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MODELING ACTIVATED SLUDGE MASS TRANSFER IN A TREATMENT PLANT

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ABSTRACT

To keep overflows of raw effluent to a minimum during wet weather conditions, we investigated the ability of a secondary clarifier of an activated sludge treatment plant to accept hydraulic overloads without being washed out. The experiments, which were conducted on a full scale 8000 p.e. treatment plant, showed the feasibility of the project, and suggested some features, which were included in a one-dimensional model designed to study the behavior of the sludge blanket in the clarifier. This model takes into account the effect of convection currents, suspected to play an important part in the rising of sludge blankets. The sensitivity of the model to sludge settleability prevented its use with long times-series, unless a continuous recalibration was performed. Nevertheless, this model appears very interesting for a better understanding of the dynamics of the clarifier, as described by measured data. It could be used in relation with sensors to improve the operation of the treatment plant. © 1999 IAWQ Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

Hydraulic overload; process control; secondary clarifier; separate sewerage; wastewater treatment plant.

INTRODUCTION

Despite their design, separate sewerage networks display a specific behavior during rainfalls. They collect extraneous waters, which induce peak flowrates. These of course are not as important as they are in combined systems, but exceed usual treatment plant capacities (Belhadj *et al.*, 1995; Joannis, 1993). Upgrading several thousands of rural treatment plants that exist in France, or even building stormwater retention tanks is not conceivable over a short period. So we investigated the possibility of admitting temporary flowrates exceeding the reference capacity of an extended aeration activated sludge treatment plant, to avoid upstream bypasses. Such an operating strategy uses the ability of a secondary clarifier to store activated sludge washed out of the aeration tank. As far as the effectiveness of the treatment is concerned, one trusts the reliability of the extended aeration process. This point, however, should be further studied, but is beyond the scope of this paper, which focuses on secondary clarifier dynamic behavior. Moreover the study conducted here is restricted to the thickening performance of the clarifier: The efficiency of the clarification process stayed very high during the experiments conducted on the particular plant under investigation, and it was not included into the model.

Former modeling of secondary clarifier, especially when using flux theory, usually focused on near-steady state conditions, e.g., for optimizing of return sludge flowrates (Ozinsky and Ekama, 1995). But, as explained previously, non steady-state conditions encountered during overloads can be of great interest. So we tried to describe the dynamic behavior of secondary settlers through a model, which could meet several objectives:

1. For a particular treatment plant, and provided a proper calibration has been achieved, a model can be used to test the overall efficiency of any operating strategy used to control flow admission. That is to say, one can use a reference time-series of incoming flowrates, and calculate how much volume is treated for an admission strategy, defined by maximum flowrates, maximum duration of overload conditions, and flowrate condition for recovery after an overload event. This is an off-line extrapolation of observed behavior over a longer period and under different operating conditions. We will search to include some features (e.g., the geometric dimensions of the facilities), which reflect physical reality, in the model, so that a few experiments or observations can be sufficient to calibrate the model.

2. An on-line model of the process under control could be very useful for real-time control. It can be used to assess current values of parameters that cannot readily be reached through direct measurements, but rather derived from the behavior of the process. This is typically the case for parameters describing the settleability of activated sludge. The values so fitted can be used to adapt control strategy to real conditions, or even be considered as stand-alone information, and used for general operating purposes. On the other hand, a discrepancy between model output and on-line measurements can detect a problem, regarding either the process, or sensors.

