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COMBINED CONTROL OF SEWER AND TREATMENT PLANT DURING RAINSTORM

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ABSTRACT

The use of flow predictions and on-line nutrient sensors in BNR plants has given the basis for introduction of radical operational changes. Because of the detailed monitoring, the control actions are allowed to go closer to critical process limits while balancing between hydraulic and biological capacities.

One of the new modes of operation, settling in the aeration tanks as an active control, is documented below. This new operation, Aeration Tank Settling (ATS) has been tested at full scale and shows a great potential for storm water control. With ATS control the hydraulic capacity is increased 25-75% on existing plants without reducing the organic capacity in periods ranging from 2 hours to 2 weeks.

ATS control can be initiated directly by raising the inlet flow to the treatment plant, but even better by 1/2 - 1 hour prediction of the inlet flow. These predictions of flow are achieved from statistical grey-box handling of data from on-line rain gauges and measured inlet flow pattern during normal and stormwater conditions.

Hourly predictions of concentrations in the inlet to the plant and selected points in the sewer system during dry weather and storm situations will improve the combined system control efficiency radically. Copyright © 1996 IAWQ. Published by Elsevier Science Ltd.

KEYWORDS

Wastewater treatment plant; rainforests; active control; aeration tank settling; stormwater.

INTRODUCTION

In Denmark rehabilitation of sewers and handling of storm water are the largest municipal investment demands, involving new storage basins and extension of pumping stations and sewers. If the hydraulic capacity of wastewater treatment plants could be increased by approx. 50% using new control strategies (Bundgaard *et al.*, 1995), the investment in basins could be reduced significantly and future maintenance of large sewer constructions could be saved.

Combining a high capacity control at the treatment plant with an on-line control of available and controllable sewer and basin volumes, it is possible to reduce the total overflow from the system. In the combined control strategy of sewer and treatment plant, the highest concentrated wastewater is retained to be discharged to the WWTP when capacity is available, while less concentrated wastewater is discharged.

With this combined control strategy and on-line information it is possible to minimize the discharge effect on sensitive recipients at critical periods, as minimizing CSO does not always result in a minimum effect on the recieving (Rauch and Harremoes, 1996).

During excessive hydraulic loading of activated sludge plants the main control criterion is to avoid sludge loss. The most widely used control is based on return sludge and stepfeed control, which are both of limited effect or can be detrimental to organic and nutrient removal. Also, the effect of these controls is slow, i.e. it takes several hours before the control becomes effective. In the ATS control strategy, the biological activity is kept high while the activated sludge is maintained in the aeration tanks. The achievements show surprisingly good results, because the hydraulic capacity is increased with no loss of biological activity.

The use of sensors in sewer systems and treatment plants can provide important information to control storage volume in the sewer system and minimize CSO as well as to control the treatment plant (see Carstensen *et al.*, 1993).

HYDRAULIC CAPACITY OF CLARIFIERS

The key parameter regarding hydraulic capacity of a treatment plant during stormwater conditions is the sludge volume loading, SVL, to the settling tank. The SVL must be controlled as a mean value over a time period of 3-6 hours, whereas short-term variations are not important. However, it is important to keep the hydraulic surface load stable and below the sludge settling velocity.

Theoretically, the efficiency of the ATS approach can be compared to that of conventional constant SVL design for a given effluent standard (Billmeier 1986). The required clarifier volume can be expressed by the following simple expression:

$$Clarifiervol = k * Q * SS_{to-clarifier} * SVI \tag{1}$$

where k = constant dependent on effluent SS, Q = flow into the settling tank (inlet + return sludge flow), $SS_{to\text{-}clarifier}$ for settling tank = MLSS at the outlet of aeration tank, SVI=sludge volume index.

Isolating the flow, Q, the following equation is obtained:

$$Q = \frac{Clarifiervol}{SS_{to-clarifier} * SVI * k} = \frac{K}{SS_{to-clarifier}} \tag{2}$$

During one single stormwater incidence, SVI and k are assumed to be constant. Together with the clarifier volume, they make up the constant K. Hence, maximum flow Q is directly proportional to $1/SS_{to\ clarifier}$, which means the capacity is increased as the sludge concentration to the clarifier can be reduced. The improvement is further reinforced, because the amount of sludge in the clarifier is reduced and as a result, the return sludge can be decreased even further. A decrease in return sludge has a direct influence on Q, which is the sum of inlet flow and return flow. However, the effect is dependent on the specific plant configuration.

