LUND UNIVERSITY

Automatic Control in Combinded Wastewater Treatment Plants

Olsson, Gustaf

1978

Document Version:
Publisher's PDF, also known as Version of record

Link to publication

Citation for published version (APA):
Olsson, G. (1978). *Automatic Control in Combinded Wastewater Treatment Plants*. (Technical Reports TFRT-7141). Department of Automatic Control, Lund Institute of Technology, Lund University.

Total number of authors:
1

CODEN: LUTFD2/(TFRT-7141)/1-010/(1978)

AUTOMATIC CONTROL IN COMBINED WASTEWATER TREATMENT PLANTS

GUSTAF OLSSON

Department of Automatic Control
Lund Institute of Technology
May 1978

Dokumentutgivare
Lund Institute of Technology
Handläggare Dept of Automatic Control
Gustaf Olsson
Författare
Gustaf Olsson

Dokumentnamn
REPORT
Utgivningsdatum
May 1978

Dokumentbeteckning
LUTFD2/(TFRT-7141)/1-10/(1978)
Ärendebeteckning
06T6

10T4

Dokumenttitel och undertitel
18T0
"Automatic Control in Combined Wastewater Treatment Plants"

Invited paper. International Environmental Colloqium,
Liège, May 16-19, 1978.

Referat (sammandrag)
26T0
Some problems in biological wastewater treatment control are discussed. The reason for control is disturbances, and some important operational problems are described. The control means available for an activated sludge process are considered. Available dynamical models are reviewed briefly and a survey of current practice in control is given.

Referat skrivet av
Author

Förslag till ytterligare nyckelord
44T0

Klassifikationssystem och -klass(er)
50T0

Indextermer (ange källa)
52T0

Omfång
10 pages

Övriga bibliografiska uppgifter
56T2

Språk
English

Sekretessuppgifter
60T0

ISSN
60T4

ISBN
60T6

Dokumentet kan erhållas från
Department of Automatic Control
Lund Institute of Technology
Box 725, S-2207 07 LUND 7, Sweden

Mottagarens uppgifter
62T4

Pris
66T0

DOKUMENTDATABLAD enligt SIS 62 10 12

SIS-
DB 1

Blankett LU 11:25 1976—07

AUTOMATIC CONTROL IN COMBINED WASTEWATER TREATMENT PLANTS

Gustaf Olsson

Department of Automatic Control
Lund Institute of Technology, Lund, Sweden

ABSTRACT

Some problems in biological wastewater treatment control are discussed. The reason for control is disturbances, and some important operational problems are described. The control means available for an activated sludge process are considered. Available dynamical models are reviewed briefly and a survey of current practice in control is given.

1. INTRODUCTION

The demand for control of sewage treatment plants has been recognized for several years. It is only in recent years, however, that an understanding of the majority of the treatment processes has become such that meaningful control algorithms can be written. In addition, few of the required sensors have been available in a sufficiently reliable and robust form.

Several factors have contributed to a rapid development of the control and instrumentation of wastewater treatment plants. Important causes are the increasing demand for high effluent quality as well as the ever increasing operating costs. The cost for on-line computers are now so reasonable, that advanced methods for process identification and control are realistic to apply. New sensors have made more elaborate process studies possible. With an increasing interest in process dynamics and with more methods and tools available much more insight into the dynamical behaviour of essential unit processes has been achieved.

Surveys of the development of automatic control and dynamic modeling in wastewater treatment processes have been made elsewhere, see e.g. Andrews (1974), Buhr et al (1975), and Olsson (1977). Two conferences have been organized by IAWPR around the theme of control and instrumentation in wastewater treatment, the last one, see IAWPR (1977).

The purpose of this paper is to emphasize some problems in biological wastewater treatment control. In section 2 some typical operational disturbances of a treatment plant are characterized. Because of such disturbances control and instrumentation is in demand. Most emphasis has been given to the activated sludge process, as it is the most important unit process in wastewater treatment. It also has a high potential for control. In section 3 some qualitative aspects of control actions are given. The possible actions are discussed, but no quantitative figures are given. Modeling of the activated sludge process is reviewed in section 4. Quantitative models are discussed, and it is demonstrated how different disturbances are reflected in the model equations. Current praxis in control of sewage treatment plants is discussed in section 5.

2. OPERATION PROBLEMS

It is well recognized by operating people, that a wastewater treatment is hardly ever in steady state. The influent flow rate or concentration variations are such that adequate control actions would be desirable all the time. Moreover, within the plant itself disturbances are created because of the coupling between different unit processes.

Hydraulic disturbances

The hydraulic disturbances are significant in amplitude. In a plant with a concentrated sewer network, the ratio between minimum and maximum flow rate can be as much as ten. In a larger plant with a more distributed network of sewers the ratio may typically be in the order of 1.5 to 2. The frequency of the disturbances has a wide spectrum. Diurnal, weekly, and seasonal variations may be relatively easy to predict. Often, however, shock loads from rain storms or melting snow may cause major operational problems. Because of the large variability of the influent, the control of a wastewater treatment plant has to be different than many chemical process control tasks. Quasi-stationary or linear methods are seldom adequate because of the large amplitudes of the disturbances.

