Implementation Problems for Activated Sludge Controllers

Gillblad, Tomas; Olsson, Gustaf

1978

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

Link to publication

Citation for published version (APA):
Gillblad, T., & Olsson, G. (1978). *Implementation Problems for Activated Sludge Controllers*. (Technical Reports TFRT-7137). Department of Automatic Control, Lund Institute of Technology, Lund University.

Total number of authors:
2

CODEN: LUTFD2/(TFRT-7137)/1-012/(1978)

IMPLEMENTATION PROBLEMS FOR ACTIVATED SLUDGE CONTROLLERS

TOMAS GILLBLAD
GUSTAF OLSSON

Department of Automatic Control
Lund Institute of Technology
March 1978

Dokumentutgivare
Lund Institute of Technology
Handläggare Department of Automatic Control
Gustaf Olsson
Författare
Thomas Gillblad
Gustaf Olsson

Dokumentnamn
REPORT
Dokumentbeteckning
LUTFD2/(TFRT-7139)1-12/(1978)
Utgivningsdatum
March 1978
Ärendebeteckning
06T6

10T4

Dokumenttitel och undertitel

Implementation problems for activated sludge controllers

Referat (sammandrag)

The paper describes some problems that appear in the implementation of a computer control system in a wastewater treatment plant. The problems are related to the control authority of the actuators, the influence of the process design on the controller design, or the disturbance pattern. Some experience from two full scale activated sludge plants in Sweden are discussed.

Referat skrivet av
Olsson

Förslag till ytterligare nyckelord
44T0

Klassifikationssystem och -klass(er)
50T0

Indextermer (ange källa)
52T0

Omfång
12 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
P O Box 725, S-220 07 LUND 7, Sweden

Mottagarens uppgifter
62T4

Pris
66T0

IMPLEMENTATION PROBLEMS FOR ACTIVATED SLUDGE CONTROLLERS

Thomas Gillblad
Datema AB
Nynäshamn, Sweden

Gustaf Olsson
Dept of Automatic control
Lund Institute of Technology
Lund, Sweden

ABSTRACT

The paper describes some problems that appear in the implementation of a computer control system in a wastewater treatment plant. The problems are related to the control authority of the actuators, the influence of the process design on the controller design, or the disturbance patterns. Some experiences from two full scale activated sludge plants in Sweden are discussed.

1. INTRODUCTION

In 1974 a research project was initiated with the purpose to develop and implement more advanced control in wastewater treatment plants. The project is a cooperation between the Datema AB and the Department of Automatic Control, Lund Institute of Technology.

The research has been emphasizing problems in the operation and control of the activated sludge process. There are several reasons that make this unit process an interesting topic for research. It is still the most important unit process of many plants. It has a potential for improved operation and can be manipulated in various ways. During the last few years the dynamics of the activated sludge process has been studied extensively, but the knowledge and understanding of the dynamical behaviour is still far from complete, see e.g. Andrews (1), Buhr et al (2) and Olsson (3). In several plants gross process failures can be observed, and even if these are avoided it is not unusual to find significant variations in the efficiency of the process. Such differences in efficiency can be observed, both within the same plant, on an hourly or daily basis, and between different plants.

The actual project has contained several phases. Mathematical models of the activated sludge process have been developed, analyzed and simulated, see Olsson (4 - 5). Process identification of the aerator as well as settler dynamics has been performed on full scale plants, see Olsson - Hansson (6 - 7). Control strategies have been tried out by simulation and later implemented in process computers in two plants. The first plant is the Käppala sewage works at Lidingö outside Stockholm, the other one is the Duvbacken wastewater treatment plant in Gävle.

For the first control experiments at Käppala the existing Siemens process computer was used. The dissolved oxygen (DO) concentration was controlled, see (7). In 1976 a small process computer LSI 11 was installed in order to obtain more flexibility in the measurement handling, error analysis and the control algorithms. The computer control has been tested for about half a year. In early 1977 a considerably more elaborated computer control system was installed at the Gävle plant, see Gillblad - Olsson (8). Now (August 1977) further operating experiences of that system have been gained.