To take advantage of this improvement we have to control the extent of settling in the aeration tanks and in this way adjust the sludge volume loading (SVL) to the settling tank.

As ATS operation in alternating plants typically reduces the SS amount in the clarifiers by 50% and the flow to the clarifier by approximately 30%, the control more than doubles the hydraulic capacity of a given plant as shown in figure 1. In figure 1, the required settling tank volume at normal operation during a rain event is shown (assuming kxSVI = 1). The figure also illustrates how ATS operation reduces the required settling tank volume to below 50% during storms.

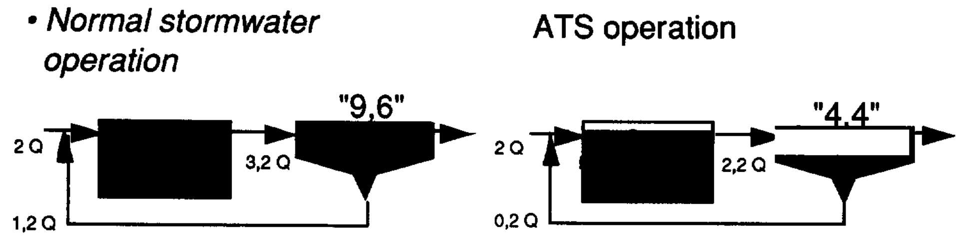

Figure 1. Required settler volume.

PRACTICAL IMPLEMENTATION

To test the strength and limitations of the ATS process, full-scale tests were conducted at Aalborg Vest WWTP by introducing the flow scheme sketched in figure 2. The inlet is to the tank with nitrification and the outlet to the clarifier is from the tank where settling and denitrification take place.

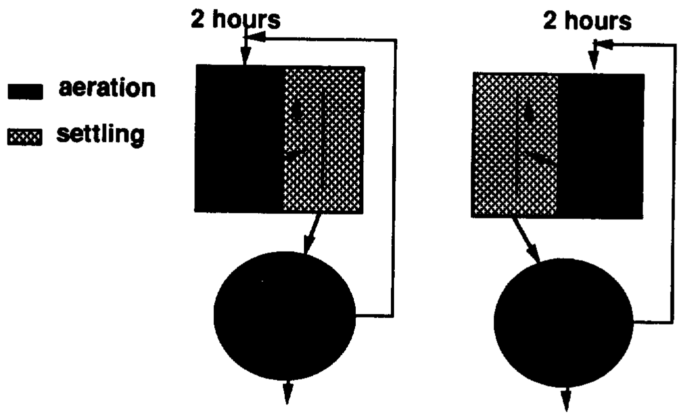

Figure 2. Flow scheme full-scale application for ATS is reported by Bundgaard *et al.* (1995).

FEATURES OF ATS

With ATS it is possible to distribute the organic and hydraulic capacity as in a conventional alternating plant or sequencing batch reactors. However, as the sludge quality is affected by maintaining this mode of operation, it must be ensured that operation only takes place in periods with a high hydraulic load of the plant.

It was anticipated that some kind of reduction of the denitrification efficiency would be observed. However, was not the cases as seen in Table 1.

For high hydraulic loads, the control system introduces settling in the aeration tanks in order to increase the hydraulic capacity by up to 2 times the hydraulic capacity in conventional operation. However, full capacity requires a correct sludge distribution between aeration tanks and clarifier. Therefore, a preparation period with a reduced flow is to be preferred, before the clarifier can process high return flows in the system. The use of flow predictions from the sewer SCADA system or from models based on rain measurements significantly reduces the critical start-up period as shown in figure 3. It is seen that during a period with a high hydraulic load, the hydraulic capacity of the clarifier will be reduced to below the high load, which may cause sludge loss. With the sketched ATS including flow predictions, the critical point will be reached earlier, but for a shorter period of time, and sludge loss might be totally avoided. Owing to the warning period, the distribution of sludge between the aeration tanks is differentiated and maximum amount of sludge is maintained in the aeration tanks before the hydraulic load reaches the plant.