Disturbances initiated within the plant also create significant operational problems. The primary pumps may cause major undesired hydraulic disturbances. If the primary pumps cannot be varied continuously, then the flow rate may change too abruptly when the pumps are switched on and off. This will sometimes upset the settler performance. No control action can damp such a disturbance. One example is shown in Fig. 1.

The hydraulic load from back-washing of deep bed filters may be of the same order as the influent flow rate. Therefore the coupling between the operation of filters and an activated sludge unit has to be considered. An equalizing tank may be necessary.

The return sludge flow rate has a dual influence as a control signal of the activated sludge process. It will affect not only the sludge transport back to the aerator but also the hydraulic load to the settler. Therefore the return sludge control must be used with much care, see e.g. Cashion et al (1977).

Concentration disturbances

Concentration or composition changes often occur in phase with hydraulic disturbances. This of course amplifies the total load variation to the plant. Industrial effluents may cause significant shock loads to a plant. Sometimes there are very strong influent streams of biodegradable organic waste, sometimes there are toxic loads. It is quite evident, that a control system must distinguish at an early stage between the different types of loads. From the plant itself supernatant from digesters or centrifuges is a significant source of concentration disturbances.

Many concentration disturbances appear as shock loads, added on top of the diurnal variations. This makes early prediction of the loads very desirable. The number of components in the influent wastewater is so large and their concentrations sometimes so small, that the concentration measurement problem is almost prohibitive. The large flow rate makes it very difficult to achieve representative samples of the liquid. Only a small fraction of the relevant variables can be measured. Moreover, the measurement delays are sometimes so large, that proper control actions cannot be taken in time.

Microbial changes

Microbial disturbances are important in the operation of wastewater treatment plants. Some of them are quite slow and cause only gradual changes. Just the fact, that they are slow makes them difficult for manual control. The sources of microbial disturbances can be divided into different groups:

- Influent water composition
- Sludge production and sludge structure
- Formation of microbial products

If the influent water contains toxic components, the biological processes can be significantly disturbed. As a result of toxic influents the substrate elimination as well as the sludge floc formation are deteriorated. If the influent water contains oil, the sludge floc may absorb the oil and form a low-density aggregate of oil and water. This will cause poor settling properties, resulting in thin return sludge and high suspended solids concentration in the effluent.

Bulking sludge is a difficult problem arising in activated sludge systems. It can be observed in the settler, when the settling characteristics and the compactability are poor. This will make the effluent suspended solids concentration gradually too low.

There are two principal causes of sludge bulking. One is caused by the growth of filamentous bacteria, or organisms that can grow in a filamentous form. The other is caused by bound water in which the bacterial cells composing the flow swell through the addition of water to the extent that their density is reduced and they will not settle. An investigation of the extent of bulking sludge and its causes is in progress in England, see Tomlinson (1976).

An important cause for the growth of filamentous bacteria is insufficient or unsuitable addition of nutrients to the activated sludge. If the nutrient concentrations are too low, then the growth of floc bacteria is limited. Because of a different relation between surface and volume for filamentous bacteria, their growth will be favoured compared to floc bacteria. It has been observed, that bulking sludge appear more seldom in plug flow reactor systems. The reason for this would be, that the nutrient concentration at the initial contact between sludge and influent water is higher compared to a complete mix reactor system, see Jenkins et al (1976).

Limited DO concentration has been noted to be a major cause of bulking. This can also be explained by the geometry of the floc, and filamentous growth is favoured at low DO concentrations.

In an activated sludge plant with nitrification the problem of rising sludge may occur. Sludge, that has good settling properties will be observed to rise or float to the surface after a relatively short settling period. This is caused by denitrification in the settler, in which nitrites and nitrates are converted to nitrogen gas.

Inherent control difficulties

There is an immense difference between the smallest and largest time constant in a wastewater treatment plant. In a non-linear system like this the word time constant is not adequate, and may be replaced by "response time". The response times for pumps, blowers, and similar equipment are less than a minute. Chemical flocculation also takes place rapidly. The oxygen transfer of gaseous oxygen to dissolved oxygen has a time constant in the order of 10 to 15 minutes. Typical hydraulic time constants are of the order several hours. The rapid uptake of substrate in a floc appear within 30 minutes, while the cell growth is a process over days and the endogeneous respiration even slower. Digestion of sludge takes weeks. On top of this, seasonal variations play a strong role, such as slow temperature and composition changes.

A conventional control system cannot solve the problem to attenuate the response of large disturbances into the system. The inherent nonlinearities are significant. Moreover, often quite elaborate decisions sometimes have to be taken which control variable to use for a certain measurement.