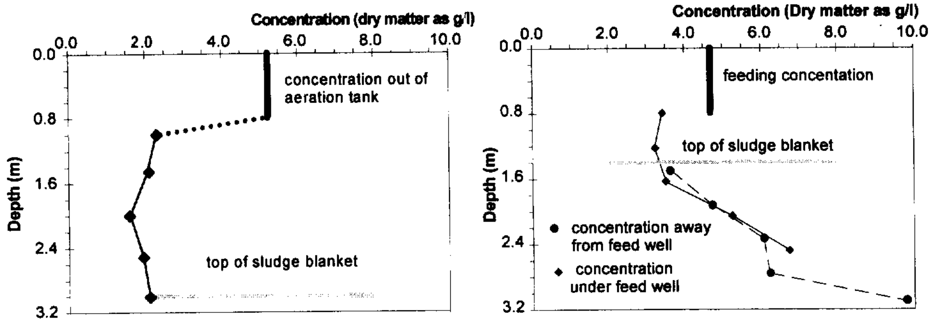

Figure 1. concentration profiles observed in the clarifier.

DEVELOPING THE MODEL

Preliminary investigations conducted on a treatment plant with a capacity of 8 000 p.e. pointed out several interesting features (Figure 1):

- When the maximum flowrate allowed by pumping capacity, i.e. 200 m^3/h, (twice the peak reference capacity) was admitted, the sludge blanket in the clarifier (circular, with a diameter of 16 m, with a scraper) rose as a whole, keeping a clear horizontal interface;
- Sludge blankets usually stayed well beneath the lower end of the feed well. So incoming sludge "dived " toward a "feeding layer ", at the top of the sludge blanket. This pattern is not considered in simple clarifier models.
- Concentration measurements conducted in the sinking plume showed that sludge experienced strong dilution as it went out of the feeding well and traveled toward the top of the sludge blanket. A dilution factor of about two was observed.

Under overload conditions, the sludge blanket rose faster than expected, at least at the beginning of the overload event. The hypothesis stated to explain that behavior is that dilution is induced by recycling currents, which go downwards under the feeding well, and upwards in outer zones. So recycling currents increase upflow velocity, and cause the sludge blanket to rise quickly (Figure 2). When it has risen high enough, the velocity decreases, as recycling current cannot develop so easily on a reduced available depth.

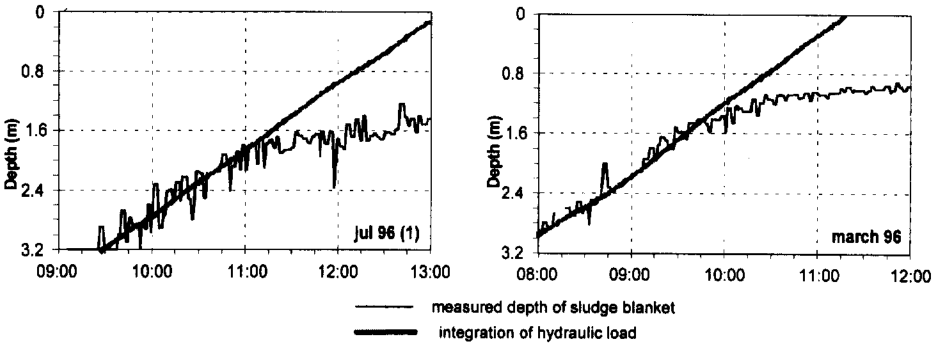

Figure 2. Rising rate of sludge blankets during two experiments of controlled overload.

Although the hydrodynamics underlying the convection currents is complex, we tried to include features for dilution and upward recycling currents in our one-dimensional model. We were encouraged to do so by the very level aspect of the sludge blanket interface .... and by the results of other researchers (Dupont and Dahl, 1995).

Settling velocity is given as a function of sludge concentration by a classical exponential law (Vesilind and Jones, 1990).

$$v_{s,i} = \alpha . e^{\beta . Xi}$$

with: α, β = parameters
X_i = sludge concentration (g/l)
$v_{s,i}$ = settling velocity (m/h)

For calibration purposes, the two parameters of this law are derived from a settleability index by an empirical equation (Daigger, 1993):

$$\alpha = 0.13.DSVI + 26.5 \text{ and } \beta = -63.8\ e^{(-0.04.DSVI)}-0.56$$

The model also includes a diffusion law (Watts *et al.*, 1995).