The purpose of the paper is to discuss some practical considerations in the implementation of a computer control system in a plant. Many of the problems that appear are by no means unique for wastewater treatment plants. The combination of difficulties that appear, however, make the problems quite specific. One of the most important items is how the process design influences the design of the controller. The control authority of the control actuators is of particular interest. The success of advanced control strategies is crucially dependent of the input signal limitations. The disturbances also have a particular dynamical pattern in each plant.

The rest of the paper is organized as follows. In section 2 the actual controllers are discussed. The influence of the process design on the controller design is discussed in 3. The measurement handling and error correction problems are briefly mentioned in 4. Not only control algorithms have to be implemented in an advanced control system. A lot of logical decisions must be made before a certain controller can be initiated. Sometimes manual control must be actuated. This leads to the concept of operational stated, described in section 5. Some results of actual control experiments are discussed in 6. Section 7 summarizes the conclusions.

2. THE PURPOSE OF THE CONTROLLERS

An advanced controller should make use of the structure of the dynamics of the process. Even if the available models, particularly of the aerator, are quite elaborate, they have not been verified in detail quantitatively. Therefore it is a need to simplify the models to a reasonable complexity, which is easier to verify by practical experiments. Moreover, it is a desire to make the controllers as simple and robust as possible in the implementation.

In the paper two control schemes are discussed, DO control and by-pass control. In order to control the air flow to the aerator also the pressure must be kept within certain limits. Thus the DO controller is in cascade with a non-linear pressure controller. The DO controller itself is a PI regulator.

By-pass control must only be used when necessary. The decision if by-pass control should be initiated must be based on suspended solids mass balance calculations on the influent and effluent streams.

Return sludge control is also tried, but hitherto no definite conclusions have been made. The practical problems with this control however, are briefly discussed.

The operator interaction with the control system is of course important. The philosophy in the actual installations has been, that the computer should be able to detect certain disturbances without any specific information from the operator. On the other hand, if the computer should get information from the operator e.g. when a sensor is cleaned or a pump or blower is manually switched on or off, then the control action can consequently be improved.

5. OPERATIONAL STATES

Even with an advanced control system there are a lot of measurement and control tasks that cannot be implemented into a computer. A wastewater treatment system is an excellent example of a truly complex system, that needs both automatic and human control in cooperation. Many biological parameters cannot be measured, because instrumentation is either too expensive or not available at all. Human observations are therefore crucial complements to the automatic measurements for a good control.

In an earlier paper (8) the concept of operational states was described. It has been implemented at the Gävle computer control system. Now, more practical experiences have been obtained. The details of the concept will not be repeated here, but some basic ideas will be mentioned here for convenience.

In a complex system like the activated sludge process the control can be said to be realized in two steps. In the first step the computer program will determine - based on all available information - which control actions to take. This means, that it has to determine which control variables to use. Such a decision is a logical one. In the second step the actual control algorithms are initialized.

The calculations in the first step lead to a logical decision, that the process is in a certain "operational state". It gives a qualitative information to the operator about the process state. Examples implemented in Gävle are

- o bulking sludge
- o sludge buffer full
- o too low growth rate
- o too high effluent suspended solids concentration
- o the sludge is not evenly distributed between the aerators

The operator can act in different ways as a result of the information. If he does not act at all, the computer tries to make the best of the available information. In many cases the control will be comparatively cautious. If the operator interacts, several things can happen. He may just verify by observations, that the computer detected the proper state. He may also take additional laboratory tests in order to give the computer additional information for a less cautious control.

One example is by-pass control in Gävle. Naturally by-passing should be avoided if possible. The control is based on the following measurements, to raise the air flow rate (fig. 2 c) but hits an upper limit because the pressure has reached its lower limit (fig. 2 d). Then the controller cannot act any more and freezes the air flow rate to 80 Nm^3/min. When more air capacity is possible, or when the DO concentration increases again, the controller automatically restarts.

The return sludge flow rate is of course limited by the pump capacity. The thickener, however, may limit the control authority further. When the return sludge is used for organism dosage control to the aerator, the dry mass flow is the adequate variable. The sludge concentration is a function of the underflow velocity in the thickener. Therefore the computer has to make sure, that the dry mass flow increases for an increasing sludge flow rate.