The lack of adequate sensors is and will be a major problem in wastewater treatment. Even if new sensors are developed still only a small fraction of all components can be measured. Moreover, some measurements are very difficult to perform automatically. No sensors can replace an operator's judgement of patterns of the sludge, of odors or of colours. Therefore any control system should be constructed in such a way that automatic measures are used to their limits. Any additional information from laboratory tests or manual observation then can be added in order to make more advanced control actions, see Gillblad and Olsson (1977).

The proper location of sensors is an unsolved problem. In an aerator the concentrations are not uniform along the tank. It is not self-evident where to locate DO or other concentrations sensors. Different locations give different sensititivity to disturbances, or different information to a controller. The spatial distribution of the processes give both practical problems (like the sensor location) and theoretical problems. The natural description of both a reactor and a settler is by partial differential equations, which of course gives a high complexity to the dynamics.

The different process disturbances appear quite differently in the modeling equations. Flow and concentration disturbances appear in the input variables of the equations. Other disturbances, like pH changes, toxic inputs etc. either change a parameter like the specific growth rate or cause other products to be formed, i.e. new equations are suddenly getting significant in the model. Such process changes are quite typical for biological processes. Therefore the reproduction of certain experiments is extremely difficult and it is difficult to achieve the proper knowledge of the relevant control actions for certain disturbances.

3. CONTROL OF DISTURBANCES

There are few control actions possible to damp hydraulic disturbances. Special hold-up tanks or trunk sewers can be used as equalization basins. However, it is not trivial to empty the tanks, as sedimentation may occur. Therefore the load from the equalization tanks must be considered carefully. In the design of the plant the primary pumps must be considered also from a control point of view. Not only the absolute value of the flow rate but also the flow rate change is an important factor for the settling behaviour.

The DO concentration is a crucial variable for the operation of an activated sludge process. It is of vital importance for the biological behaviour in the reactor, it affects the economy of the plant and it is strongly related to the mixing conditions in the reactor.

It is a non-trivial problem to determine the desired level of the DO concentration. In a non-homogeneous reactor there will appear a DO profile, and it has been shown, that this profile is intimately related to the biological reactions in the aerator, see Olsson and Andrews (1978). The consequence of this conclusion is briefly discussed later.

The limiting concentration for bacterial growth is quite different for different species. For floc forming bacteria it is larger than for filamentous bacteria. This is one of the causes for bulking sludge. Nitrifying bacteria has different limiting concentrations of DO than the Heterotrophs.

There is a complex dual relationship between mixing and DO concentration. The degree of mixing will naturally determine the DO, but it will also affect the floc size and formation. Therefore it is related to the causes of bulking sludge as well as changes of the dispersion in the hydraulics of the reactor.

The control of DO as a physical variable - as soon as the desired value is known - does not require any in-depth knowledge of the process. There are, however, several practical problems that appear in the implementation of a DO control system, which make the control non-trivial. The control authority of the actuators as well as the measurement handling are important factors to consider. Some of these problems and their solutions are discussed in Gillblad and Olsson (1978).

The information about the DO concentration is an important variable to indicate the organic, biodegradable load to the reactor. The DO concentration variations in time as well as in space give significant information in this respect.

With the return sludge flow the internal distribution of sludge can be affected in the reactor-settler system. It is conventionally used as a control variable for the control of organic loading. As the process is multivariable, a change in the return sludge flow rate will cause several outputs to change.

There is an immediate hydraulic change into the aerator, which in turn is changing the load to the settler. According to empirical experiences this will change the effluent water suspended solids concentration, see e.g. Pflanz (1968). The transport of sludge by the return flow has an upper limit, and the underflow concentration from the settler is related to the flow rate. Of course the sludge buffer - the sludge blanket - of the settler is changed by the return sludge flow. The control authority of the return sludge flow to meet organic loads is limited because of the opposing effects of sludge transport to the aerator and the increasing hydraulic load to the clarifier. These phenomena may compensate for each other, see Cashion et al (1977), so that no improvement is achieved.

With an increasing return sludge flow rate the hold-up time of sludge in the settler is changed. This may be a suitable control action to avoid denitrification and rising sludge in the settler. If nitrification occurs it may be possible to achieve denitrification in the aerator as well. The air flow distribution can be controlled so that anaerobic conditions will occur at the head end of the reactor so that denitrification may occur. The return sludge flow rate must be large enough, so that denitrification in the settler is avoided.

Step feed control has been recognized for a long time as a useful control strategy to manage certain hydraulic or organic disturbances to an activated sludge process, see Torpey (1948). The main idea is to transport the sludge within the reactor-settler system to the location where it is best needed. Typically the sludge is transported to the head end of the reactor.

Step feed control has been analyzed by Busby and Andrews (1975), Andrews and Lee (1972), and by Olsson (1975). It should be mentioned, that step feed control sometimes has been misunderstood. If only statical considerations are made, it can not improve the plant operation compared to e.g. a plug flow design. It must be used dynamically, i.e. to damp undesired disturbances by changing the flow pattern in the plant for a certain amount of time.

