Modelling and test of aeration tank settling (ATS)

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Abstract The use of aeration tank settling during high hydraulic loads on large wastewater treatment plants has previously been demonstrated as a reliable technique and proven valuable. The paper proposes a simplified deterministic model to predict the efficiency of the method. It is shown that a qualitatively correct model can be established. The simplicity of the model allows for on-line identification of the necessary parameters, so that no maintenance is needed to use of the on-line model for control.

The practical implementation on three plants indicates that implementation of STAR with ATS control gives 50% increase of plant capacity for 3% extra cost.

Keywords Wastewater treatment; modelling; on-line control; hydraulic capacity; stormwater control; activated sludge

Introduction

The settling in aeration tanks is often a problem in activated sludge wastewater treatment plants. Especially for low loaded plants or during anoxic conditions during nutrient removal correct mixing intensity is important. Traditionally, these problems are solved by introduction of mixes or by installation of excess aeration capacity in the tanks to assure homogeneity in the reaction tranks.

During recent years more controllers are accepting part settling in the aeration tanks during intermittent aeration, as presented at IAWQ ICA Workshop 1997. Other controls are today emphasizing intentional settling in the aeration tank (Bundgaard *et al*., 1996) to increase the hydraulic capacity of the plant. As Wett *et al.* (1997) demonstrated, introduction of mixing in the denitrifying clarifiers has no effect on the reaction rates. Similar experiences have been reported in aeration tanks with intentional settling (Bundgaard *et al*., 1996).

As there is no negative effect on reaction rates by no mixing and the hydraulic capacity can be increased, there is a potential to save energy and improve plant capacity by use of aeration tank settling in activated sludge plants. Thus, many mixers might be saved in future plants.

To be able to design the controllers for these processes, it is necessary to be able to predict when and how much sludge settling will occur in the tanks during stop of aeration. Then it is possible to model the effect on transport of sludge to clarifiers, and hence the hydraulic capacity of the plant can be calculated. To adjust the capacity to predicted needs, the periods of settling can be adjusted, and in alternating plants the settling can be further expanded by intermediate phases where settling is taking place in the whole volume as shown in Figure 1.

In the following a simple model for settling in aeration tanks is proposed. The model is a little different for alternating and recirculating systems. However, the aim is to describe a model, which can be used for design and adjustments of the control strategies and which can obtain 30–100% extension of the hydraulic capacity for the plants.

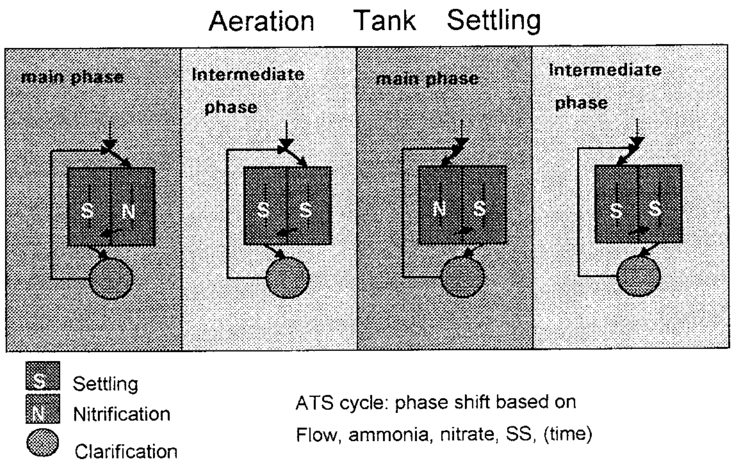

Figure 1 Dynamic phase length control schemes for STAR control

Theory for modelling

The sludge settling starts when the turbulence in the tanks is reduced after stopping both aeration and mixing. When the settling starts, the formula for hindered settling dependent on the mixed liquor suspended solids, MLSS, in the interface is proposed as a two-layer model with dynamic layer heights. The upper layer is assumed to be clear water while the lower layer is assumed to contain all the initial sludge content which concentrates as the sludge layer height decreases during the settling period.

The settling rate model for sludge proposed by Vesilin (1979) and quantified by Härtel *et al.* (1991) is used:

$$v_{SS} = v_{S,0} \cdot e^{-n_v \cdot SS} \quad (1)$$

where v_{SS} and $v_{S,0}$ are the actual and the unhindered settling rate of sludge particles respectively, and n_v is an empiric concentration effect factor.

The modelling of the sludge blanket depth, d_{SB}, can be done by integration of the settling rate over time:

$$d_{SB} = \int_{t_0}^{t} v_{SS} dt \quad (2)$$

The relevant sludge concentration starts at the MLSS value in the aerated tank and increases during the settling as sludge concentrates towards the bottom.

The starting time to is when the turbulence is reduced.

To predict the outlet SS from the tanks in non-ideal full-scale plants the details of the inlet, outlet and tank geometrical design must be included in the model.