The lower limit of the return sludge flow rate is also determined by the settler properties. The sludge level will rise if the return flow is too low. Therefore the buffer capacity of the settler is a natural lower limit of the return sludge flow. Consequently a large buffer capacity of the settler is crucial for an adequate return sludge control. See further the results reported by Cashion and Keinath (11).

The relevant controller complexity is determined by the limitations of the control variable. If the limitations are too narrow, then other considerations than control algorithms are significant, and logical decisions for the control become relevant, see 5.

4. MEASUREMENT HANDLING AND CORRECTION

The significant disturbances to the activated sludge system are related to the influent flow. As both concentration and flow rate disturbances cover such a broad range of the spectrum - from minutes to days - the detection of the disturbances is not an easy problem. Fast disturbances can be significant in amplitude. With a slow filter they are consequently not detected properly.

It is hardly possible to achieve a proper stochastic model of the influent disturbance pattern, as it is a non-stationary stochastic process. Therefore the used filters are not based on any á priori model. The disturbances faster than the sampling frequency are filtered in analog devices. For slower disturbances digital exponential filters are used. The filters have been tuned successively, when more experiences have been gained.

Some disturbances are quickly detected, but still too little can be done to control them, due to small control authority (see section 6). In such cases feed forward control would help, but measurements may be difficult.

Certain disturbances are caused by human interaction, and can be recognized due to their specific pattern. When a pump is switched on, there is a particular hydraulic change, that can be easily recognized by the flow rate and the magnitude of its derivative. When a sensor is taken up for calibration or cleaning the corresponding measurement value is easily recognized, and a proper action can be taken.

The operator interaction with the control system is of course important. The philosophy in the actual installations has been, that the computer should be able to detect certain disturbances without any specific information from the operator. On the other hand, if the computer should get information from the operator e.g. when a sensor is cleaned or a pump or blower is manually switched on or off, then the control action can consequently be improved.

5. OPERATIONAL STATES

Even with an advanced control system there are a lot of measurement and control tasks that cannot be implemented into a computer. A wastewater treatment system is an excellent example of a truly complex system, that needs both automatic and human control in cooperation. Many biological parameters cannot be measured, because instrumentation is either too expensive or not available at all. Human observations are therefore crucial complements to the automatic measurements for a good control.

In an earlier paper (8) the concept of operational states was described. It has been implemented at the Gävle computer control system. Now, more practical experiences have been obtained. The details of the concept will not be repeated here, but some basic ideas will be mentioned here for convenience.

In a complex system like the activated sludge process the control can be said to be realized in two steps. In the first step the computer program will determine - based on all available information - which control actions to take. This means, that it has to determine which control variables to use. Such a decision is a logical one. In the second step the actual control algorithms are initialized.

The calculations in the first step lead to a logical decision, that the process is in a certain "operational state". It gives a qualitative information to the operator about the process state. Examples implemented in Gävle are

- o bulking sludge
- o sludge buffer full
- o too low growth rate
- o too high effluent suspended solids concentration
- o the sludge is not evenly distributed between the aerators

The operator can act in different ways as a result of the information. If he does not act at all, the computer tries to make the best of the available information. In many cases the control will be comparatively cautious. If the operator interacts,several things can happen. He may just verify by observations, that the computer detected the proper state. He may also take additional laboratory tests in order to give the computer additional information for a less cautious control.

One example is by-pass control in Gävle. Naturally by-passing should be avoided if possible. The control is based on the following measurements,

(i) if the effluent suspended solids concentration as well as the influent hydraulic load are large, the by-pass valves are opened only as long as the dry mass of suspended solids out from the plant is larger than a pre-determined value,

(ii) if the suspended solids in the effluent cannot be measured, the decision about by-passing is based only upon flow rate measurements,

(iii) if neither flow rates nor suspended solids concentrations can be measured the computer will alarm the operator. Any decision about by-passing must be made by the operator.

The operational states can help the operator to calibrate the actuators. One example is, if the computer discovers a significant difference between the dry masses in the different aerators. Then the operator gets a message. With the automatic sampling system he can adjust the valves of the aerator inlets, while he continuously registers the suspended solids concentrations. Such a calibration of the inlet flows will be made much cheaper in this way than with precision valves.

