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ESTIMATION AND IDENTIFICATION PROBLEMS IN WASTEWATER TREATMENT

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Abstract

Wastewater treatment systems are excellent examples of highly complex, distributed, nonlinear systems. The characterization of the influent wastewater in terms of flow rate, composition and concentrations is considered. Sensor problems, the need for prediction as well as control of sewer flows are discussed. An activated sludge plant is chosen as an example of biological treatment systems. Modeling compromizes, instrumentation problems are illustrated and identification results are shown. It is discussed how estimation theory can help to overcome some of the shortcomings of current instrumentation.

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1. INTRODUCTION

The concern about environmental quality has contributed to the increasing interest in the control of wastewater treatment processes. More strict regulations have been stipulated by the regulatory agencies. The investment costs for wastewater collection and treatment systems are enormous and it is therefore desirable to use the systems as efficiently as possible. The operational costs have risen rapidly due to increasing costs for power, chemicals and salaries.

It ought to be emphasized that the wastewater treatment system is part of a larger water quality system, if an adequate systems analysis should be successful. The coupling from the sewer system to the treatment plant and further to the receiving water must be considered. There is a trade-off between the operation of the collection system and the treatment plant which is by no means negligible.

This paper will present unsolved problems as well as some recent advances in estimation, modeling and identification of treatment systems in particular. Some developments are illustrated by case studies at a full scale activated sludge plant.

The paper is organized as follows. In section 2 the problems of measurement, prediction and control of sewer network flow rates are discussed. The influent stream water quality is reviewed in section 3. Problems on biological process modeling are discussed in section 4 with particular emphasis on an activated sludge system. The choice of model complexity and structure for different purposes is discussed to some extent. Parameter identification in biological systems is described in section 5. It is illustrated from a case study of a full scale activated sludge plant. The combination of measurements and estimation algorithms is mentioned in section 6. Some conclusions are summarized in 7.

2. SEWER AND PLANT INFLUENT FLOW RATE

From a treatment point of view a sewer network system should be operated in such a way that flow rate and water quality changes could be early predicted and the influent flow rate to the plant could be controlled within certain limits.

Most of the disturbances to a wastewater treatment plant are related to the influent flow rate, composition, or concentration changes. The flow rate of the feed stream can vary significantly in contrast to many other areas of process control. In a small plant with a concentrated sewer network the ratio of peak to minimum flow rate can be as much as ten. In a large plant with a more distributed network of sewers this ratio is more limited, but still it is large enough to create significant flow rate disturbances of the operation. Therefore linear dynamic models are seldom adequate.

Hydraulic variations can appear in vastly different time scales. A rainstorm or melting snow can create a shock load to a plant within hours. Therefore these disturbances must be controlled quite differently compared to diurnal or seasonal variations.

2.1 Measurements

Even if flow rate is a physical variable it is not a trivial task to measure it with good precision and high reliability. In particular storm-water flow rate measurements pose special problems. An acceptable storm-water in-sewer flowmeter must overcome a lot of obstacles like high transient flows, large operating ranges, high suspended solids and frequent collisions with large debris. Consequently, more suitable flowmeters need to be developed, see Molvar (1975).

From a control theory point of view some contributions can, however, improve the situation. The possibilities to systematically use filtering theory to achieve better flow rate measurements have not been fully explored. For example, flow rates are often measured by differentiating level measurements in a sewer tunnel. As the level variations may be quite small but noisy the resulting flow rate value is quite unreliable if the signals are not filtered properly.

2.2 Predictions

Flow rate prediction in a sewer network is important for many reasons:

- the inflow to the sewer network must be predicted in order to make the proper routing of flows across the network,
- the outflow from the sewer network must be predicted with a lead time for adequate control actions in the wastewater treatment plant.

It is quite natural, that the problem of sewer network modeling and control is similar to that of a river system for hydroelectrical power generation. A sewer network has a large number of input flow sources and is generally distributed over a large area. The flows are collected into few or maybe only one large trunk sewer, that enters the treatment plant.

Rainstorms, melting snow and infiltrations can create major changes in the sewer network flow rate. In a large system also the local variations in rainfall must be taken into account. In order to predict the sewer inflow several models have been developed during many years. Most of these models are extremely complex and mostly deterministic, see e.g. Chen and Shubinski (1971), Papadakis and

Preul (1973) and Offner (1973). Actual applications are found in the cities of Seattle (see Leiser (1974)) and Cleveland (see Anderson and Pew (1974) and Pew et al (1973)) in USA.