Input data are:

- flowrate going through the treatment plant;
- recycling flowrate;
- concentration of sludge coming out of the aeration tank. This information could have been considered as a parameter rather than an input, as it does not change very fast on a daily time step. Yet it appeared in other studies that the precise pattern of concentration on a short-time scale was important, and that transferred sludge concentration could become very low, when mixing devices were stopped. This is the case for our treatment plant, as aeration and mixing are achieved by brushes. Moreover, we had a feeling that a continuous monitoring of this concentration was easy. So this measurement was used to feed the model, for calibration and validation purposes.

Outputs are:

- the level of the sludge blanket
- the vertical concentration profile in the sludge blanket
- the concentration of return sludge

Parameters are:

- the sludge settleability, described by two parameters of the exponential sedimentation law (this characteristic could be best considered as input data, but it changes much more slowly than the other ones, and is much more difficult to measure accurately);
- a dilution coefficient;
- the upper limit of the dilution zone;
- a diffusion coefficient.

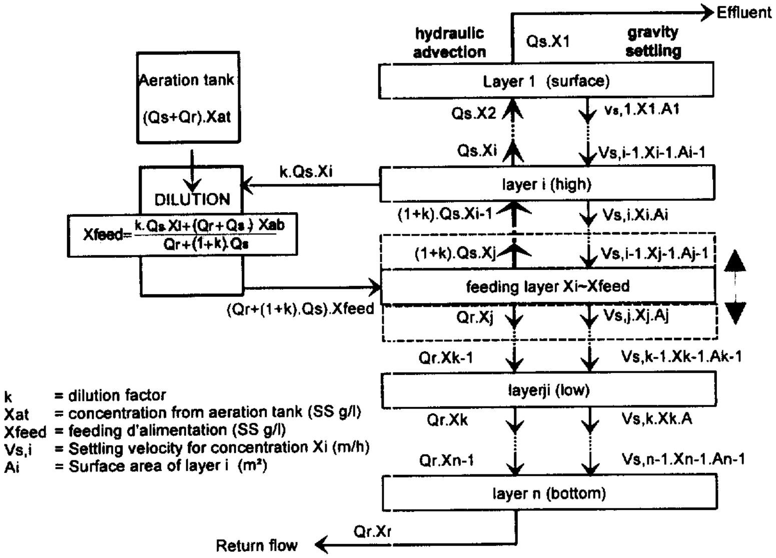

Figure3. Diagram of the structure of the model.

CALIBRATION AND VALIDATION

As stated above, a full-scale treatment plant has been selected for investigation purposes. It has been equipped with sensors to record flowrates, and sludge transfer between the aeration tank and the clarifier, as well as pollutant concentration at both inlet and outlet of the plant (Russell, 1994). The most important pieces of information used for the model are output flowrate, sludge blanket level, sludge concentration entering the clarifier and sludge return flow. Operating conditions were also monitored, as return pump and aerator operating sequences.

Two sets of data are available for the validation of the model:

Controlled overload experiments, for which an available stormwater basin, as well as a tertiary lagoon, are used to provide enough (waste)water to induce overloads during several hours. These experiments are scheduled in advance, so we can choose sludge concentration in the aeration basin, and to some extent its ability to settle. During one of these experiments, vertical concentration profiles in the clarifier have been measured, by the means of a multi-bottle sampling device.

Routine monitoring of treatment plant behavior over months, with a time-step of one hour. The quality of the information provided by this monitoring depends on the occurrence of rain events, and on operation problems.