Hitherto the experiences from the Gävle plant are encouraging. It has been demonstrated, that the concept of operational states give an excellent way of communication between the computer and the operator. Only few false alarms have been given hitherto, so the operators can have confidence in the messages from the computer. More operational states will be defined, when more specific knowledge of the plant dynamics has been obtained. Also, when new instruments are achieved it is possible to implement more operational states.

6. CONTROL STRATEGIES

In the design of control algorithms the purpose has been to make the controllers as simple and robust as possible, but still intelligent and flexible. In order to be able to do the right compromizes the dynamics of the plant must be known adequately. Initially the goal was to develop adaptive regulators, that could take the time varying behaviour of many parameters into consideration. The limitations of the control signals, however, was a major problem, and consequently the full potential of the algorithms could not be used.

A consequence of the limited control authority is shown in fig. 3, Saturday night. The DO concentration, fig. 3 a, rises sharply to more than 5 mg/l. The reason is, that the plant load falls at the weekend, and the dry mass flow in the aerator, fig. 3 b, decreases rapidly. The controller tries to decrease the air flow rate, fig. 3 c. Consequently the air valve cannot be closed any more, as the pressure would rise even more. The controller has to permit that the DO concentration rises, but the desired control signal is stored into the computer memory.

On Sunday morning the load increases again, causing a rising demand for air, so the pressure drops, fig. 3 d. The controller memory, however, is too long. The controller has not been able to actuate the whole desired control signal, and is still trying to decrease the air flow, when the demand for air is rising again. The controller memory causes an oscillation in the DO concentration, and the DO value will get an undershoot to about 2 mg/l. This type of problem has been avoided by making the controller memory limited.

A good controller should take a changing environment into consideration also in other ways. An example of this is shown in fig. 3, where a blower is turned on. The air pressure suddenly increases at about Friday noon, fig. 3 d. The corresponding air flow rate has to be adjusted, and is decreased, fig. 3 c. In the DO concentration, fig. 3 a, there is a sharp positive peak, but the controller manages to get the concentration back to the reference value 3 mg/l relatively quickly. It is obvious, that the control behaviour could be improved considerably, if the controller had got any direct information, that the blower was turned on.

7. CONCLUSIONS

A lot of practical considerations have to be made before a computer control system can be implemented. A few have been mentioned in this paper.

The control authority and the variability of the actuators are crucial factors. If the flow rates are not changed smoothly enough, the suspended solids concentrations may be significantly disturbed. A limited authority has several consequences. Generally speaking, a control has to be extended in time in order to compensate for a limited amplitude. This causes a time lag in the controller, and its memory has to be chosen with care. Otherwize undesired oscillations may occur. The problem could be compared in principle with the wind-up problem, that may occur in a standard PI controller.

Even if a computer is available, there is usually a lot of manual control tasks in a plant. It has to be carefully considered, how to detect manual controls, e.g. when motors, pumps, blowers etc. are turned on or off.

It has been demonstrated that the concept of operational states has been rewarding. It is a good way of communicating between the process and the operator. Moreover it is a natural link between the measurements, manual observations and the control algorithms.

ACKNOWLEDGEMENTS

The financial support for the project has come from the Swedish Board for Technical Development in cooperation with the Datema AB. The staff at the Käppala wastewater treatment plant, particularly Dr. K. I. Dahlqvist and Mrs. E. Hjelmvik have provided a lot of help and support. Mr. R. Olsson and Mr. L. Johnsson in connection with the Gävle plant have also given a lot of support.

REFERENCES

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

(2) Buhr H.O., Andrews J.F. and Keinath T.M., "Research Needs for Automation of Wastewater Treatment Systems". Proceedings of a workshop, sponsored by the U.S. Environmental Protection Agency in cooperation with Clemson University, Clemson, S.C. (1975).