It is not self-evident, that the complexity of the urban run-off or storm-water models should be as large as in the mentioned papers. The possibility to model the stochastic nature of the phenomena has not been fully explored. Still the structure of the deterministic part of the model has to be retained. A good example of a mixture of deterministic and stochastic elements in such a model for a river system is found in Lorent and Gevers (1976).

The prediction of rainfall or urban run-off into a sewer system has to be improved in many places. There is an increasing interest of radar measurements in order to predict the travel direction and the intensity of rainfall, see Cole (1976). Typically short-term predictions (1-2 hours) are desirable for the sewer operation. Also more long term predictions are desirable from a treatment plant operational point of view. If the influent flow could be predicted 8-10 hours ahead the plant operation could be better prepared by rerouting the flows within the plant. In an activated sludge plant step feed control then would be appropriate. (See further section 4.)

2.3 Control

There is a tremendous difference in the operation between different wastewater collection systems. Most of them are not operated or controlled at all except some local pump control stations.

In an advanced sewer system there are several objectives for control. They are mainly related to the hydraulics:

- o the storage capacity of trunk and interceptor lines within the network should be utilized so that overflows caused by storm inflow are reduced or eliminated,
- o the daily flow should be regulated for the best operation of the treatment plant.

Other objectives from a water quality point of view are:

- o overflow points should be selected to cause the least harm to receiving waters, when overflows cannot be avoided,
- o early warning of exceptional water quality or toxic materials should be given to the plant operators.

The water quality aspects are further discussed in section 3.

In order to control a treatment plant for hydraulic disturbances different control actions should be taken depending on the amplitude of the disturbance, the length of it and the preparation time.

If a shock load caused by a rainstorm is entering an activated sludge plant three control actions are possible. If there is an equalization tank then it should be used of course even if the disturbance could be predicted for a long time (several hours). If there is no equalization tank (which is an expensive device) then some plants are equipped with step feed control facilities. This control, however, demands that the disturbance is known well ahead (longer than the hold up time of the process) so that the process flows could be redirected. The step feed control could damp out both the detremental effects of increasing hydraulic load and concentration load to the plant. If, however, only short term predictions of the flow rate could be obtained very little can be done. The flow rate must be accepted and the increasing hydralic load to the sedimentation tanks will create severe increases in the effluent suspended solids concentrations.

Fig. 1 gives an example how the secondary clarifier effluent concentration of a full scale plant will change due to a disturbance of the influent water flow rate.

3. PLANT INFLUENT WATER QUALITY

Wastewater is by no means a well-defined liquid. There is a great diversity of contaminants. In fact, this diversity is so great and the concentrations are so low that only a few substances exist at a measureable level.

If a significant part of the influent water contains industrial effluents the composition and concentration can vary rapidly and significantly. Toxic substances may appear without any warning. It is typical for many heavy metal or other toxic disturbances that their concentrations are so low, that it is either technically or economically infeasible to detect the substances momentarily. The impact is not observed until the plant performance has been affected.

It is not possible to measure all different contaminants in the wastewater. Therefore it must be made clear what is the ultimate impact of different contaminants on the process operation and on the receiving water. This type of total systems analysis must be emphasized.

Most of the water quality measurements are performed by analytical instruments. They can be divided into two main groups:

- o in-stream sensors or electrodes which generate an analog signal of the variable measured,
- o automated wet-chemistry, which samples a quantity from the flow stream.

It is clear that the instrumentation cost must be related to the importance of the actual variable. Moreover, particularly for automated wet chemistry, each measurement will cost money. The sample is subject to an automated laboratory procedure, requiring reagents. The problem to allocate resources for measurements as well as control in case of measurement costs has been considered by several authors. In most cases it is assumed that no time lag is present, see e.g. Cooper and Nahi (1971), Kramer and Athans (1972), Aoki and Li (1969) and Meier, Peshon and Dressler (1967). The measurement lag could most often not be overlooked. Even if the automatic laboratory procedure may be rapid, a certain amount of time will elapse before the measured value is recorded. Olgac et al (1976) have considered the problem of river reaeration. BOD measurements are assumed to be costly and time consuming. The question is therefore whether resources should be expended upon the aerator actuation or upon BOD measurements in order to achieve the greatest improvement of the water quality.

Early detection of toxic materials is crucial. The most reliable way is of course an adequate instrumentation at each potential influent point in the sewer network, see Andrews and Olsson (1976) for more details. This is, however, not always economically feasible. Because of the great dilution in a combined sewer tunnel the instrumentation is a great problem in itself, as mentioned before.