Control actions with step feed control have typical response times of several hours, i.e. the time it takes to re-locate the sludge in the system. Therefore, if an adequate control action should be made with step feed control it is needed to predict the disturbances. Step feed control can also be used to meet diurnal variations to the plant.

Four types of disturbances can be recognized, when it may be favourable to apply step feed control:

- large organic loads
- large hydraulic disturbances
- toxic loads
- bulking sludge

In order to meet an expected large organic load it would be favourable to store as much sludge as possible at the head end. When the load comes, the flow pattern should be shifted to a plug flow reactor, thus injecting more organisms to the feed. The sludge content of the reactor can be saved at major hydraulic disturbances. The feed should be inserted downstream into the reactor. The return sludge flow rate should be at a maximum. This will save most of the sludge at the head end of the reactor. Even if the cleaning result would be poor while the disturbance lasts it will save the plant. At a toxic disturbance the plant could also be saved by letting in the influent at a point towards the tail end of the reactor.

The step feed should be considered useful to prevent bulking sludge. As pointed out earlier, too low a substrate concentration may cause substrate limitation and favour the growth of filamentous bacteria. With the step feed the F/M ratio can be suitable changed to prevent undesired sludge conditions.

The waste sludge flow rate has a very slow impact on the behaviour of the plant because of the little flow rate, compared to the influent flow rate. The control action is noticed over days and weeks, but has a significant influence over the long term behaviour of the plant. Primarily the sludge age (or better, the specific growth rate) is affected. This in turn will determine which species will grow in the cultures. Nitrification is primarily affected by the waste sludge flow rate.

4. ACTIVATED SLUDGE MODELS

The understanding of the dynamics of the activated sludge process has increased rapidly during the last few years. Still, however, the knowledge is far from complete. It is not unusual to find significant variations in plant efficiency in a plant or between different plants. There are of course several reasons for this. There is insufficient understanding of many basic phenomena in the biological process, but also inadequate instrumentation, poor monitoring and knowledge of the influent flow characteristics, sometimes inadequate competence of the operating personnel.

It is important to emphasize, that the biological reactor (aerator) and the settler should be considered as one system, because of the strong interactions. The modeling of the activated sludged process has been developed along two lines. The first one is complex deterministic models, derived from basic knowledge of the physics, chemistry, and biology of the process. The second one is models derived from process identification on pilot or full scale plants.

Deterministic dynamical models

The purpose of seeking a deterministic or mechanistic model is to allow an explanation for the response of a process to variations in the input variables or parameters. If such a model can be determined, the response of the processes to input variables which cannot be examined experimentally due to equipment or time limitations, can be examined. Deterministic models nearly always have empirical qualities, and it is unlikely that a system as complex as a biological wastewater treatment plant will ever be described exactly by a theoretical model.

It is not the purpose of this paper to review the literature on complex dynamical models, as detailed reviews are found elsewhere, e.g. by Andrews (1974), Stenstrom (1975), Olsson (1977), Tyteca et al (1977). Particularly models for nitrification are reviewed by Murphy et al (1977), Sharma and Ahlert (1977), Poduska and Andrews (1974).

In the development of a structured model of the activated sludge process the following items have to be considered:

- the degradation of degradable pollutants, containing both organic carbon and nitrogen
- the solubilization of particulate degradable organic carbon
- cell growth and basal metabolism
- the oxygen requirements of the system

- the flow regime in the aeration basin
- the effect of secondary parameters, such as wastewater temperature, pH, and toxic substances

Reactor dynamics

In a structured model it is assumed that the organic substrate (or pollutant) is degraded into following steps:

(i) The substrate penetrates the cell membrane by a purely physicochemical process. The removed substrate is thus "stored" in the floc phase. This procedure can take place within 15-30 minutes if the cells are in the right condition.

(ii) The pollutants stored in the sludge are metabolized to give viable organisms. This synthesis phase is a process which has a response time of the order of days.

(iii) The organisms are degraded to inert mass through endogeneous respiration and decay. Typical time scale for the process is several days.

The number of state variables in a structured model tends to be extremely large, if an adequate description of the dynamics should be given.

It is sometimes adequate to represent the substrate in two forms, a soluble substrate phase and a part of collodial or suspended substrate. The latter parts need more time for the rapid uptake (i).

It is clear that there are several species of organisms present in an aerator. In many models the viable bacteria are only represented by one variable. It is normally assumed that the floc forming Heterotrophs could represent all species. If, however, bulking sludge phenomena should be described by the model, it should be necessary to include filamentous bacteria or dispersed bacteria. The growth of these types of species is favoured during oxygen or substrate limiting conditions.

The growth of Nitrosomonas and Nitrobacter can be sustained if the sludge age is long enough. Due to the metabolism of the nitrifying bacteria ammonium nitrogen is oxidized to nitrite and nitrate. Nitrate is the final oxidation state of the nitrogen compounds, and as such represents a stabilized product.

As the mixed liquor consists not only of viable bacteria, there has to be at least one state representing inert organisms.