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

(4) Olsson G., "Activated Sludge Dynamics I." Biological Models. Report 7511, Dep of Automatic Control, Lund Institute of Technology, Lund Sweden (1975)

(5) Olsson G., "Activated sludge dynamics. Static Analysis". Dept of Civil Engineering, Univ of Houston, Houston, Texas (1975)

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

(7) Olsson G. and Hansson O., "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. (1976)

(8) Gillblad T. and Olsson G., "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 (1977)

(9) Olsson G. and Andrews J.F.,"An analysis of dissolved oxygen profiles in the activated sludge process for the development of control strategies", Submitted to Water Research (1977)

(10) Olsson G. and Andrews J.F., "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 (1977)

(11) Cashion B.S., Keinath, T.M.and Schuck, W.W., "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 (1977)

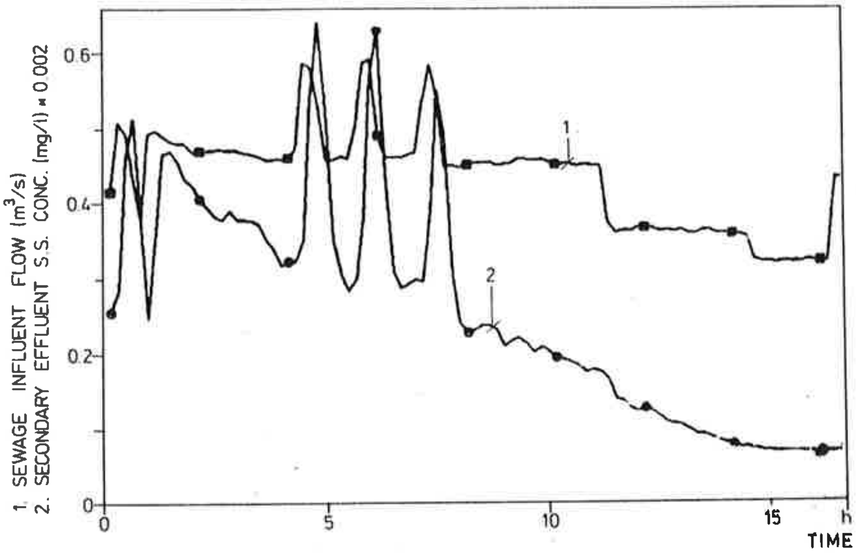
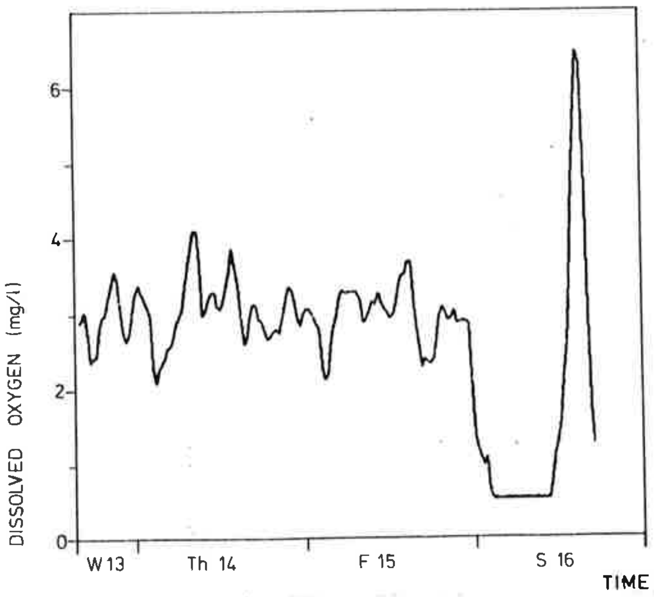
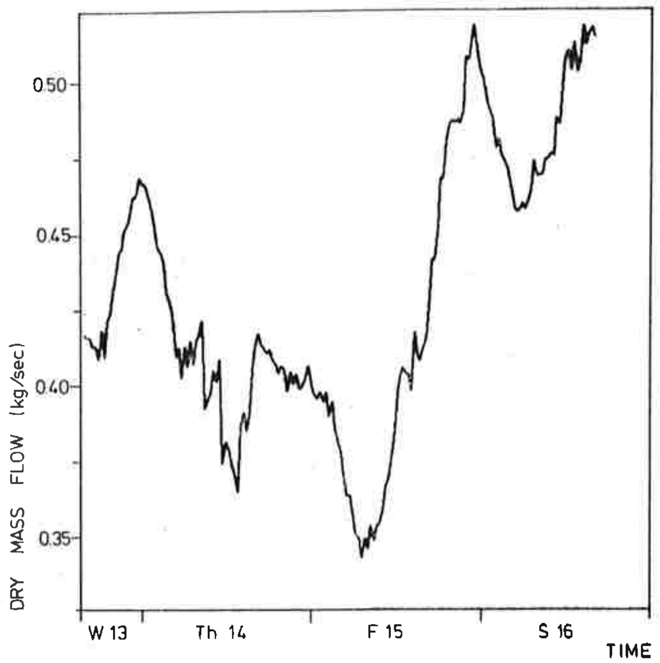