The sampling rate of measurements is particularly interesting for toxic materials. There is always a trade-off between the measurement costs and the cost of undetected violations to the process and ultimately to the receiving water. Problems falling in this category have been investigated by Brewer and Moore (1974) and Pimentel (1975). Therefore the total performance index should take both these costs into consideration. Such a multiobjective analysis has been treated extensively in theory, see e.g. Kaplan et al (1975) but hardly any of these theories have been applied hitherto to treatment systems.

The concentration variations in the influent stream can have quite different time behaviour. There are rapid shock disturbances as well as diurnal, weekly and seasonal variations. In order to achieve a suitable sampling rate the stochastic nature of the concentration variations must be taken into consideration and deterministic models are by no means sufficient. Again the necessary lead time from the warning to the process depends on the character of the contaminant as well as the concentration amplitude.

Different control actions in a wastewater treatment plant have quite different time responses (see also next section). Depending on which control action is necessary for a certain load disturbance (expressed in terms in influent flow rate and concentration) different lead times are necessary. Dissolved oxygen control needs just a few minutes prediction, while step feed control will need a lead time of several hours. To change the total mass of organisms in order to meet higher loads will take several days.

4. BIOLOGICAL PROCESS MODELING

The understanding of the dynamical behaviour of biological sewage treatment processes is still far from complete. It is not unusual to find significant variations in process efficiency in a plant or between different plants. There are of course several reasons for this, such as insufficient knowledge of the basic phenomena, inadequate instrumentation, not always adequate competence of the personnel and significant variations of the process dynamics.

During the last few years extensive research has been spent to develope dynamical models of biological treatment processes, in particular the activated sludge process. This is by far the most important unit process for wastewater treatment in large systems. It typifies several problems which are general for biological systems. It is also a challenging process from a control engineer's point of view.

4.1 The activated sludge process

In the activated sludge process microorganisms react with the organic pollutants in the wastewater and with oxygen dissolved in the water to produce more cell mass, carbon dioxide and water. The aerobic environment is achieved by the use of diffused air or mechanical aeration or even by pure oxygen. In the latter case, the tanks are covered. The effluent of the reactor flows to a sedimentation basin, where the activated sludge is separated from the liquid phase, fig. 2. A portion of the concentrated sludge is recycled in order to maintain enough mass of viable organisms in the system and a reasonable food to mass ratio. Part of the settled sludge is wasted. The process effluent consists of the clarified overflow from the settler tank.

Because of the recycle of sludge the biological reactor is inseparable from the settler. The recycle serves the purpose of both increasing the concentration of microorganisms in the aerator and maintaining the organisms in a physiological condition, such that they will readily flocculate. However, recycle also results in difficulties in understanding and modeling the process since it creates a feedback loop, thereby causing a strong interaction between the aerator and the settler.

Sophisticated models of the biological part of the process are now developed. Reviews can be found in Andrews (1974), Buhr et al (1975) and Olsson (1976). The settler models have not yet attained the same degree of sophistication as the biological reactor models and lack some fundamental properties due to the coupling forces between the settling particles or flocs in the thickener, see further Keinath (1975), Fitch (1975) and Stenstrom (1975).

Generally the activated sludge models are very complex and describe the dynamics in a deterministic way from physical basic laws, essentially mass balances for each component. The reactor design can be a complete mix type, several subreactors in series, or a long channel-system. Consequently the hydraulics has to be modeled to fit the aerator flow pattern.

The models still lack verification in pilot plant or full scale operation and this remains an awkward problem. At best the models available are semi-quantitative, i.e. the responses are in the right direction and have the right order of magnitude.

In a structured model it is assumed that substrate (or pollutant) is degraded in the 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 (cells) 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 this process is several days.

4.2 Model structure and complexity

A mathematical model is a representation of a system that retains only the essential elements of that system in such a way as to allow prediction of the behaviour of the system for a particular purpose. The key words here are essential elements, prediction and purpose.

It is quite natural that the model complexity should be quite different for different prediction and control purposes. The questions of complexity are discussed here from the following characteristics:

- o choice of state variables
- o time scale
- o nonlinearities
- o spatial distribution
- o adaptivity

State vector size

The state vector of a biological system should contain both pollutant and organism concentrations. It is quite clear that different organisms feed on different types of pollutants. Morever only certain parts of the substrate are biodegradable and some are not. Therefore the representation of the substrate must be complex enough to reflect this fact. The living organisms must generally be represented by two or more state variables. Sometimes new species appear such as filamentous organisms, dispersed bacteria or ciliated Protozoa. All of them have different settleability properties. Even if their synthesis rates may be weighted together, in a model their relative concentrations will vary due to the coupling between the biological reactor and the settler.

