt

ABSTRACT

Approaches to process modelling to aid the diagnosis and operational optimisation of wastewater treatment are discussed briefly.

A case study is described involving the modelling of a small extended aeration packaged plant. Process modelling was a component of the investigation of non-compliance with the effluent quality consent conditions, mainly associated with excess suspended solids due to poor sludge settleability and rising sludge. Plant configuration and a lack of process control were found to be the main factors contributing to poor performance.

A simplified process model of the system was used to determine modifications to the aeration tank inlet and outlet arrangements to induce a pronounced dissolved oxygen profile around the tank under normal operating conditions. Other process management requirements were identified including better control of the aeration system and the rates of returning and surplussing activated sludge. A marked improvement in the effluent quality was observed following the modifications to the tank configuration, pumps and controls.

INTRODUCTION

The application of process modelling in the water industry has been mostly for the design of new works. Examples of process models being applied for operational purposes often have been for problems that could have been solved by simple calculations, for example of hindered settling theory.

A common feature of the commercially available process modelling software is the large number of process states and associated parameters. This complexity is a consequence of the approach to model development that has been to include all the biochemical processes thought to be involved in treatment. The result has been modelling software that is over-complex for many applications, requires large amounts of data and for which it is difficult to estimate the values of the many parameters included.

In contrast models developed for operational applications must be simplified in recognition of the limited data normally available. Model for use in operations must be formulated with a clear specification of the results required; this in turn can also lead to reduction in model complexity.

Whilst in principle it is possible to simplify complex models to suit a specific application this requires both the ability to modify the equations within the modelling software and also a capability to undertake generalised sensitivity analysis to identify which are the most important components influencing model output.

An alternative approach to modelling is preferred where the model structure is identified from the observations of process behaviour. Additional model complexity is only introduced where it can be shown that an improvement in predicted performance is obtained. Defining what is acceptable and unacceptable model performance is an essential part of the process. In some cases indications of overall behaviour are more important than the accuracy of the predictions. This approach ensures that only those model parameters that can be estimated from the data are included in the model. Simplified models are thus developed that are designed for specific applications where the required input data exist and the parameter values can be estimated. There are a number of approaches to model identification and parameter estimation the choice of which depends on the type of model employed i.e. steady-state or dynamic, stochastic or deterministic. Recursive estimation techniques are useful for identifying model structure by allowing the examination of the variation in parameter values over the period of simulation. Genetic algorithms have been used successfully for problem specific parameter estimation. Monte Carlo simulation is a robust technique for undertaking generalised sensitivity analysis, i.e. determining which parameters have most influence on model behaviour.

In summary, process modelling should be kept a simple as possible whilst producing the results to accuracy required.

WORKS DESCRIPTION PRIOR TO MODIFICATION

The works studied was a small extended aeration activated sludge plant serving an equivalent population of about 1,850 in the UK. The final effluent standard was 30 mg/l SS and 20 mg/l BOD for the whole year, and 10 mg/l NH_3 for the summer season (May to October). The works failed to comply with the SS and BOD limits in 1992. Early in 1993, Tynemarch undertook studies to investigate the causes of the observed process failure and propose solutions.

A process flow diagram is shown in Figure 1(a). Crude sewage flow was pumped to the inlet works for screening and then biologically treated in a compound extended aeration system where the outer chamber (840 m^3) forms the aeration tank and the inner chamber provides settlement (232 m^3 and 129 m^2). Clarified effluent was discharged into a Copabrush tank for tertiary treatment and then to the nearby stream.

The settled sludge was pumped into a high-level splitter box where the returned activated sludge (RAS) and surplus activated sludge (SAS) flows were separated. RAS flow was returned to the aeration chamber and the SAS flow held in a storage tank prior to removal from site.

Flow to treatment was restricted to a maximum of 40 l/s. Flows in excess of this limit were discharged to the stream after screening.

The aeration system comprised two surface aerators (15 kgO_2/h each) and two venturi aerators (7.5 kgO_2/h each) located at equal spacing around the tank as shown in Figure 1(a). Normal aeration was provided by the surface aerators running at fixed submergence depth. The first venturi aerator operated when the DO level fell below 2.0 mg/l, and the second venturi aerator when the DO fell below 1.5 mg/l.