The dissolved oxygen concentration is crucial for the operation of an activated sludge reactor. Its dynamics has to be included in the models if the oxygen control actions should be represented adequately. Moreover, the dissolved oxygen influence on the specific growth rates has to be considered carefully.

The concentrations of dissolved oxygen, substrates and organisms are generally spatially dependent. This distribution depends of course of the design of the reactor, and can vary from homogeneous concentrations (complete mix reactor) through dispersed plug flow reactors to the other extreme, purely plug flow.

Each one of the process variables can be suitably described by a diffusion equation of the structure

$$\frac{\partial c}{\partial t} = E\,\frac{\partial^2 c}{\partial z^2} - v \cdot \frac{\partial c}{\partial z} + f_1(c) - f_2(c),$$

where E = dispersion coefficient, v = stream velocity, c = c(z,t) = concentration (substrate, organism, oxygen), z = spatial coordinate, t = time, f_1 = production rate of element c per unit volume and time, f_2 = corresponding consumption rate.

A derivation of the diffusion equation above is found e.g. in Olsson and Andrews (1978). The boundary conditions of the equation are functions of the settler performance, and are consequently quite complex. There is a certain relationship between the head end and tail end concentrations, determined by the settler. The complicated boundary conditions make the simulation of the activated sludge system, described in this way, extremely complex.

The effect of wastewater temperature, toxic substances or pH will not change the structure of the model equations, but the growth and decay rate parameters will be changed. The temperature influence on bacterial growth is relatively well known, but normally the temperature is assumed constant in the models. A lot of research has been spent on the influence of pH or toxic substances on growth rate or decay rate parameters. In dynamical situations, however, the problem is very complex. The reactions of the different organisms for toxic inputs depend on the time scale. The bacteria can be gradually adjusted to different toxic inputs, why several changes are not exactly reproducible.

Reactor model simplifications

Before a model is developed its purpose should be made clear. All kinds of simplified models are found in the literature. In order to judge their relevance their use should be described. Any added complexity gives new difficulties, as more parameters are added. The verification of a fully structured model is an awkward problem, and very little verification work of such models has been done hitherto. Many dynamical models are derived to give a qualitative description of a process. The answers are in the right direction and the values in the right order of magnitude.

A model with only two states, substrate and living organisms, can show the basic metabolism. It cannot, however, describe oxygen limitation, which most often appears in a plug flow reactor at the head end. If a contact stabilization or a step feed reactor should be described adequately, then the rapid uptake must be taken into account.

If bulking sludge should be predictable in a model, then filamentous bacteria must be included in the model. Sometimes nitrification must be considered, even if the model purpose should not be to describe the removal of ammonia nitrogen. Nitrification will significantly affect the oxygen demand. In order to achieve a proper aeration both nitrification and carbonaceous removal has to be considered. Nitrification and denitrification must be considered if rising sludge should be explained.

The flow regime of the aerator is complex, and quite seldom it would be sufficient to describe a reactor with complete mix or a plug flow. Often it seems to be adequate to represent the aerator by four reactors in series. This is quite a good approximation of a long reactor, a fact which has been analyzed in Olsson (1975).

Settler models

Also for the settler a whole spectrum of models can be derived. The simplest one considers the underflow concentration constant, independent of any disturbances or changes of the return sludge flow rate. In another approach there is a constant compaction ratio between the feed and the underflow concentrations. Such a model is inadequate for dynamical changes, and quite unrealistic results can appear, see Gustavsson (1977).

A common model approach is based on the zone settling theory, see Kynch (1952). The basic assumption is made, that the settling velocity depends only on the local concentration of sludge. The vertical sludge mass transport in the settler consists of two components, one being the settling of the sludge relative to the fluid, the other the bulk movement caused by the underflow. A mass balance can be set up, showing the sludge concentration distribution in along the vertical axis of the thickener,

$$\frac{\partial c_s}{\partial t} = - f_s(c_s) \frac{\partial c_s}{\partial z_s}$$

where c_s is the sludge concentration and z_s the vertical distance in the settler. The function $f_s(c_s)$ is a nonlinear function of the sludge concentration and corresponds to the total flux velocity. The boundary conditions are obvious. The bottom of the separator represents a physical boundary to sedimentation. Therefore, the settling flux at the bottom of the separator is zero. Moreover, the flux input to the settler is determined by the aerator tail end conditions.

It can be shown, that the mass balance model based on the Kynch assumption is not adequate for dynamical conditions. The reason is, that the sludge level is not a stable function of the load to the settler. There are two ways to overcome this dilemma. One is to include limitation in the parameters of the mass balance equations. The settler is discretized into a number of vertical spatial points and the partial differential equations are suitably approximated. The model is then constrained in such a way, that the concentrations at all points above the compression zone are kept from exceeding the concentration at the limiting flux, see Stenstrom (1975).

The other way - more complex but also more adequate - is to include not only mass balance but also momentum balance equations for the settling sludge. There is, however, an extremely complex problem to find out the true nature of the forces acting on the particles. The reason is, that the density of the sludge is so close to that of water. Therefore it is hardly possible to judge which forces are dominating, gravitation, friction, water displacement or other phenomena. A combined momentum balance and mass balance equation leads to a system with a stable sludge level. On the other hand it must be emphasized, that the parameters of the model are so difficult to obtain, that more empirical models probably must be derived.