The size of the state vector may vary with time. Organisms may be killed by toxic pollutants. Certain species of organisms may grow very fast while other types of organisms may stop growing. This state vector change is generally extremely difficult to predict and is intimately related to the feed water composition.

Still another problem is connected to the fact that the feed water composition changes. Not only the concentration but also the physiological state of the microorganisms in the process may be time varying. Their response to changes may reflect past conditions as well as the present one. In other words, the state vector of the system must include not only present organism concentrations but also variables, that reflect how these concentrations have been reached - the history of the organisms. This fact has been recognized for several years by biochemists, see e.g. Powell (1967).

In some control schemes a detailed process description is not necessary. For dissolved oxygen control or mixed liquor suspended solids control much simpler models will suffice. If, however, bulking or rising sludge appear in the settler more complex actions must take place.

When the settling rate gets poor the sludge is said to be bulking. There are several causes for sludge bulking but one important cause is due to change of sludge composition, i.e. new organisms such as filamentous organisms with poor settleability properties may have been growing too much. This in turn depends on the feed composition, dissolved oxygen concentration as well as other physical and chemical conditions in the process.

Rising sludge is still another phenomenon, quite different from bulking sludge. Generally the sludge may have good settling properties but occasionally the sludge rises to the surface after a settling period. This is sometimes caused by denitrification in which nitrates and nitrites are converted into nitrogen gas. As nitrogen gas is formed in the sludge layer most of it is trapped in the sludge mass. If enough gas is formed the sludge may rise to the surface.

Nitrification in itself is a desirable process, because then the nitrogen content of the pollutant is reduced. It is made possible by the interaction of Nitrosomonas and Nitrobacter organisms. The nitrification process occurs only for long aerator retention times. If, however, nitrification is desirable, then the process must be modified so that denitrification can occur without causing rising sludge.

Time response

There is an immense difference between the smallest and largest time modes of a biological system. The response times for physical equipment like pumps and blower systems are less than a minute. Also chemical precipitation is very fast. The oxygen transfer of gaseous to dissolved oxygen takes place in about 15 minutes. Typical hydraulic response times for an activated sludge system are several hours. The rapid uptake of substrate into the cells can take place within 15 to 30 minutes, while the synthesis is a process over days. The endogeneous respiration is even slower. Anaerobic digestion of sludge typically operates over almost a month. On top of this there may be strong seasonal variations. The organisms are temperature sensitive, and therefore the control problem may look quite different in summer compared to winter in many countries.

Nonlinearities

Nonlinear characteristics of the dynamics appear frequently. Because of the large disturbance amplitudes linearizations are seldom adequate. In the biological reactions the rate coefficent is a nonlinear function of the substrate concentration. The settler is also a typical nonlinear unit process. The secondary clarifier in fig. 1 typifies this. The effluent concentration does not decrease for the negative step change of the hydraulic load but increases significantly for the positive step input.

Bilinear approximations of biological reactors can easily be derived. Because of the recirculation of activated sludge the product of the return sludge flow rate and the concentration of organisms appear in the state equation. In the dissolved oxygen balance equation there is also a bilinear behaviour of the oxygen transfer mechanism. It can typically be described by

$$k_1 u(c_s - c)$$

where

c = dissolved oxygen concentration

c_s = saturation value of dissolved oxygen concentration

$k_1 u$ = overall oxygen transfer coefficient

u = air flow from compressors

If it is assumed, as here, that the oxygen transfer coefficient is proportional to the air flow, then the bilinear character is obvious.

The analysis of a bilinear environmental system with respect to state observation has been made by Williamsson (1975). This model approach may be relevant for a laboratory process but is generally oversimplified for most full scale plants.

Spatial distribution

The concentrations of substrate, sludge and dissolved oxygen are in general space dependent in the biological reactor. In an activated sludge system with a dispersed plug flow reactor the profile of substrate or dissolved oxygen is showing significant variations along the aerator. Fig. 3 is a typical example. The information of such a profile can be used in order to achieve better control compared to conventional methods. This is further analysed in Olsson and Andrews (1976).