INITIAL PROCESS AUDIT/DIAGNOSIS

In March 1993, a process audit study was undertaken by Tynemarch to investigate the causes of non-compliance with the effluent quality discharge consent conditions. The following possible causes were identified:

Lack of Process Control

The average MLSS concentration of 1,625 mg/l was relatively low for an extended aeration plant. In contrast the RAS and SAS rates were high at 2.70 and 0.39 times the average flow. As a result the RAS and SAS had a low SS concentration of around 2,200 mg/l.

These conditions could be attributed to poor design and to the lack of controlled operation of the activated sludge recycle system. The desludging of the final settling zone suffered from blockages to the draw-off bellmouth. As a consequence the bell-mouth had been set at its lowest position giving the maximum rate of withdrawal. The activated sludge was then pumped to a high-level splitter box where the intention of the design was that the ratio of SAS:RAS was to be controlled manually. This feature of the design was very difficult to operate and was considered to be both unreliable and energy inefficient.

Lack of Aeration Control

The aeration tank was generally over-aerated due to a lack of control. A survey of the DO profile around the tank indicated a DO of 4 to 5 mg/l immediately downstream of the surface aerators falling to 2 mg/l upstream. The surface aerators were set at a fixed immersion depth and the venturi aerators used for DO control. However, the automatic control system was reported to be unreliable, and the venturi aerators were in constant operation. The DO probe was set at a depth of about 1m below the surface and maintained on a weekly basis. Previous attempts to control the DO level by varying the immersion depth (by adjusting the outlet weir height) had led to serious surging problems in the flow to the final tank producing high effluent solids.

Poor Sludge Settleability

Poor sludge settleability was identified as the main cause for solids failure in the final effluent. Process calculations indicated that the settling tank could accommodate mixed liquor suspended solids (MLSS) concentrations of at least 2,000 mg/l for the maximum inflow rate of 40 l/s, a RAS rate of 450 m^3/d (1.5 x average flow) and an assumed sludge settleability of an SSVI of 100 ml/g. This contrasted to the typical operating MLSS concentration of 1,625 mg/l or less. Poor sludge settleability was attributed to the combination of both high RAS rates and over-aeration. Visual inspection of the sludge indicated pin-point floc.

Rising Sludge in the Final Settling Tank

The long retention in the final settling tank (FST) of approximately 18 h at average flow, combined with the lack of any anoxic activity in the aeration tank were the most likely causes of rising sludge. The general appearance of the FST was poor with a high concentration of suspended floc. The MLSS also appeared to be of poor quality and there was no established sludge blanket due to the high underflow rates, (RAS+SAS). The feed to the FST was from the section of the tank having the lowets DO which would increase the tendency for denitrification to occur in the FST.

In summary the recommendations of initial process audit were:

- improved aeration control
- reduced RAS and SAS rates

* introduction of pronounced DO profile around the aeration tank
* feed the FST with aerated MLSS

IMPLEMENTATION

In May 1993, a follow-up study was undertaken by Tynemarch to identify the most practicable means of implementing the above recommendations. The suggested modifications to the process are described briefly below and summarised in the modified process flow diagram, Figure 1(b).

Aeration of the Feed to the Settling Tank

The diversion of the feed pipe to the settling tank from upstream to downstream of the surface aerators to ensure that the feed to the settling tank was well-aerated to inhibit the onset of rising sludge.

Improved Control of the RAS and SAS Rates

A modification to the sludge recycle and surplussing system was proposed. It was recommended that the existing two pumps be used to pump a constant RAS rate of 300 m^3/d (about 1.0 x average flow) directly to the aeration tank, and that an additional smaller pump be used to pump the SAS flow to the sludge thickener. The existing high-level splitter-box would no longer be required.

