Modelisation of the contribution of sediments in the treatment process case of aerated lagoons

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H. Jupsin and J.-L. Vasel

University of Liege, Département Sciences et Gestion de l'Environnement, Unité Assainissement et Environnement, 185 Avenue de Longwy, 6700 Arlon, Belgium (E-mail: *jlvasel@ulg.ac.be*)

Abstract In aerated lagoons and even more in stabilization ponds the specific power (W/m^3) is not high enough to maintain all the suspended solids in suspension. Some part of the suspended solids (including biomass) settles directly into the reactor and not in the final settling pond. The gradual accumulation of those sediments on the pond bottom affects performance by reducing the pond volume and shortening the Hydraulic Residence Time. However, the role played by these deposits is not restricted to such a physical effect. Far from being inert sediments they are also an important oxygen sink that must be taken into account when designing aerator power and oxygen supply, for example. On the other hand, under aerobic conditions, the upper layer of sediments may contribute to the treatment as a biofilm compartment in the reactor. In aerated lagoon systems another process contributes to the interaction of deposits and the liquid phase: the operating (often sequencing) of aerators may induce a drastic resuspension of deposits. In a 3,000 m^3 aerated lagoon we evaluated that 3 tons of deposits were resuspended when aerators were started. Due to those processes we consider that a mathematical model of an aerated lagoon or of a stabilization pond has to take into account the contribution (positive and negative aspects) of deposits in the process. In this paper we propose a model for sediments including production but also biological processes. Simulations of the aerated lagoon with or without the "sediment compartment" demonstrate the effect and the importance of this compartment on the process. Of course a similar approach could be used for facultative or even maturation ponds. The next step would be to include anaerobic activities in the bottom layer.

Keywords Oxygen demand; ponds modelization; resuspension; sediment

Introduction

Usually the design of aerated lagoons is based on Eckenfelder's (1991) model. The main assumptions of this model are:

- a perfectly mixed reactor functioning as a chemostat
- no settling in the aerated lagoon: the biomass concentration in the outlet water from the pond is the same biomass as in the pond and settling will occur only in the settling pond.
- The sediments have no effect on the treatment. The accumulation rate is such that removal should be done approximately after 10 years which fits rather well with common practice on domestic wastewaters (Vasel, 1992).
- Aeration is calculated by the usual equations including catabolism and endogenous respiration, due to the fact that the sludge age, which in the case of a chemostat is also the HRT, is usually more than 10 days. Thus endogenous respiration has to be taken into account. The effect of sediments on total oxygen balance is often evaluated roughly by increasing the OC (Oxygenation Capacity) by 30% in summertime (Vasel and Namèche, 1994).

A comparison to the activated sludge process can be done by considering that the aerated lagoon is a process with low volumetric loading (around 30 g BOD m^{-3} d^{-1}) but

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relatively high F/M ratio (= ~0.3 kg DBO_5 kg X^{-1} d^{-1}). Nitrification can occur in the aerated lagoon when the temperature is favourable.

The way to manage the aeration system can vary greatly depending on the aeration system but also on the operator's know how. This may yield specific energy consumption in the range of 1 to 7 kWh cap^{-1} $month^{-1}$. This means that there is a demand to optimize aerated lagoon performances taking into account the effect of sediment but also the interaction between the hydrodynamics (Namèche and Vasel, 1998) of the pond and the aeration process.

The model

Schematically the model is composed of three sediment layers and a liquid phase as indicated in Figure 1. The liquid phase is a chemostat but with a settling function.

The hydrodynamics of the pond are described by a tank in series model where the number of tanks can be chosen by an equation proposed previously (Namèche and Vasel, 1998).

The sediment upper layer is aerobic (when the liquid phase above is also aerobic). Nitrification can also occur in this layer. The intermediate layer is anoxic with denitrification on the nitrate diffusing from the upper layer.

At present the bottom layer is just modelized to accumulate sediments with no anaerobic activity. The particles settled from liquid phase, as well as the biomass produced in both aerobic and anoxic layers, are transferred to the bottom layer. The thickness of those two upper layers as well as solid concentration are maintained constant.

The biological processes in those thin reactors are described by Monod equations and Petersen Matrix for those processes can be described. The exchange fluxes between aerobic and anoxic layers are approximated by a constant flowrate (Q2 on the figure).

The activity of the upper layer is calculated from a Sediment Oxygen Demand equation that was deduced from previous experiments (Chabir *et al.*, 2000). Assuming the respiration rate of sediments the other state variables are deduced.