Calibration of the model

To calibrate the model we have used a criterion for the goodness-of-fit between simulated results and measured ones. As the main "useful " and "verifiable" output of the model is sludge blanket level, we first used it as the sole criterion. However, we noticed that many equivalent sets of parameters could provide the same quality of simulation. So we included other measured data in the criterion. The concentration of recycled sludge was not considered as reliable enough, and we preferred vertical sludge profiles, although only few data were available. The criterion used to evaluate the efficiency of the calibration is:

$$QES = \frac{\sum_{t}\left(zsb_t - \hat{zsb}_t\right)^2}{\bar{z}sb} + \frac{\sum_{t}\sum_{z}\left(X_{t,z} - \hat{X}_{t,z}\right)^2}{\bar{X}}$$

with :
zsb_t = measured depth of the sludge blanket (m)
$\hat{zsb}_t$ = simulated depth of the sludge blanket (m)
$\bar{z}_{sb}$ = average measured depth of the sludge blanket (m)
$X_{t,z}$ = measured sludge concentration at depth z and at time t (g SS/l)
$\hat{X}_{t,z}$ = simulated sludge concentration at depth z and at time t (g SS/l)
$\bar{X}$ = average sludge concentration at depth z (g SS/l)

Thanks to this criterion we managed to achieve a very good calibration for our reference experiment.

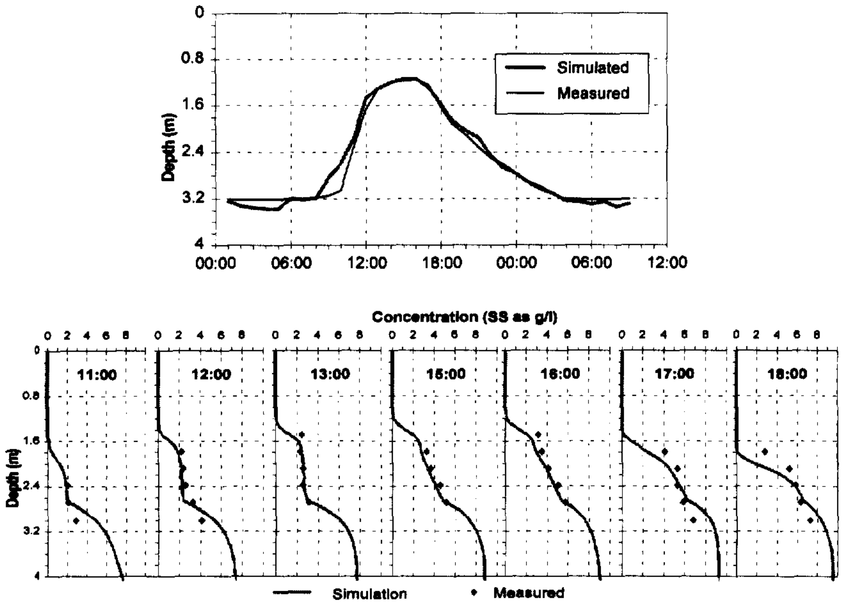

Figure 4. Calibration of the model according to the results of a controlled overload experiment.

Sensitivity

Figure 5 shows the sensitivity of the model regarding the settleability of sludge, described either by a parameter (DSVI) or by an input (sludge concentration out of the aeration tank). This sensitivity can be very important, when the sedimentation process is not overwhelmed by advection, that is to say when the sludge blanket reaches the upper part of the clarifier. Unfortunately, the model becomes sensitive in the most critical operating conditions.