Process identification

The field of process identification and parameter estimation has been developed rapidly during the last decade. Four specialized symposia have been arranged by IFAC (1967, 1970, 1973, 1976) and numerous papers on methods and applications have been published. The survey by Åström and Eykhoff (1971) and the textbooks by Eykhoff (1974) and Box and Jenkins (1970) give a comprehensive description of the methods available. The applicability of parameter estimation in wastewater treatment or water quality systems has been demonstrated. Reviews are given in Beck (1975), Olsson (1977), Sawaragi and Ikeda (1976), and Shih (1976). Here some general problems and results, particularly for activated sludge systems, will be presented.

There may be two reasons why quite few attempts have been made in wastewater treatment system identification. One reason is that sufficient data are seldom available. Although some plants have day-to-day composite samples available, it is still rare to find frequent grab samples on an hour-to-hour basis. Another reason is that many persons in the environmental engineering profession are not familiar with the statistical approach.

With more and more on-line computers being installed the potential for identification and control is steadily increasing. Most of the computers are still only used for data acquisition, but the available number of real data is increasing significantly. This fact was clearly demonstrated at the IAWPR (1977) conference on instrumentation and control.

Studies have been made to correlate the effluent filtered or total BOD from a plant to its influent BOD, mass flow, and flow rate at different plants in Wisconsin, USA, see Shih (1976). At first the results look quite discouraging, as a poor correlation between the influent characteristics and the effluent BOD are found. The parametric models have a poor quality. There are two important remarks to be made. First, the results demonstrate that the plant capacity is so large, that the influence of input variations to output variations is hidden by the noise in the data. This is a sign that the plant may be overdesigned. Secondly, there has been no or only little manipulation of the inputs. In order to achieve reliable results, the input amplitudes have to be large enough. Moreover the different inputs should be manipulated independently of each other. This is an awkward problem, and very seldom the influent stream concentrations can be manipulated.

The dynamics of dissolved oxygen (DO) in the aerator has been studied at the Käppala wastewater treatment plant near Stockholm, Sweden. The plant has a dry weather flow of about 1.3 m^3/sec. Details of the results are presented in Olsson and Hansson (1976a, 1976b). The following aspects of the DO dynamics have been examined:

- the hydraulic dispersion and transportation of DO in the aerator
- the transfer mechanism from gaseous to dissolved phase
- oxygen uptake rate due to sludge activity

The air flow rate has been manipulated. In the hydraulic experiments the influent flow rate was redistributed within the plant in order to get desired rate to the experimental aerator. The return sludge flow rate has been manipulated as well. The settler and clarifier dynamics have been examined in other experiments, see Olsson and Hansson (1976b). Typically the underflow concentration and the effluent concentration were identified as functions of flow rate, mass loadings to the settler, and the underflow velocity.

A typical representation of the model structure in the parameter identification is an autoregressive --moving average model (ARMA) like

$$A(q^{-1})\ y(t) = \sum_{i=1}^{p} B_i(q^{-1})\, u_i(t) + \lambda C(q^{-1})\, e(t),$$

where A, B, and C are polynomials in the shift operator q, while y and u_i are the output and the inputs, respectively. The disturbances are a sequence of independent Gaussian zero mean stochastic variables. The parameters in the polynomials can be identified with the Maximum Likelihood method.

The derived models are usually simple and contain few parameters. The parameters generally have no clear physical interpretation. Further, a weak aspect of the time series approach is a sense of too much empiricism because it does not take explicit account of the underlying mechanisms of the process under study. Therefore it is crucial to verify the identified model against a structured model. The two model approaches should certainly be considered as complements to each other. With a step by step verification by process identification there is a hope to improve the knowledge of the internal structure of such complex systems as the activated sludge process.

5. CURRENT PRACTICE IN CONTROL

There has been hardly any applications of control schemes derived directly from structured models. Most control strategies used in practice are either simple conventional control schemes of local loops or algorithms based on steady-state assumptions. A more detailed review can be found in Olsson (1977). Here a short summary of some applied control schemes for the activated sludge process are summarized. DO control is fundamental for the operation, not only conventional DO control but also the control of the shape of the DO concentration profile. Return sludge control and waste sludge control is also discussed.

DO control

When DO is controlled in an aerator with the air flow rate there are two types of methods that are dominating. In one the air flow rate is ratio controlled to the influent wastewater flow rate, without any other measurements being made. In the other scheme the DO concentration is controlled around a set point with a simple conventional PI controller. There are several commercially DO control systems available today.