Because of the spatial dependence of the different concentrations the instrument location is crucial. As instruments are expensive and several variables very difficult to measure the choice of location should be analyzed carefully. Analysis of sensor location is made e.g. by Bar-Shalom and Cohen (1976) for an environmental surveillance system. For an activated sludge system some preliminary analysis of the instrument location is made in Olsson (1975).

The concentration of sludge in the thickening part of the settler is space dependent. It is crucial to know this distribution if the buffer capacity of the return sludge flow should be calculated. This buffer capacity determines the control authority of the return sludge flow variable.

Adaptivity

A biological system is generally much more complex than other physical-chemical systems because of its adaptive properties. It can adjust to certain disturbances, and therefore the dynamical properties may change in a slow time scale of the order of days. Typically a certain industrial pollutant entering the plant as a rapid and large amplitude pulse may kill some organisms. If the same amount of pollutant enters the plant gradually the organisms may adapt and use the substrate for their synthesis.

5. IDENTIFICATION OF BIOLOGICAL WASTEWATER PROCESSES

The field of identification and parameter estimation has developed rapidly over the past decade. Four specialized symposia have been arranged by IFAC (1967, 1970, 1973 and 1976) and numerous papers on methods and applications have been published. The review and survey paper by Åström and Eykhoff (1971), the textbook by Eykhoff (1974) give a comprehensive description of the state of the art. The applicability of parameter identification in water quality systems has been demonstrated in several publications. Recent reviews and surveys are given in Beck (1975), Olsson (1976) and in Sawaragi and Ikeda (1976). Here some general problems of identification in biological wastewater treatment systems will be given. Then some recent results of activated sludge system identification will be presented.

5.1 Special problems in biological systems

If a wastewater treatment plant is compared with other physical--chemical processes there are some major differences in the applicability of identification techniques. The most important ones are:

- o the influent flow rate, composition or concentration can seldom or never be manipulated,
- o instrumentation is a major obstacle,
- o the level of understanding of the underlying phenomena is often poor.

Unfortunately because of these restrictions very often only natural excitations - particularly of concentrations or compositions - can be observed. General and artificial disturbances are most often precluded. This tends to mean that normal operational records exhibit just one particular mode of process behaviour. There is a low signal/noise ratio. Routine measurement sampling rate may obscure some of the most important time constants for the system.

There are, however, in general better possibilities to perturb a wastewater treatment system than a river system, which will be shown in next section.

Data collection is an awkward problem. First it is a truly labour intensive affair of manual or automatic sampling followed by laboratory analysis. Because of the spatial distributions a large amount of sensor or sampling locations are needed to get truly representive data. Still - because of poor â priori knowledge of the model - the data acquisition may be inadequate.

5.2 Dissolved oxygen identification - a case study

The dynamics of dissolved oxygen in an activated sludge plant has been studied in a full scale wastewater treatment plant at Käppala in Stockholm, Sweden. The plant serves some 300,000 - 400,000 people of the northern suburbs of Stockholm. It was completed in 1969. The average dry weather flow rate is about 1.3 m^3/sec. The details of the results are presented in Olsson and Hansson (1976a, 1976b).

Dissolved oxygen (DO) dynamics is interesting from two reasons, the economic incentive and the relation between DO and the biological activity of the organisms. The DO dynamics contains four basic terms:

- o the hydraulic dispersion and transportation of DO in the reactor,
- o the transfer mechanism from gaseous to dissolved phase,
- o the oxygen demand from the cell synthesis,
- o the oxygen uptake due to endogeneous respiration.

Three of these phenomena have been studied in the identifications. The hydraulic properties were identified by manipulating the influent flow stream or the sludge recycle flow rate. The oxygen transfer could be studied by artificially disturbing the air flow from the compressors into the reactor tank. The oxygen uptake from cell synthesis could be manipulated by dilution of the mixed liquor. Then the suspended solids concentration and consequently the organism concentration was varied. This manipulation, however, was difficult to make and the input variation was too limited to give accurate models.

The fact that the time scales are significantly different of the different phenomena can be systematically used in the experimental planning. The oxygen transfer mechanism has a response time of the order 15 minutes. Therefore the synthesis or endogeneous respiration rates can be neglected during an air flow change experiment. On the other hand the oxygen transfer dynamics is considered instantaneous in a hydraulic experiment.

In order to estimate the model parameters Maximum Likelihood (ML) identification techniques have been utilized. By this technique both deterministic and stochastic parts of the models have been identified. This will give not only a meaningful physical interpretation of the parameters but also a measure of the model accuracy as well as the parameter accuracy.

