Application of Activated Sludge Model No. 1 to biological treatment of pure winery effluents: case studies

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Abstract The practical applicability of computer simulation of aerobic biological treatment systems for winery effluents was investigated to enhance traditional on-site evaluation of new processes. As there is no existing modelling tool for pure winery effluent, a model widely used for municipal activated sludge (ASM1) was used. The calibration and validation steps were performed on extended on-site data. The global soluble COD, DO and OUR were properly reproduced. Possible causes for the remaining discrepancies between measured and simulated data were identified and suggestions for improvement directions were made to adapt ASM1 to winery effluents. The calibrated model was then used to simulate scenarios to evaluate the plant behaviour for different operation or design. In combination with on-site observations, it allowed us to establish useful and justified improvement suggestions for aeration tank and aeration device design as well as feed, draw and aeration operation.

Keywords Aerated storage; ASM1; calibration; winery effluent

Introduction
From 1994 to 2001 Cemagref has evaluated a series of new biological treatment systems for winery effluents before they were widely launched on the market. The assessment of treatment performance, design guidelines, and operation strategies was usually performed on the first full scale plants set up at wineries in the Bordeaux area. The systems were monitored through sampling and sensor recording for at least 5 weeks during the peak pollution period (grape harvest and first stages of wine making). However they were often operating under unfavourable conditions, combining start-up of the biological activity and final process development, tuning, and troubleshooting by the manufacturers. It was thus difficult to draw conclusions about the treatment potential and best operation strategies of the plants under normal conditions.

This is why during the 2000–2001 campaigns, first trials were made to enhance the on-site evaluation procedure of aerated storage plants with membrane effluent separation with a computer simulation approach. As there is no specific modelling tool for pure winery effluent, existing model and software developed for municipal sewage were used. To describe the biological activity, the widely used Activated Sludge Model No. 1 (ASM1) was chosen. It has already been used outside its original application range, for mixed sewage containing a high food industry discharge fraction, including winery effluents (Beck et al., 2005), or even for pure pig manure (Boursier et al., 2002). The objectives of this work was to assess the applicability, restrictions and benefits of ASM1 to pure winery effluent treatment by aerated storage.

Methods
The treatment plants
The 3 monitored plants consist in a jet-aerated tank for biological degradation by aerobic suspended growth, and membrane microfiltration for treated effluent separation. This new
compact generation of aerated storage processes specifically designed for small wineries are described and evaluated in detail by Racault and Stricker (in press). The systems differ in the way the treated effluent is withdrawn. Plants B1 and B2 can be compared to a sequenced batch reactor. The tank is filled gradually for several days. When the maximum level and the objective COD concentration are reached, 2/3 of the volume are filtered out within a few hours by a high-flow mobile filter unit. The concentrate remaining in the tank is used as seed and dilution for the next cycle. Process A works in a more continuous way: the level in the tank is maintained between 2 limits through filtration at a low flowrate by a fixed filter unit as soon as the objective COD is reached. The main design characteristics of the 3 plants are summarized in Table 1.

The simulation procedure

The ASM1 (Henze et al., 1986) is a set of equations describing COD and N removal in activated sludge. It is based on bacteria population growth and decay processes. As for winery effluents the main concern is the organic carbon load, the nitrogen part of the model was switched off by setting nitrogen related population and parameters to zero. For COD the model considers inert, biodegradable and biomass fractions. The inert matter is then divided according to physical properties in soluble and particulate variables. The biodegradable matter is divided according to kinetic criteria in readily and slowly biodegradable variables. The biomass is only represented with one group called heterotrophs. They grow under oxic conditions on readily biodegradable COD (Ss), and slowly biodegradable substrate (Xs) after a hydrolysis step. Their decay generates some Xs which is recycled, and some inert particulate products Xp.

The simulation software GPS-X was used to build the plant’s layout and solve the ASM1 equations as a function of time. The layouts consisted in an influent, an aerated tank, and an ideal clarifier (zero volume, zero suspended solids in the effluent) representing the membrane filter. The operational and environmental conditions (feed, aeration, filtration, temperature) were input to the software based on the data loggings.

Calibration on batch tests. To collect appropriate model calibration data under well-controlled conditions, 4 batch tests were conducted on site by introducing one single initial pollution load into the storage tank and monitoring its degradation under continuous aeration for 3 to 6 days until the filtered COD was stabilized. The tank was initially either empty (tests 1 and 2), or contained some residual sludge from previous treatment cycles (tests 3 and 4).

Validation on 6 weeks actual operating. Plants A and B2 were monitored during their first peak season for 6 weeks as described in Racault and Stricker (in press). The 2 sets of data were used for model validation.
**Prediction scenarios.** During on-site evaluation the plants received lower influent loads than their design base and were handicapped by operation problems such as:
- various breakdowns of aeration or filtering devices which caused treatment delay (all plants)
- troubleshooting and tuning of automation (all plants)
- strong foaming which generated overflows (all plants)
- unusual rainfalls which generated high infiltration flows and caused dilution and overflows (plant B2)

Once the modelling tool was considered representative, it was thus used to predict behaviour of plant A and B2:
- with the real feed scenario but under ideal operation (ideal case) to determine the maximal treatment performance
- with design loading scenarios under ideal operation to test the design guidelines

**Results and discussion**

**ASM1 calibration on batch tests**

As all 4 cases cannot be shown here, case 1 will be shown as an example and the discussion will be extended to all cases.

The COD profiles are properly reproduced (see Figure 1). For DO and OUR the main trends are also reproduced but not all the variations. The simulation shows 4 main stages which can be better understood when looking at the single COD variables (Figure 2).

The first stage (0 to 0.5 d) with low but increasing oxygen demand is due to the initial biomass exponential growth, which could also be a reactivation period of existing biomass.