Olsson and Andrews (1978) have suggested using the shape and position of the DO profile in the aeration tank to determine whether the supply of oxygen is adequate or in excess of requirements. By this technique the aeration tank is used as an on-line respirometer, and the oxygen supply is regulated directly according to the needs of the microorganisms present (specific oxygen utilization rate, SCOUR). Fig. 2 illustrates how the DO profile varies with the plant load in Enköping, Sweden. Corresponding dynamical changes of the DO profile are simulated in Olsson and Andrews (1977). The practical implementation of such a scheme has been realized in Gävle, Sweden, see Gillblad and Olsson (1977).

Return sludge control

In a previous section it has been discussed, that the control authority of the return flow is quite limited. If the recycle flow rate is controlled at all, the most common control is to vary the sludge recycle flow rate in proportion to the influent flow rate. This control strategy is of course far from optimal. It does not take concentration variations of the influent wastewater into consideration. Neither does it consider changes in the recycle flow concentration. Due to the limited control authority, however, constant recycle ratio seems to be a good strategy, according to simulations, see Briggs and Jones (1977) and Olsson and Andrews (1977). Alternatively the recycle rate should be the lowest rate that is consistent with the proper functioning of the final sedimentation tank. In fact, simulations suggest that only actions which do not create additional disturbances should be used on a continuous bases. The DO control is such a control method. The inherent ability of the biomass to minimize changes in effluent quality must be exploited as far as possible.

Organic load estimation

Although it is not strictly necessary for control purposes it may be extremely useful to measure the organic matter in the system. Today there are several commercial monitors available, such as COD, TOC, or UV monitors. The last one is based on the measurement of the ratio of the absorbance by the sample of light in the ultra violet and the visible part of the spectrum.

The aerator itself can be used as a respirometer to estimate the organic load. If the DO is controlled in one point, then the air flow variation is a measure of the load of biodegradable matter to the reactor. The DO profile shape is another way to estimate the specific oxygen utilization rate. In Gävle, see Gillblad and Olsson (1977), the respiration is calculated on-line in the computer from DO measurements.

Waste sludge flow rate control

The main objective of the waste sludge flow rate control is to keep the sludge age (or sludge retention time) at a desired value. Several control schemes, however, consider other variables for the control, because of simplicity. In one control scheme the sludge is wasted so that the mixed liquor suspended solids concentration (MLSS) is kept constant, in other words, the purpose is to keep the total mass of sludge in the system constant. If, however, the sludge concentration varies significantly in the aerator (as in a step feed system) or if the buffer volume of the settler is large, then a constant MLSS is a poor measure of the sludge mass.

Sludge is also wasted based on sludge blanket height measurements. Mostly on-off control is used to keep the height between desired limits. Sludge wasting is used also if poorly settling or bulking sludge is encountered, in order to prevent the sludge blanket level from rising too much. To waste sludge under bulking conditions may be a wrong control action, if the bulking sludge is caused by process overloading. By wasting the sludge, the total sludge mass in the system is further decreased.

Some proposed control schemes keep the recycle flow rate constant but vary the waste sludge flow rate in an attempt to keep the food-to microorganism ratio constant. Because of the small flow rate of the waste sludge such a strategy will have only a marginal influence in a short time scale on the sludge content of the aerator.

6. REFERENCES

Andrews J F and C R Lee (1972): Dynamics and control of a multi-stage biological process. Proc. IV IFS: Ferment. Technol. Today, 55-63.

Andrews J F (1974): Dynamic models and control strategies for wastewater treatment processes. Review Paper, Water Research, 8, 5, 261-289.

Åström K J and P Eykhoff (1971): System identification, a survey. Automatica 7, 123-162.

Beck M B (1975): Identification and parameter estimation of biological process models. In System Simulation in Water Resources (Ed. G C Vansteenkiste), North Holland, 19-44.

Box G E P and G M Jenkins (1970): Time-series analysis, forecasting and control. Holden-Day, San Francisco.

Briggs R, G L Jones (1977): Aspects of automation of the activated sludge process. Technical note, Water Research Centre, Stevenage, England.

Busby J B and J F Andrews (1975): Dynamic modeling and control strategies for the activated sludge process. J. Water Pollution Control Federation, 47, 5, 1055-1080.

Buhr H O, J F Andrews and T M Keinath (1975): Research needs for automation of wastewater treatment systems. Proc. of a workshop, sponsored by US EPA and Clemson Univ, Clemson, S.C., USA

Cashion B S, T M Keinath, and W W Schuk (1977): Evaluation of instantaneous F/M control strategies for the activated sludge process. Paper 82, IAWPR Int. Workshop on Instrumentation and·Control for Water and Wastewater Treatment and Transport Systems, London, May.

Eykhoff P (1974): System identification. Wiley.

Gillblad T and G Olsson (1977): Computer control of a medium sized activated sludge plant. Paper 62, IAWPR Int. Workshop on Instrumentation and Control for Water and Wastewater Treatment and Transport Systems, London, May.

Gillblad T and G Olsson (1978): Implementation problems for activated sludge controllers. Report TFRT-7137, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden.