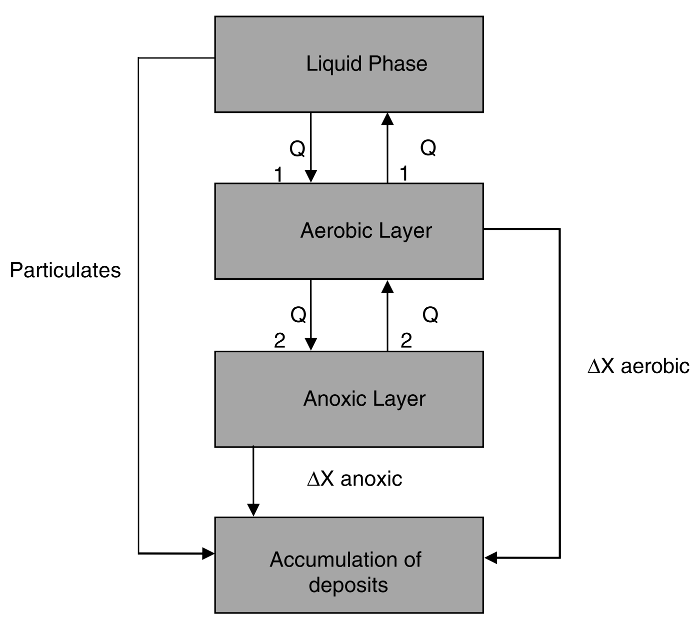

Figure 1 Scheme of the sediment model

In the case of an aerated lagoon another function is added to describe the resuspension of solid during aeration.

Inlet and outlet functions for the sediment compartment

Settling of suspended solids

As mentioned the biological activity in the various layers is described by Monod-like equations and the Petersen matrix corresponding to the IWA model 1.

To complete the model, inlet and outlet functions have to be described: the inlet function will be a settling function and, in the case of aerated lagoons, the outlet function will be related to the resuspension of sediments induced by the aeration process.

To calculate the effect of settling we adopted an equation first suggested by Joo-Hwa Tay (1982) to describe the combined effect of flocculation and settling. We verified that this model can be used to describe with a good accuracy the settling process in ponds and aerated lagoons (Rajbhandari, 2004). This equation is

$$\frac{X}{X_0} = \frac{1}{1 + \theta/t_{50}}$$

where X_o is the inlet SS concentration; X is the outlet SS concentration; θ is the hydraulic residence time; t_{50} is the time (experimental) to get 50% efficiency.

This model is simple and has only one parameter (t_{50}) that can be fitted from batch tests. For larger ponds the model needs little modifications to take into account the hydrodynamic of the system.

Resuspension of sediments

Very often the aerators in aerated lagoons are run intermittently to save energy. For example with a specific installed power of 5 W/m^3 the energy required for aeration is much lower than the energy required to maintain the solids in suspension. This may yield large specific energy consumption (around 6–7 kWh cap^{-1} $month^{-1}$). One of the ways to save energy is to run the aerators intermittently. The consequence is that settling will occur in the ponds. When aerators are started up again some of the sediments will be resuspended. In a 3,000 m^3 aerated lagoon located in Belgium we measured that at each aeration period about 3 tons of SS were resuspended (Vasel and Namèche, 1996).

An example is given in Figure 2. It can be seen that during aeration the suspended solids concentration starts to increase to reach progressively a maximum value, depending on the geometry of the pond and on the aeration system.

Such a curve corresponds well to a first order process that can be modeled by an equation such as

$$Ln(X_{\max} - X) = Ln(X_{\max} - X_0) - K_S{}^{*}t$$

where $X_{\max}$ is the maximum value that corresponds to a given pond; K_s is the experimental 'resuspension' parameter.

We evaluated those parameters in two types of aerated lagoons: with surface aerators and a diffused air system (Vasel and Namèche, 1994). The results are provided in Table 1.

Results and discussion

For the development of this model we decided to apply the procedure suggested by the IWA group on modelization for the development of this model. According to this procedure the first step is to get a realistic model based on the knowledge of the process,