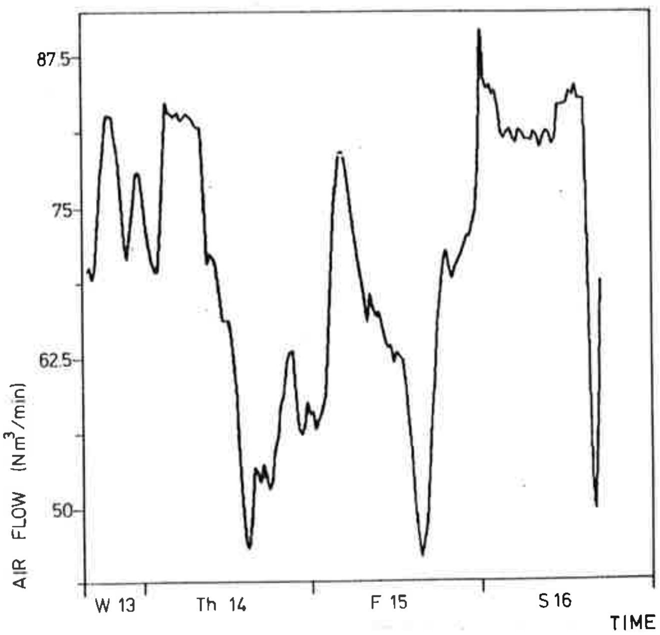
Fig. 1. The curves show the influence of influent hydraulic shocks on the secondary settler effluent suspended solids concentration. The experiment was made in Käppala on Nov 26, 1976.



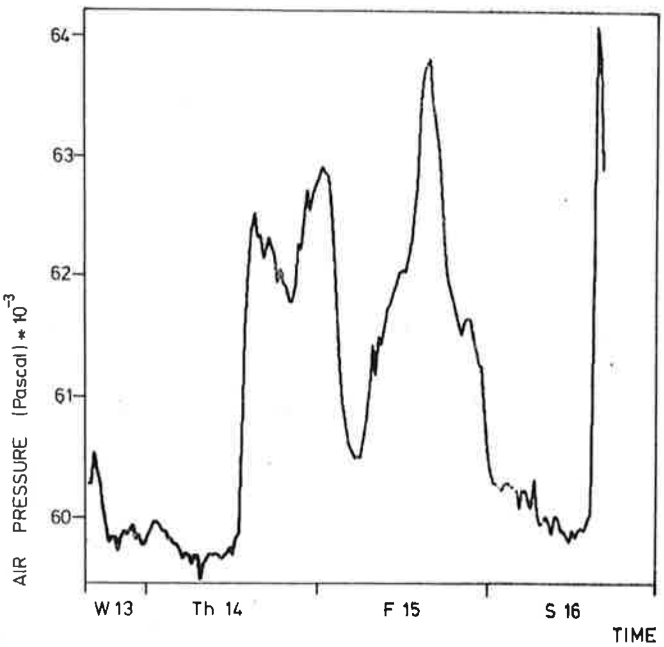
2 a



2 b



2 c



2 d

Fig. 2. The consequence of a limited air flow rate for the DO control. On Saturday morning the DO concentration drops sharply, necause of an increasing plant load. The load is represented as the mixed liquor suspended solids concentration time the hydraulic flow in the aerator. The air flow rate is increased by the controller (c) but is limited due to the pressure lower limit (d). Therefore the controller is turned off automatically and the air flow rate is set constant (c). Later the controller is automatically restarted, when the DO concentration can be raised above 0.5 mg/l. The experiment was recorded at Käppala between Aril 13 and 16, 1977.