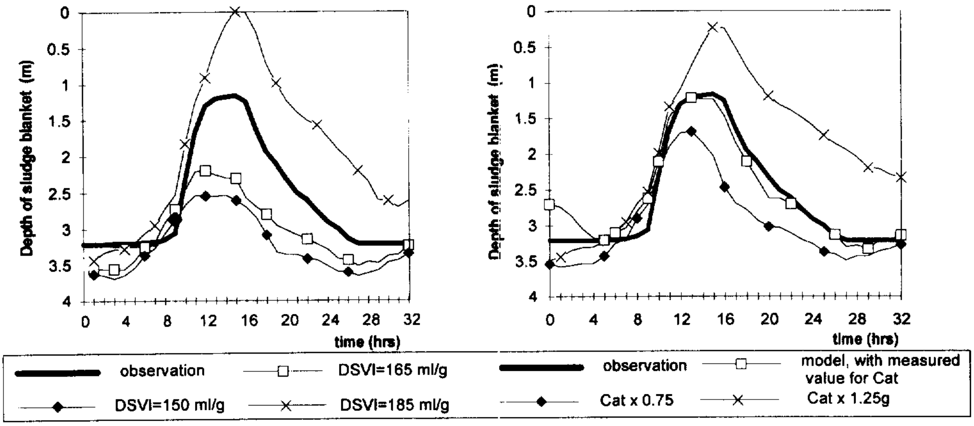

Figure 5. Sensitivity of one output of the model (sludge blanket depth) regarding the variations of one input (concentration out of the aeration tank) and of one parameter (Dilute Sludge Volume Index).

Long-term simulation

Ideally, once a model has been calibrated on the basis of reference data, it should be validated with new data, without changing the value of calibrated parameters. In our case this procedure is not easy to apply because of the following.

1. One of the inputs of the model is the concentration of sludge coming from the aeration tank. This concentration is not easy either to measure, or to simulate (as it varies along with the operation of aerators). We chose to use measured values. Still, even with some expurgated data, the results are not quite reliable.

2. The settleability of sludge is a parameter of the model, but it varies along with time, although not very quickly. This settleability may be described by indexes as sludge volume index, but these evaluations are rough, and involve so many uncertainties that they do not suit model validation.

So a direct comparison between model output and sludge blanket depth measurements is liable to reflect the quality of input values, or the luck in guessing settleability, rather than the ability of the model to simulate the process. Moreover, designing a criterion to assess the goodness of fit between simulated results and measurements is not easy. Because when a discrepancy appears, it can have long lasting consequences: if the model forecasts a sludge overflow, or simply a rising of the sludge blanket, which does not occur in reality, getting back "in pace" will be hard.

To overcome this problem, we tried another procedure. We still calibrated the model during the "validation" run, but this calibration is restricted to one parameter only (DSVI), from which the two parameters of sedimentation law are derived. Moreover this calibration must comply with some constraints, and the results must be "logical". If these requirements are met, the model will be considered as valid.

To decide whether the calibrated values of DSVI are logical, we designed a simple quality index for the measurement of sludge feed concentration. This index is the difference between each hourly value and the previous one, averaged on a daily basis. This index increases as more "noise" is present in the measurement.

The calibration process by itself is conducted on a daily basis. The mean error for one day is used to tune DSVI for the next day, with no backward effect on parameters and output values for older time steps.

Figure 6 shows that our model can usually fit observation with an adjustment of DSVI, which could reflect a real evolution of sludge settleability. When more drastic action is needed, this can be connected with the poor quality of input values, or abnormal operating conditions. These are usually stoppages of recycling, which may have different origins, such as a failure of scraper, or of the recycling pumps, or "sludge wastage events" (see Figure 7).

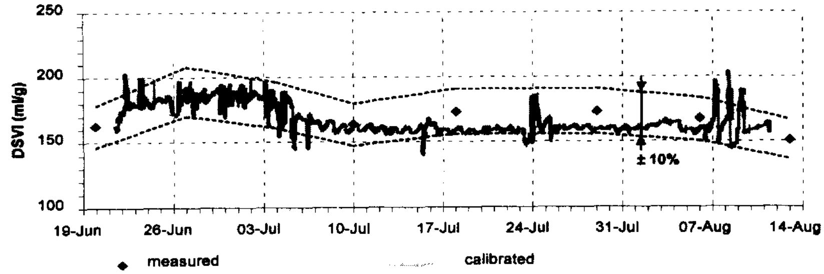

Figure 6. An example of continuous calibration results for DSVI, compared with measured results.