Introduction of a pronounced DO profile around the aeration tank

A mathematical model was constructed to predict the DO profile around the aeration tank, calibrated using the DO profile data collected during the Summer of 1992, Figures (2) to (4). Modelling the DO around the aeration tank for a number of configurations demonstrated that low DO conditions could be induced in about 25% of the aeration tank without introducing baffles by:

* modifying the use of the current aeration equipment and;
* diverting the feed and RAS flows to a point three quarters distance round the tank downstream of the main surface aerators.

The aeration tank was represented in the model by a number of completely mixed tanks in series with a mass balance through each equivalent tank. No mixing was assumed between the hypothetical tanks. Conventional Monod kinetic equations were assumed for the degradation of BOD and NH_3. The DO was assumed to be a function of the MLSS concentration and the removal BOD and NH_3. The return of oxygen from de-nitrification was ignored as it was thought that relatively little de-nitrification was likely to occur.

The model was used to identify the most effective location for the influent and RAS return to achieve the desired DO profile as discussed above. The best use of the existing aeration equipment to achieve this profile was as follows:

* one surface aerator only during average loading conditions.
* all surface and venturi aerators during maximum loading conditions.
* one surface aerator during minimum loading conditions to maintain mixing requirements, although low DO conditions would not be achieved to the extent desired.

The use of two DO probes instead of one was recommended for aeration control and set-points proposed.

IMPLEMENTATION PROGRAMME AND PERFORMANCE IMPROVEMENTS

The modifications to the works were completed as follows:

01/06/93	installation of new variable speed sludge pumps.
23/08/93	diversion of the feed pipe to the aeration tank.
01/11/93	diversion of the feed pipe to the settling tank.

The plant status before and after modifications is summarised in Table (1). The effluent quality parameters and MLSS are displayed in Figures (5) to (11). The graphs show a significant improvement in performance after the works was modified. The average BOD, SS and NH_3 concentrations decreased by 63, 47 and 86% respectively and remained consistently below their respective consent limits.

There was an apparent reduction in crude sewage quality (about 20% in BOD load), but this alone would not account for the observed improved performance. Some of this reduction would have been due to the lower load from supernatant liquor return as a result of the smaller surplus sludge volumes with a higher concentration.

A MLSS of around 3,000 mg/l was maintained following the modifications without solids carry-over, Figure (8), which is an indication of the improved sludge settleability, although no SSVI data were available to confirm this supposition. The reduced the average F/M ratio from 0.08 d^{-1} to 0.05 d^{-1} which is more usual for extended aeration plants.

END POINT

Most commercially available process modelling software packages are not well suited to applications to solve operational problems due to the large amount of data required and the difficulty in estimating appropriate parameter values.

Simplified process models can be used to assist in the diagnostics of commonly encountered problems, such as identifying the most effective means of achieving dissolved oxygen profiles in activated sludge plants, including modifications to the inlet and outlet arrangements, together with the implementation of better aeration and process control.

With respect to the case study described the works achieved 100% compliance with the effluent standards for the period monitored of 1.5 years after the modifications were implemented.

Table (1) - Average Plant Status Before and After Modification

	Apr 92 to May 93	Jun 93 to Oct 94	Difference (%)

Crude sewage			
Flow (m^3/d)	303		
BOD (mg/l)	374	304	-19
SS (mg/l)	380	321	-16
NH_3 (mg/l)	51	57	+10
COD (mg/l)	769	644	-16
Control parameters			
RAS rate (m^3/d)	830	300	-64
SAS rate (m^3/d)	118	75	-54
Process parameters			
MLSS (mg/l)	1,625	2,752	+52
F/M ratio (d^{-1})	0.08	0.05	-37
Sludge age (d)	5.2	7.1	
Final effluent			
BOD (mg/l)	11.8	4.4	-63
SS (mg/l)	24.3	13.0	-47
NH_3 (mg/l)	2.2	0.3	-86
NO_2 (mg/l)	0.6		
NO_3 (mg/l)	27.4		
COD (mg/l)	63.5	48.3	-24

DISCUSSION

Question **John West** **Birmingham University**

Did you look at nitrate modelling?

Answer

Nitrate modelling was not included as it was judged as being unlikely that significant denitrification would occur with the modified DO profile. Our approach to modelling is to only include phenomena that have a clear influence on system behaviour.