Table 1. Operation data with and without ATS

	Operation method	Usual operation	ATS operation	Effect of ATS
	units	23/9-10/11	11-21/11	
Effluent Inorganic Nitrogen	mg/l	6.17	3.62	-41%
Effluent Ortho Phosphorus	mg/l	0.71	0.51	-28%
Effluent Turbidity	NTU	7.43	9.05	22%
Iron consumption	t/d	8832	7030	-20%
Energy consumption	kWh/d	9757	10720	10%
SS in aeration tank	g SS/L	3.45	4.45	29%
SS in return sludge	g SS/l	8.28	10.41	26%

Introducing the ATS principles and optimum control of the start-up periods according to flow predictions, the capacity of the plants is increased significantly without the nutrient or organic capacity of the plant being reduced. If the extra hydraulic capacity is not needed, it can be converted to organic capacity by increasing the MLSS in the plant assuming sufficient aeration capacity is available. The aim is optimum control of the settling in the tanks.

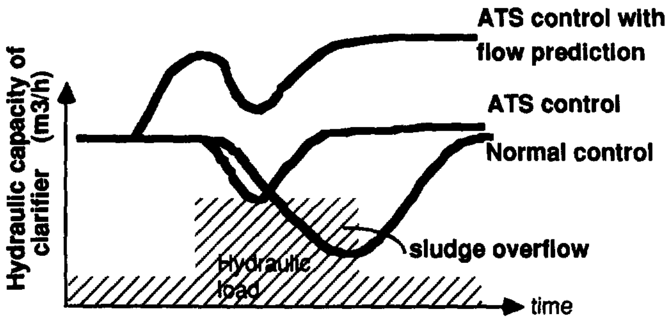

Figure 3. Capacity of clarifier with different control schemes during rainstorm.

CONCENTRATION DETERMINATION IN COMBINED CONTROL

The material loads of the wastewater and rainfall runoff are probably the most desired information for efficient control of the sewer system. The implementation of on-line sensors has resulted in an enormous amount of new information, which can be used for estimating the normal daily and weekly variations. These variations are continuously adjusted to compensate for seasonal variations and changes in the area of the runoff surface. These load estimates are reported in Carstensen (1993). Using this methodology to adjust the general simple load description, we have the basis for quantifying the amount of settling and resuspension of pollutants dependent on flow variations and time between rain events.

It is essential for optimizing the control of the sewer system to be able to predict material concentrations during rain at those points in the sewer system that are affected by control. If a statistical evaluation is made based on many different sewer systems, the *first flush effect* is probably overestimated since on average only 60% (10%) of the material load is contained in the first 50% of water during a rain event. However, the practical experience from individual sewer systems and measurements on CSO shows that some sewers do have sufficient first flush effect to be exploited by adaption, which the deterministic modelling so far has failed to describe. A grey-box approach is applied such that the CSO and wastewater concentration during rain are continuously estimated using models capable of adapting to on-line data. This is shown in figure 5 and 6.

In order to identify these concentrations reasonably well, it is first necessary to find the dry weather variations. Such a description includes one or more of the following terms: "adaptive mean, daily double-harmonic, weekday dependency". These are very well identified - in theory and practice - due to the abundant data from dry weather periods and the reliable UV and turbidity meters available today . Furthermore, if these parameters are not available the OUR or NH3 at the plant can be interpreted to describe the load variation as shown by Nielsen and Onnerth (1995b). A typical daily variation is found in figure 4.

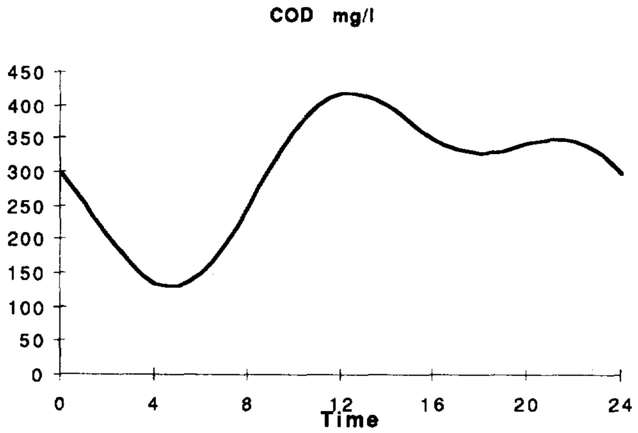

Figure 4. Daily variation in COD concentration (an example).

After the detailed description of load into the plant is found, correlations with measurements upstream in the sewer system can be used to quantify the concentration dynamics at the control and discharge points, such that the control of the integrated system is optimized to retain the most contaminated wastewater in available volumes and prioritize discharge to the different recipients depending on their sensitivity.