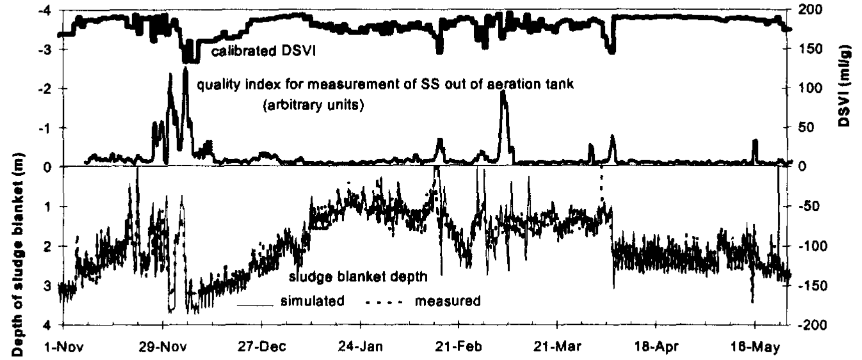

Figure 7. Comparison of simulated and measured depth of the sludge blanket, along with calibration results for DSVI, and values of a quality index for concentration measured out of the aeration tank.

USING THE MODEL

The main objective of the model was off-line optimizing of flow control strategy, on the basis of reference time series of incoming flows. The sensitivity to sludge settleability, either intrinsic or related to concentration, may be a problem for that purpose, unless one can assume that this parameter can remain constant by proper operating conditions. Nevertheless, it is more likely that its variation must be taken into account. Further investigations are needed to improve our knowledge of how the sensitivy of models to settleability affects flow control strategies, or if some strategies are robust.

Otherwise, the model can be used for on-line evaluation of settleability, but again further investigations are needed to understand better how to use this information to adapt flow control strategies, on a short-term perspective. So we still have not examined whether our model could meet the objectives quoted in the introduction of this paper.

However, the model already appears to be a valuable tool to validate measured data, and to get a better understanding of their meaning. On fig.7 we present a summary of a 6-month period in the life of the clarifier. The level of the sludge blanket displays several patterns of variation, on a time-scale ranging from one to several weeks. Sharp decreases of the sludge blanket level are linked to sludge wastage events: usually sludge is wasted daily, but in some case, the operator of the treatment plant uses more drastic actions: he stops the recycling pumps, to allow for the sludge to accumulate and concentrate in the clarifier. Several events of this kind occurred in the period, with very different effects. For instance, in December, this wastage was very efficient: sludge concentration in the aeration tank decreased dramatically, and so did the height of the sludge blanket in the clarifier. Then both went up gradually, and finally stabilized. At the beginning of April another wastage event was much less influential on aeration tank concentration, but it did succeed in lowering the sludge blanket level, which remained at a low level for several weeks. We plan to "replay" these events with the model, and give different values for concentration out of the aeration tank, or input flowrate, or DSVI, to know precisely what happens. Yet the event of March suggests that the clarifier may have several states of equilibrium.

As far as the validation of the results provided by the sensors is concerned, the discrepancies between recycling concentrations forecast by the model and measured values mean that measured values cannot achieve mass balance around the clarifier, and that the sensors must be checked.

CONCLUSION

Investigations conducted on a full-size treatment plant show that complex hydrodynamic patterns must be involved in the sludge separation and thickening process. The observation of a strong dilution below the feed well suggests that convection currents are responsible for both the dilution and the quick rising velocity of the sludge blanket under hydraulic overload conditions. Nevertheless, we tried to include this feature in a simple, one-dimensional model, based on the classical assumptions of flux theories. This model performance is good at simulating the behavior of sludge blankets, but appears highly sensitive regarding the settling characteristics of the sludge. Indeed, this feature is not to be ascribed to the specific structure of the model, as it is linked to its classical part, that is to say when dilution and convection can no longer develop. However, this may prevent the model from fulfilling one of its objectives, which is the off-line simulation of long time series to test operating strategies, especially regarding input flowrates. Nevertheless, other domains of uses are promising, which are more real-time oriented: checking of measured values, understanding of the behavior of the process, deriving some indicators, such as the sludge settleability index, which can be used by human operators, or automated control systems.

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