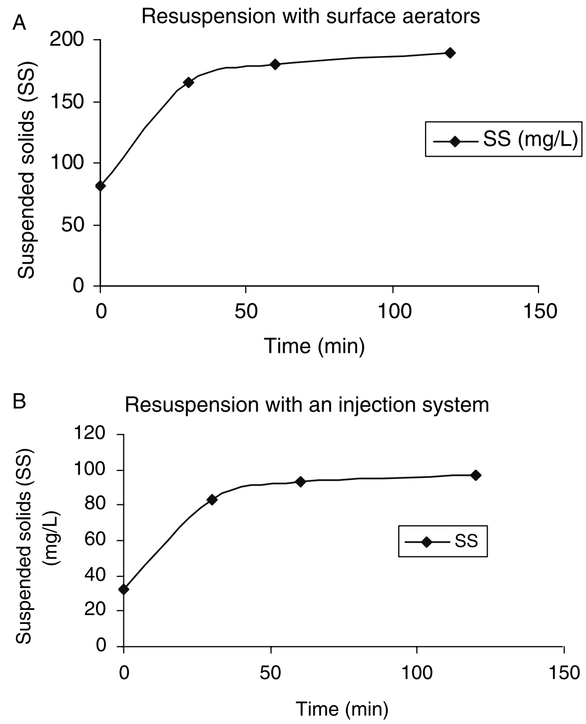

Figure 2 Sediment resuspension over time

using the usual parameters issued from IWA models for example, and without any fitting of parameters based on experimental data. We consider that this paper corresponds to this first step and further dedicated experiences, notably based on respirometry, are still needed to fit the final model. Our model development is also divided into three steps.

Step 1, we simulated the lagoon system as three ponds in series, which corresponds to many treatment facilities, but to express that the pond lagoons are not a perfectly mixed reactor, each of those ponds is simulated as a three perfectly mixed tanks in series system, and as a chemostat from the biological point of view. Simulations were compared to the abacus we developed previously to estimate the performances of aerated lagoons in series. The results are shown in Figure 3.

The points issued from the model are calculated at nearly "steady state" conditions.

To get these values, based on BOD_5 as main state variable, we had to modify slightly the following parameters: Y_h and K_s (half saturation constant for heterotrophs) of the IWA1 model. As can be seen, the model (chemostat) provides efficiencies lower than the previous methods based on real data.

Table 1 Resuspension of sediments (experimental results for two types of ponds)

	Pond 1 (surface aerators)	Pond 2 (diffused air)
Installed power (kW)	8.8	6.8
Specific power W/m^3	2.6	1.9
Surface influenced (m^2)	286.3	952.5
K_s (d^{-1})	35.7	21.6
K_s/area d^{-1} m^{-2}	0.125	0.023
K'_s (d^{-1}kW^{-1}m^{-2})	0.014	0.003
K''_s (m^3 d^{-1} W^{-1})	13.7	11.36

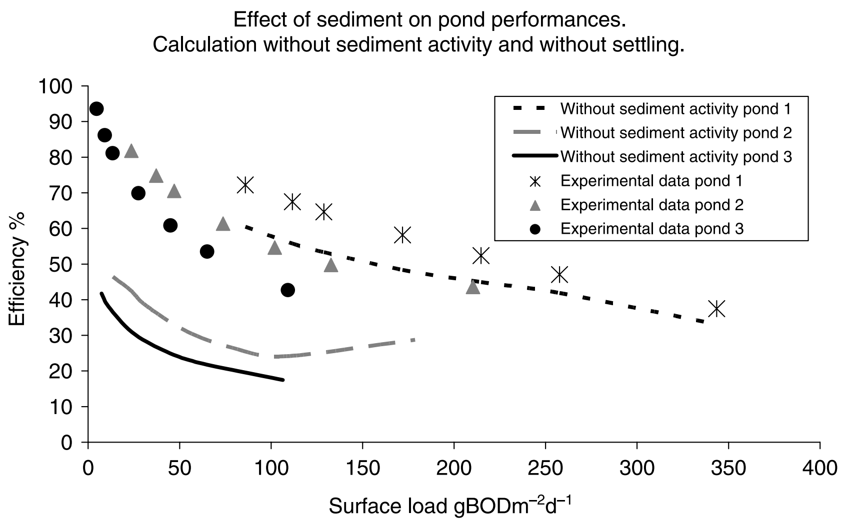

Figure 3 Efficiencies of aerated lagoons in series. Comparison to literature data

Step 2, we added the effect of sediments. The sediment compartment corresponds to the system described here above. In this step there were no inlet and outlet functions i.e. no settling and no resuspension of sediments. Only the biological activity of deposits was taken into account, with an accumulation rate corresponding to the biological synthesis. The results are shown in Figure 4. As can be seen, the efficiency of the ponds on BOD removal is increased by about 10% in our case.

Step 3 combines the effect of biological activities in the deposits and settling of inlet BOD and settling of a part of the suspended solids, including biomass. Results are presented in Figure 5. As can be seen, the global efficiency of the system can be evaluated in a rather realistic way.

To get those values, the t_{50} parameter of the settling model had to be changed, confirming that this parameter has to be quantified by an experimental procedure.