As a first simple model for SS in the top weir outlet of the aeration tank and inlet to the clarifier, SSout, can be made as a calculation of suction depth, dsuct (Figure 2). The suction depth is predicted for the specific outlet and the concentration is modelled as:

$$SS_{out} = \frac{d_{suct} - d_{SB}}{d_{suct}} SS_{bl(\,)} \quad (3)$$

Of course, the suction depth is varying with the flow rate, and the distribution of the actual flow is not proportional with the depth. These unmeasurable factors are modelled by data fitting to full-scale measurements.

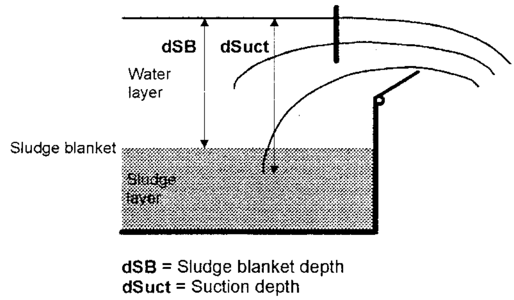

Figure 2 Parameter definition for modelling effluent SS

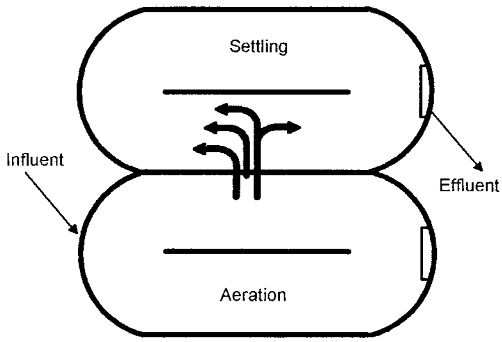

Figure 3 Physical description of outlet modelling in settling aeration tanks in an alternating plant

Physical model

Alternating systems

In the alternating system typically two tanks are available. As a rule only the last tank before the clarifier is relevant for settling. The inlet will normally be from an adjoining tank as seen in Figure 3, and the inlet velocity and distribution is of paramount importance for the efficiency of the settling as well as the outlet distribution as it is in other clarifier designs.

Apart from simple ideal settling the model must include the reduced efficiency of the aeration tank as a clarifier because inlet and outlet are not optimal. Further the storage of sludge on the bottom will limit the capacity for settling after some time in the same phase, as there is no sludge removal from the aeration tanks during the phases.

The inlet turbulence must be adequte enough to distribute the incoming water sufficiently in the tank under settling operation to avoid short-circuiting. For the modelling, the limitation in settling efficiency is not simply described by reducing the efficient volume of the aeration settling tank.

The outlet is more important for the time distribution of the aeration tank efficiency for settling. The outlet is assumed to be via a weir, and the suction depth is a function of outflow. As shown in Figure 2, the concentration of sludge in the outlet is dependent on the sludge blanket level and the SS concentration under the sludge blanket that is sucked out in the effluent from the tank.

The sludge build-up and concentration profile on the bottom is modelled as a single layer model, but to be able to fit the model to practical experiments a virtual bottom is assumed, and the sludge concentration below the sludge blanket and the virtual bottom is assumed homogeneous.

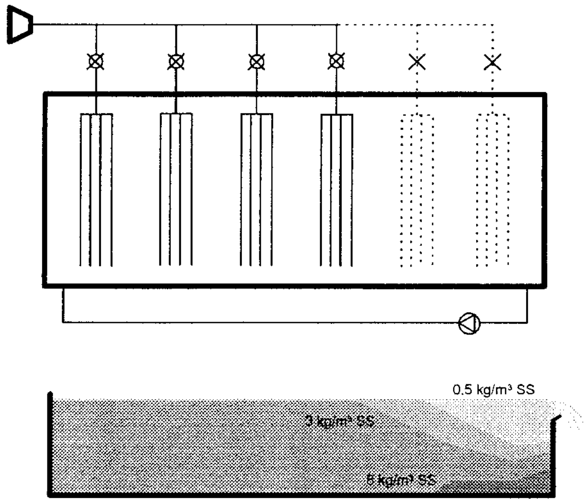

Figure 4 Physical description of outlet modelling in a recirculating plant

With these assumptions we have a simple model for the concentration out of an aeration tank at any time dependent on present and previous load and on the period since the settling started as shown in Figure 7.

Recirculating plants

In recirculating plants the settling can take place in the effluent part of the aeration tank. Apart from the stopping of the aerators in intervals, the priority can be to stop the effluent end aeration grids as shown in Figure 4 to obtain settling in the outlet end. The return of sludge can use the existing recirculation system.

Plant capacity

The capacity of the clarifiers is often the limiting factor during rain events. In stationary situations, the capacity of the clarifiers, according to normal design rules (like the ATV rules), is inversely proportional to the sludge volume index, SVI, and the concentration of suspended solids, SS. Billmeier (1986) describes the steady state hydraulic capacity of the clarifiers as

$$Q = \frac{V_{clarifier}}{SS_{out} \cdot SVI \cdot k} = \frac{K}{SS_{out}} \qquad (4)$$

where k is a proportionality factor, specific for a given plant design, and

$$V = \frac{V_{clarifier}}{SVI \cdot k} \qquad (5)$$

is a plant specific value for a given sludge quality.