Gustavsson G (1977): Comparison of different dynamical models of secondary sedimentation in biological wastewater treatment. Rep. TFRT-5190, Dept. of Automatic Control, Lund Inst. of Techn., Lund, Sweden

IAWPR (1977): Int. workshop on Instrumentation and Control for Water and Wastewater Treatment and Transport Systems, London and Stockholm, May.

Jenkins D, M Sezgin and D S Parker (1976): A unified theory of filamentous activated sludge bulking. Paper, Annual conf. of the Water Poll. Cont. Fed., Oct 4.

Kynch G J (1952): A theory of sedimentation. Transactions, Faraday Society, 48, 166-176.

Murphy K L, P M Sutton, and B E Jank (1977): Dynamic nature of nitrifying biological suspended growth systems. Prog. Water Tech., 9, 279-290.

Olsson G (1975): Activated sludge dynamics I. Biological models. Report TFRT-3121, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden.

Olsson G (1975): Activated sludge dynamics. Static analysis. Dept of Civil Engineering, Univ. of Houston, Houston, Texas.

Olsson G (1977): State of the art in sewage treatment plant control. AIChE Symp. Series No 159, 72, 52-76.

Olsson G and J F Andrews (1977): Estimation and control of biological activity in the activated sludge process using dissolved oxygen measurements. Proc. IFAC Symp. Environmental Systems Planning, Design and Control, Kyoto, Japan.

Olsson G and J F Andrews (1978): The dissolved oxygen profile - a valuable tool for control of the activated sludge process. Accepted for Wat. Res.

Olsson G and O Hansson (1976a): Modeling and identification of an activated sludge process. Proc. IFAC Symp. on Identification and System Parameter Estimation, Tbilisi, USSR, Sep., 134-146.

Olsson G and O Hansson (1976b): Stochastic modeling and computer control of a full scale wastewater treatment plant. Proc. Symp. on Systems and Models in Air and Water Pollution, The Institute of Measurement and Control, London, Sep.

Pflanz, P (1968): Performance of (activated sludge) secondary sedimentation basins. 4th Int. Conf. on Water Poll. Res., Prague.

Poduska R A and J F Andrews (1974): Dynamics of nitrification in the activated sludge process. Proc. 29th Ann. Ind. Waste Conf., Purdue Univ., Lafayette, Ind.

Sawaragi Y and S Ikeda (1976): Identification methods in environmental pollution problems. A survey of the researches in Japan. Proc. IV IFAC Symp. on Identification and System Parameter Estimation, Tbilisi, USSR, 169-189.

Sharma B and R C Ahlert (1977): Nitrification and nitrogen removal. Water Res., 11, 897-925.

Shih C (1976): Investigation of dynamic performance of wastewater treatment plants. PhD thesis, Dept of Civil and Environmental Engineering, Univ. of Wisconsin-Madison, USA.

Stenstrom M K (1975): A dynamic model and computer compatible control strategies for wastewater treatment plants. PhD thesis, Dept of Environmental Systems Engineering, Clemson Univ., Clemson, S.C.

Tomlinson E J (1976): Bulking - a survey of activated sludge plants. Technical report TR 35, Water Research Centre, Stevenage, England, Nov.

Torpey W N (1948): Practical results of step aeration. Sew. Works. Jour., 20, 781-788.

Tyteca D, Y Smeers, and E J Nyns (1977): Mathematical modeling and economic optimization of wastewater treatment plants. CRC Critical Reviews in Environmental Control, 8, 1-89.

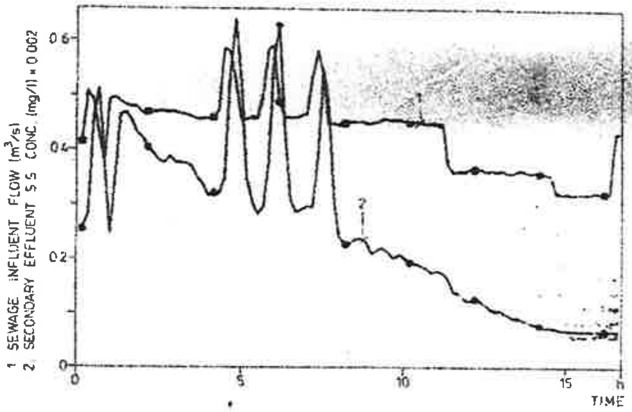

Fig 1. Influence of influent hydraulic shocks on the secondary settler suspended solids concentration. Experiment at Käppala, Stockholm.

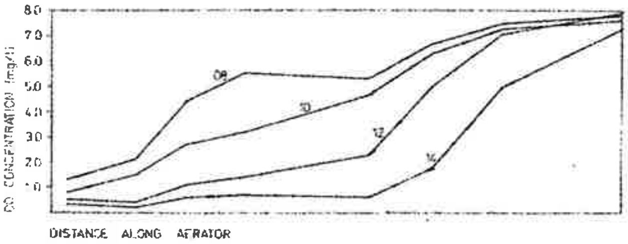

Fig 2. Influence of diurnal load variations on the DO concentration profile, without any control. Recordning from Enköping, Sweden.