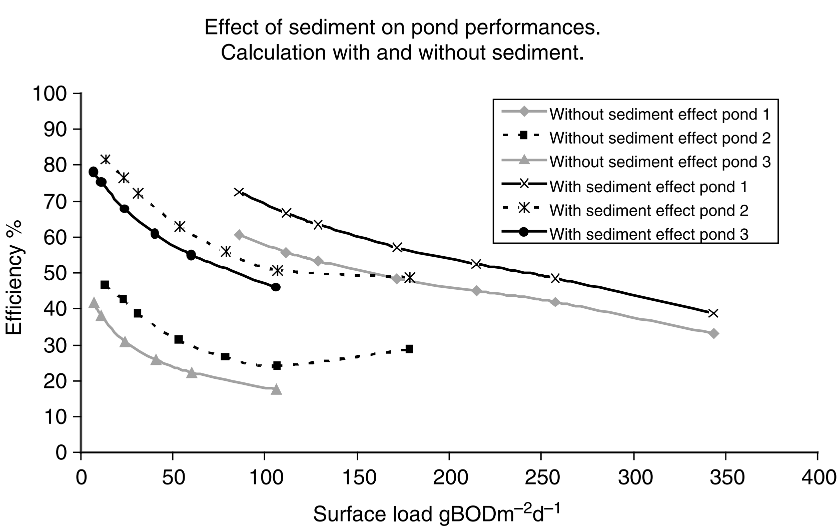

Figure 4 Effect of sediments. Comparison with the 'chemostat' model

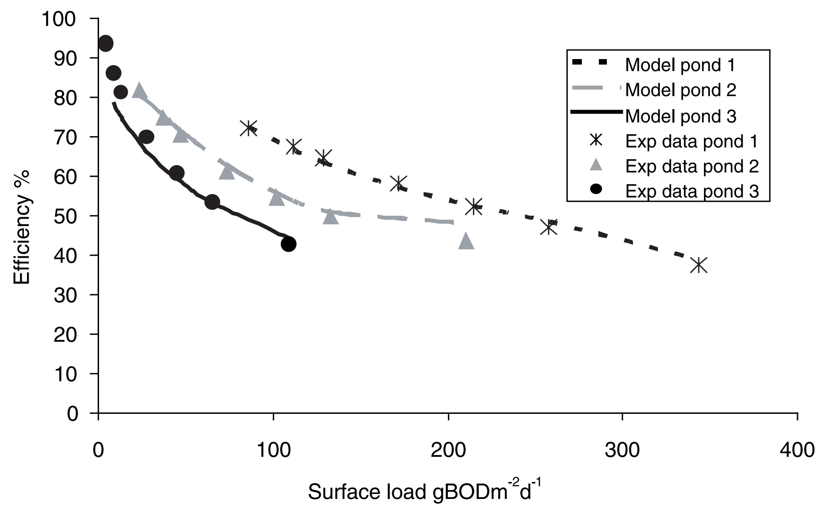

Figure 5 Comparison of model results with experimental data

The next step will be to evaluate the complete inlet–outlet functions for the sediment compartment. Then the model will be suitable to optimize BOD removal efficiency, but also to improve N removal by increasing the nitrification–denitrification processes. One of the ways for this optimization will be to manage the aeration system properly. Aeration has an influence, of course, on the oxygen balance and on oxygen availability for heterotrophs and for autotrophs as well. Meanwhile mixing in the pond is mainly due to the aeration process. Thus settling will increase when the aerators are stopped and resuspension will be directly affected by the running period of the aerators. Obviously a dynamic model should help greatly to optimize this bioreactor taking those processes into account.

Conclusions

The mathematical model developed for aerated lagoons fits well with data collected on various full scale facilities. It provides already a rather realistic representation of the aerated lagoon technology.

The first simulations demonstrate the rather important effect of sediments on the global performances of the system. From this model the effect of increasing the sediment area (reducing the water depth) for a given volume can be deduced.

The resuspension of sediments can also be evaluated. So far we cannot make an a priori calculation of this effect. Fitting of the "resuspension" model on experimental data on the system is needed. We hope that a further general correlation could be deduced based on geometry and specific power consumption when more data will be available.

The hydrodynamics of the pond can be described by tanks in series, but in this case an adaptation of the settling model is needed.

We consider that step 1 of the general model development methodology is reached.

The following steps will focus on better tuning of the model based on data collected on real scale facilities together with a dedicated experimental procedure to fit the settling and resuspension parameter appropriately.

Then the dynamic model will be used to define the best aeration cycles in each pond aiming at higher efficiencies for BOD removal but also at improved N removal. The net production of sediments would be calculated for longer time periods.

At this time, the model will be a very good tool to optimize aerated lagoon design and to save energy and operation costs. Various developing countries are interested in combining aerated lagoons with stabilization ponds. This can lead to simple and very robust technologies but the energy consumption has to be managed very carefully. We hope that this type of model will help this task greatly.

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