Hence, at a plant with a given clarifier volume and sludge volume index, the hydraulic capacity of the plant is inversely proportional to the suspended solid concentration out of the aeration tank as shown above.

By introducing the aeration tank settling (ATS) operation before and during rain, the necessary clarifier volume is reduced as illustratrated in Figure 5 taken from Nielsen *et al.* (1996).

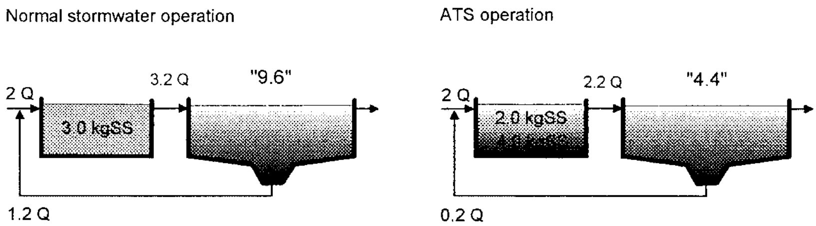

Figure 5 Required settler volume for two control schemes (Nielsen *et al.*, 1996).

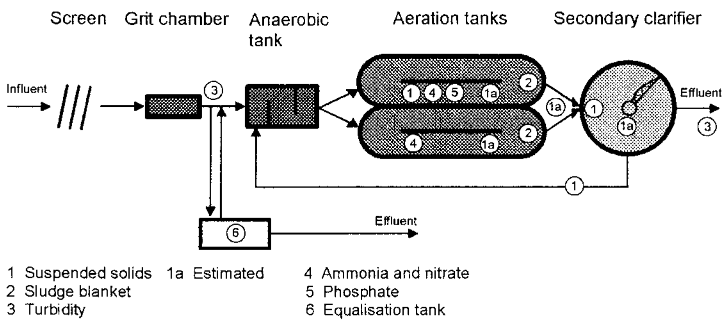

Figure 6 Description of the Aalborg East alternating WWTP

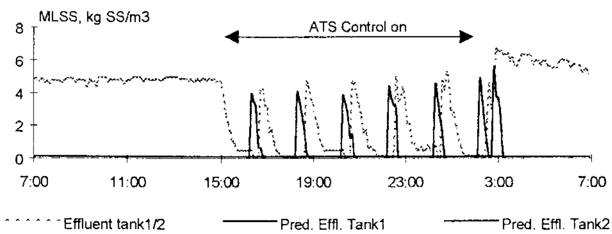

Figure 7 Measured and modelled MLSS out of aeration tanks

Practical test

To test the model, the data from a full-scale application at Aalborg East WWTP shown in Figure 6 are used.

At present this configuration is used on three alternating plants serving approximately 700,000 p.e. in Scandinavia. At minor rain events the model and reality look as shown in Figure 7 below. Compared to conventional extension of clarifier volume, the use of control to extend the capacity can be achieved by typically 1/10 of the cost.

The modelled and measured MLSS out of aeration tanks during storm events with settling in the aeration tanks are shown in Figure 7.

As it can be seen the modelled MLSS is nearly 45 minutes ahead of measured values. This is due to delay from: (1) SCADA system, (2) Rotation in horizontal channels and (3) delay from stop of micro-turbulence after stop of aeration and mixers, all of which are not included in the model.

Equal results are experienced from other alternating plants. Control has been introduced on a recirculating system at the Sydkysten WWTP, but they have not been documented online yet. However, it has been experienced that the return sludge flow must be reduced proportionally by the length of the aerator stop periods to maintain constant concentration in return sludge (Nielsen and Önnerth, 1995), so a significant but smaller effect will be obtained.

Discussion

It is seen that the proposed model is qualitatively correct. Its quantification is sufficient for most control, however, there are some empirical constants which are only adjustable from practical fitting based on on-line data. Although these constants are explained above, as having a physical meaning, they are only found from data fitting to experiences during rain events.

However, experiences show that the model can be transferred from one plant to another. Only small adjustments, and update to actual MLSS concentration and SVI is needed, hence practical experiences from one plant can be transferred to another similar plant, and the on-line update can be obtained from the first rain event's experiences.

By use of the model and the prediction of flow from rain gauges or the sewer system it is possible to predict the needed efficiency of the ATS control and optimize the organic versus hydraulic capacity of the plant.

Conclusion

Aeration tank settling is a robust reliable technique, which by use of models can be designed and controlled to perform efficiently, in alternating plants, to increase their hydraulic capacity by 30–100% within a few hours.

The use of the same model methodology can predict the hydraulic capacity for recirculating plants. When further experiences of the methodology of the settling sludge and recirculation of the sludge are collected from full-scale, the standard design technique will be extended to cover most plug flow and other recirculating activated sludge plants too.

Acknowledgements

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