In the model there are several time-varying parameters, and on-line parameter identification gives a possibility to track them. As an example, it is crucial to update the overall oxygen transfer coefficient - probably on a daily basis - if a good estimate of the biological activity (or the specific oxygen utilization rate) should be obtained.

Due to the measurement quality and the number of sensors the model complexity is in general quite low. As already mentioned it is extremely difficult to verify highly structured models. Such a procedure should demand a much more massive acquisition of data. More variables should be recorded in more spatial points. With the available low order models only relatively simple control laws could be derived.

A couple of examples may illustrate the results. Figs 4 and 5 show an experiment where the influent flow rate has been manipulated according to fig. 4. The flow rate changes have caused the mixed liquor suspended solids concentration to vary, fig. 4. Both these variables will affect the DO concentration. The identified model output (the deterministic part) is compared with the experimental DO in fig. 5. As a spin-off result the hydraulic dispersion in the aerator can be determined from a series of such experiments.

The identification of secondary thickener dynamics can illustrate another advantage with the identification procedures. The underflow concentration changes may be caused by several input variables, like influent flow rate, mixed liquor suspended solids concentration of the aerator as well as underflow rate. By systematic tests of different model complexities with different inputs the cause-effect relationships can be established and verified. It should be noted, that a systematic test of parametric models with different inputs give more accurate and reliable results than simple correlation analysis. In particular it was found in the Käppala experiments, that the influence of the influent water flow rate on the underflow concentration was negligible. The experimental result is illustrated by fig. 6.

6. MEASUREMENT AND ESTIMATION

As already mentioned the instrumentation problems in wastewater treatment are most often formidable. Therefore the possibilities for on-line parameter and state estimation should be better explored in order to overcome some of the sensor limitations. The papers by Brewer and Moore (1974) and Pimentel (1975) emphasize this point for more general environmental systems.

It should be emphasized that no sensor could replace the judgement of a good human operator and his ability for pattern recognition. It would be very difficult to detect settleability problems, rising or bulking sludge, the presence of certain organism species or certain odors with reliable sensors. It is probably not even desirable to replace the human operator in all his functions. Instead, the dynamical models should be constructed in such a way, that inputs from the operator observations easily could be inserted in a continuous operation.

The organism activity in a biological wastewater treatment plant is a crucial variable for the control and operation. It is taken here as a good example, where estimation can complement measurements. There has been considerable work devoted to establish measurement techniques of ATP or DNA concentrations as measures of the activity. There is, however, considerable disagreement in the literature of their value as a measure of sludge activity. However, there seems to be almost a universal agreement that the specific oxygen utilization rate (SCOUR) would be an indicator of biological activity in aerobic systems. The SCOUR parameter has been explored as a parameter for control purposes by Andrews et al (1974). It is intimately related to the growth rate of the organisms. The SCOUR can be related to the dissolved oxygen concentration. Therefore estimation theory suits nicely to get the biological activity from the relatively easy DO measurements.

Estimation procedures can also be used in a more systematic way in toxic pollutant warning systems. Toxic contaminants could be noticed in the early part of the process.

For the system analyst another problem area should be emphasized. Hitherto there has been too little sensor requirement studies in parallel with modeling, simulation and control system design investigations. There is today a lack of definition of necessary need of instrumentation, such as what measurements are really needed in order to exert effective control over the plant.

7. CONCLUSIONS

Dynamic modeling, real time prediction, estimation and control are still fairly new concepts for many sanitary engineers. The interest for the new tools available is, however, rapidly increasing.

The areas of prediction and estimation are probably the most profitable areas for control theory applications in the field of wastewater treatment systems. The instrumentation is a serious problem and will probably be for a long time. State variable and parameter estimation can contribute to overcome this dilemma.

The stochastic nature of sewer network flow rates and water quality variables should complement the deterministic descriptions. Better predictions are still needed both from a sewage network operational point of view and from the treatment plant point of view.

A better understanding of basic phenomena is needed. More work needs to be devoted to develope a family of dynamical models for different purposes. Identification and model building can be combined more systematically to make progress in this area.