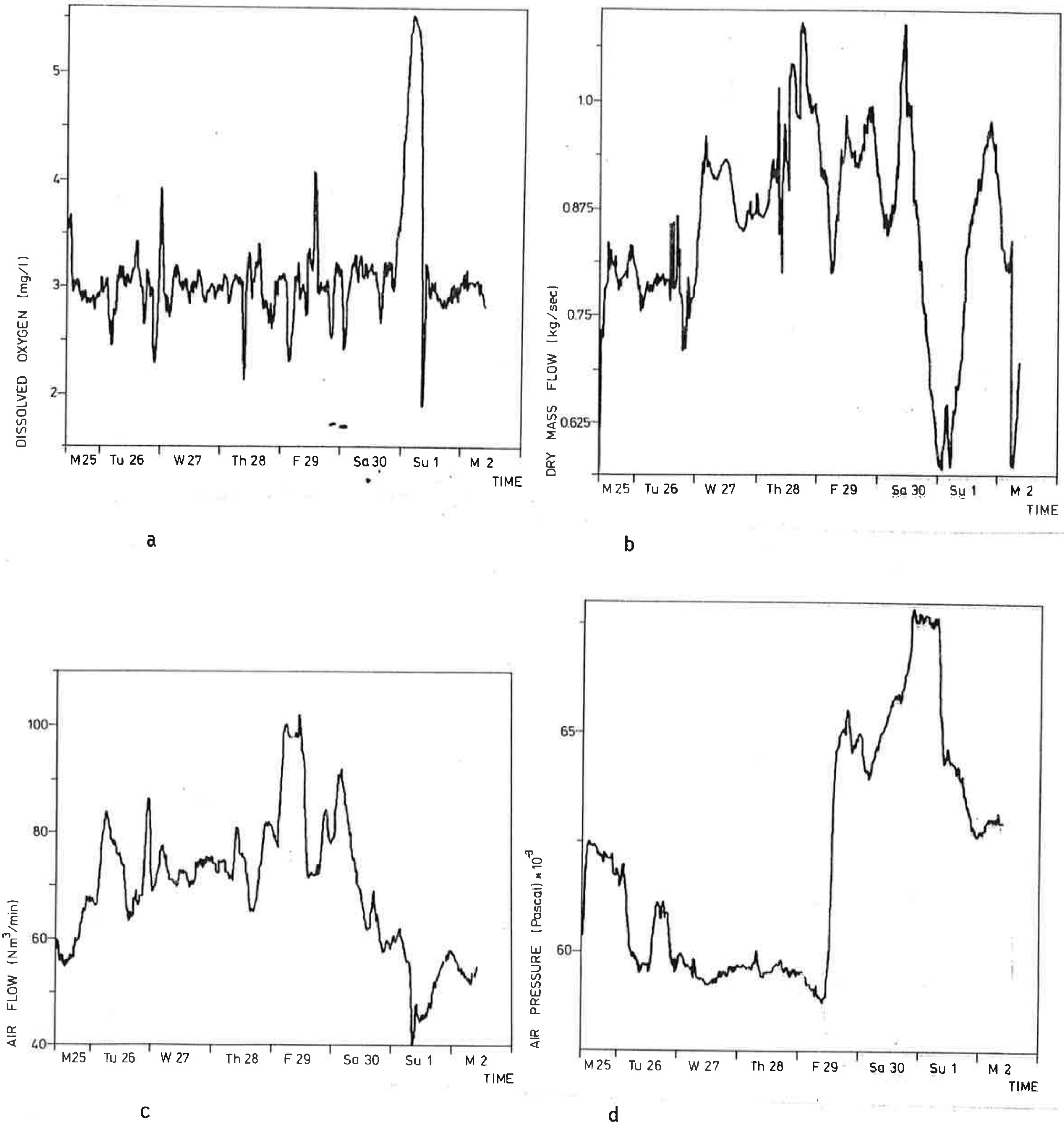


Fig. 3. The sequence of curves illustrates two different controller properties. At Friday noon a blower is turned on. On Saturday night the plant load gets down. The controller does not manage to keep the DO concentration constant. The experiment was recorded at Käppala between April 25 and May 2, 1977.