The parameters necessary to describe the adaptive model are: "water volume in the sewer, amount of deposits and release rate of deposit". These parameters are very difficult to quantify theoretically and most likely not constant, but with the aid of modern sensors, computing power and mathematical tools, these calibrations are available at reasonable costs using the approach proposed by Nielsen *et al*. (1995).

Figure 5 and 6 show the concentration gradients for two sewers with different liquid volumes but the same amount of deposit release during the rain. In both figures, the concentration variations with different release rates during the rain event are illustrated (the deposits are released over 10, 20 and 40 minutes). The simulations are compared with a simple dilution model where excess water is assumed to contain 100 mg/l COD.

The amount of resuspended material during a storm is naturally dependent on the length of the dry weather period until the last heavy rain (sediment build-up), and the rate of resuspension depends on the magnitude of present as well as previous flows.

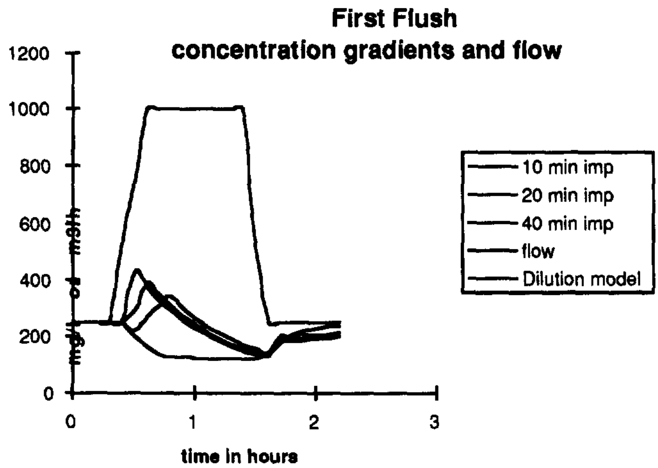

Figure 5. Simulated concentrations with 120 minutes dry weather flow as holding volume of the sewer system.

The adaptive model will select the appropriate form as sketched in figure 5 and 6, dependent on the on-line measured data from previous rains. Unimportant relations for the interpretation of data are removed (Nielsen *et al.*, 1994) and as experiences are gained from more rains, the model performance for predicting material loads will improve. The costs of calibration can be reduced considerably compared with the conventional deterministic modelling approach, where calibration often is so time-consuming and costly that it is considered irrelevant for control to take any first flush effect into account.

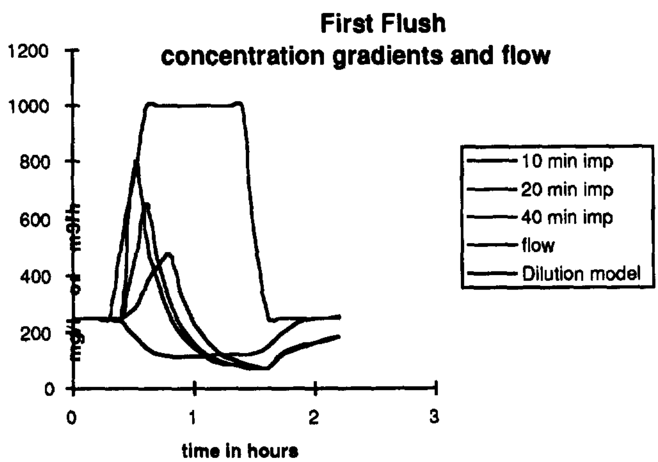

Figure 6. Simulated concentrations with 50 minutes dry weather flow as holding volume of the sewer system.

This approach is considered for full-scale implementation at the Frederikshavn sewer system and treatment plant. It will be tested in the coming years under the EUREKA-financed project MUST.

CONCLUSION

On-line sensors and grey-box modelling give new useful information which has improved our control, understanding and design of wastewater treatment during storm situations.

The use of ATS (aeration tank settling) during peak hydraulic loading increases the hydraulic capacity of alternating WWTP by at least 50%, and does not reduce the organic and nutrient removal capacity of full-scale plants.

There is a great potential for combining sensors and information technology in wastewater transport and treatment. The present paper only describes a few of the possible improvements which can be obtained through this combination. In many systems, these improvements will prove to be much more cost-effective than traditional design solutions.

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