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FIGURES

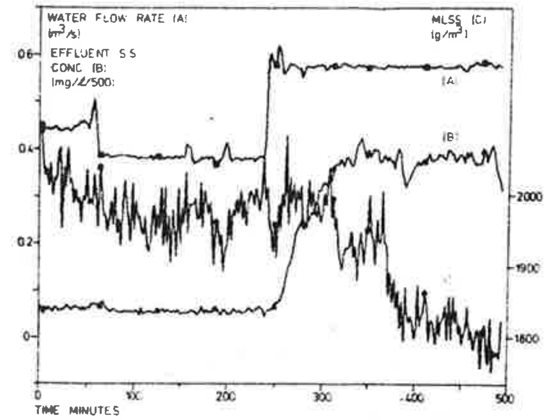

Figure 1. Input and output signals of a hydraulic experiment in a wastewater treatment plant. The water flow rate (A) has been manipulated, causing the effluent suspended solids concentration to vary (B). The MLSS concentration (C) is also affected by the water flow change.

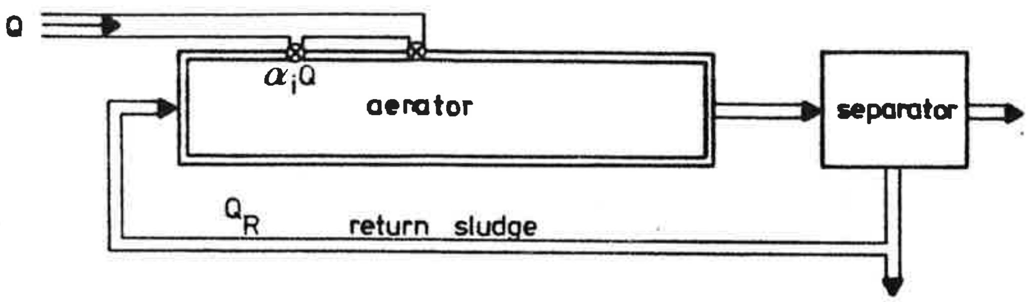

Figure 2. The activated sludge process.

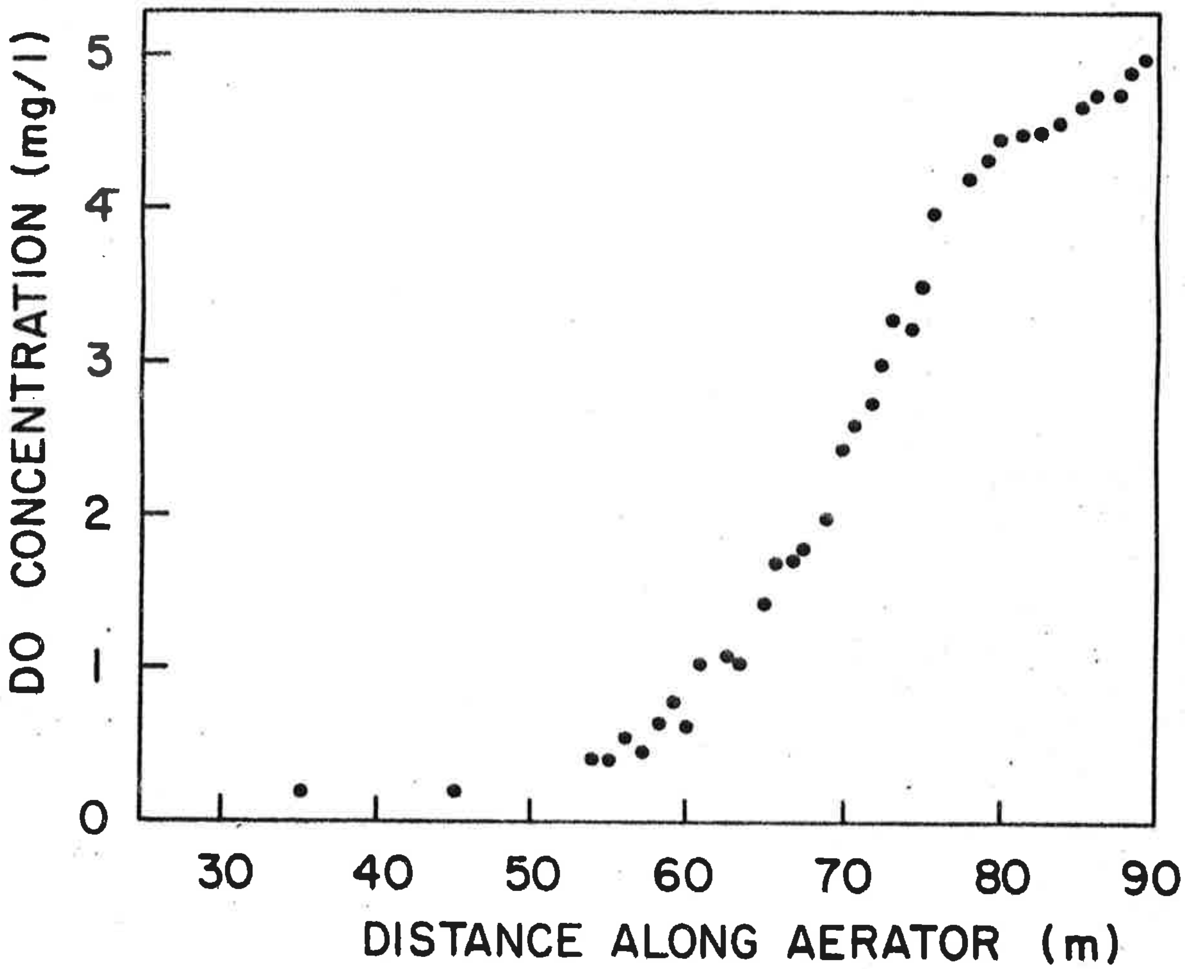

Figure 3. Typical profile of dissolved oxygen at the activated sludge process of the Käppala wastewater treatment plant, Stockholm.

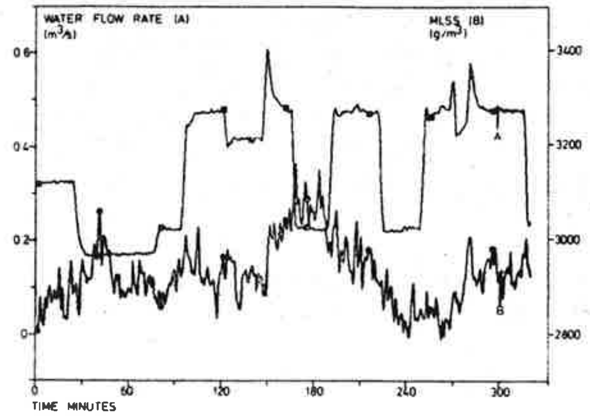

Figure 4. Disturbance signals of a hydraulic experiment in the Käppala wastewater treatment plant. The water flow rate has been manipulated, causing the Mixed Liquor Suspended Solids concentration to vary.

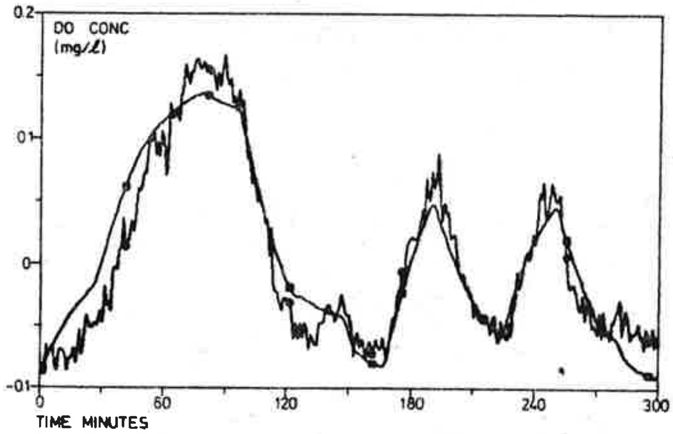

Figure 5. DO output from the experiment in fig. 4. The experimental DO output is compared with a first order model output. The water flow rate and the MLSS concentration (fig. 4) are the inputs.

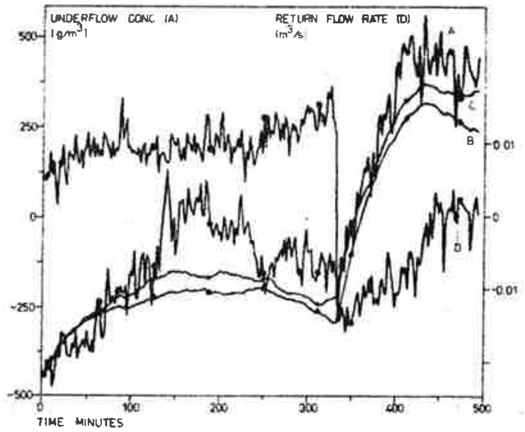

Figure 6. Input and output signals of a hydraulic experiment for the thickener identification. The return sludge flow rate (D) has been manipulated. The underflow concentration output is compared with two model outputs, only return flow rate as input (B), also Mixed Liquor Suspended Solids as input (C).