**Figure 1** Measured (dots) and simulated (lines) results for batch experiment 1

**Figure 2** Simulated evolution of the main COD state variables in the tank
The second stage (0.5 to 1.5 d) with high oxygen demand is due to the growth on Ss. Once it is all used, the OUR temporarily decreases until the second substrate Xs is utilized. The influent $S_{s0}/X_{s0}$ ratio was specifically adjusted to match this transition. Once the biomass runs out of both external substrates at 2.8 d, it starts to decrease by endogenous respiration or decay which generates a lower, slowly decreasing oxygen demand and some Xp accumulation. Together with the inert particles brought initially with the waste ($X_{i0}$), they account for residual particulate COD.

The measured OUR and DO curves show more complex variations: the model underestimates the amplitude of the first transition at 1.5 d, and cannot reproduce at all the other transitions at 2.3, 3.2 and 4.2 d. Several hypothesis can be made:

- If the transitions are indeed due to substrates, the winery effluents cannot be described with only 2 groups of substrates. Either more groups are initially present, or their degradation generates intermediate compounds which have different degradation rates and even some inhibitory effect.

- The transitions could also be due to changes in biomass. It is well known that in a batch successive communities develop and die, whereas ASM1 considers only one population standing for stabilized biocenosis under continuous feed. One obvious specific biomass group for winery effluent would be yeast. The microscope observations showed that yeast and bacteria co-exist and the abundance of each group fluctuates strongly with time. However the number is not a sufficient indicator of biodegradation activity. Furthermore, within each group, single species which cannot be identified through microscope observations probably relayed each other.

However, even though the OUR and sometimes the total COD were not too well represented, the soluble COD profile was properly represented for all batch tests. As this is what matters the most for the plant simulation and actual performance, it was decided to pursue the modelling work.

As no specific lab experiment could be conducted to determine the model influent COD fractions, they were roughly estimated by combining analytical characteristics of the input load and calibration on monitoring data from the batch tests. One result to be highlighted is that compared to municipal sewage, winery effluents have much higher readily biodegradable content ($S_{s0}$ 50–77%). This is confirmed by their lower COD/BOD$_5$ ratio and by fractionation tests conducted by Beck et al. (in press).

The kinetic and stoichiometric parameters related to the heterotrophic biomass and their Arrhenius temperature coefficients ($\theta$) were determined based on literature, modelling experience and curve fitting on COD, fCOD, OUR and DO for each batch test. They were calibrated on the part of the curves where they have the most sensitivity. Most parameters for growth, decay and temperature had to be changed from their default values for domestic wastewater. One result to be highlighted is that the cellular yield $Y_H$ had to be decreased to better match low particulate COD production and high OUR. This is consistent with previous observations that $Y_H$ is lower on highly degradable substrates such as sugar and alcohol than on domestic wastewater.

**ASM1 validation on plant under actual operating**

The actual measured and simulated data for plant A under actual feed are shown in Figures 3 and 4. The influent fractions were determined based on the weekly samples characteristics and the fractionation obtained for batch tests. The set of model parameters was deduced from the main trends found during batch test calibrations.

For the available data, the filtered COD is properly reproduced by the calibrated model. There is also a good correspondence between simulated low OUR periods and recorded high
DO periods, which indirectly validates the simulated oxygen demand and biological degradation activity.

Scenario simulations

Simulations for plant A are shown in Figure 5 as an application example. Its real performance during 6 weeks of evaluation was handicapped by several breakdowns of aeration totalizing 25% of the time (Figure 4) and filtration device (in service only after 14 Oct), and by underdesigned aeration capacity. The objective effluent concentration of 1,000 mgCOD/L was reached only after 4 weeks. How would have the plant performed without the technical disturbances and with doubled oxygen transfer rate?

The simulations show that without aeration breakdowns (ideal case 1 jet) the objective effluent concentration would have been reached from 7 Oct onwards. This means filtration could have started one day later than in reality but would have yielded compliant effluent right away. It would have required to store all the incoming volumes until 7 Oct, namely 33 m$^3$, while the real capacity is 30 m$^3$. This also shows that the storage tank design is too tight, and/or that an equalization tank with a few days of storage capacity would be a welcome safety equipment.

With twice the aeration power (ideal case 2 jets) filtration could have started on 28 Sept, 3 days only after the beginning of treatment scenario, and the required storage volume would have been 18 m$^3$ only.

During on-site evaluation plant A was actually underloaded compared to its design criteria in terms of volume (47%) and COD load (57%). Simulations showed that under full loading and ideal start-up and operation, the required storage volume would have been around 85 m$^3$. With a second jet, it would have required 43 m$^3$. 

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**Figure 3** Measured and simulated filtered COD

**Figure 4** Measured DO and simulated OUR

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Even though the predicted numbers are approximate values and must be used with safety factors, they still give good trends. Furthermore, the simulations helped to understand the dynamics of the system. The designers actually started to implement the aeration and tank volume design recommendations.

**Conclusions**

The applicability of a model designed originally for municipal activated sludge on pure winery effluent treatment through aerated storage process was investigated. From this first evaluation on on-site data from 3 plants we can conclude the following:

ASM1 is able to reproduce the global trends on 0.1–0.2 μm filtered COD, OUR and DO if the influent fractions and the model parameters are adjusted. However, ASM1 is not able to reproduce all the dynamic fluctuations because: the macroscopic lumping of substrates and biomass groups is too strong. For winery effluents at least 3 groups of substrates (readily biodegradable, readily hydrolysable, slowly hydrolysable) and 2 groups of biomass (heterotrophic bacteria and yeast) would be necessary.

The representation of interactions between biological dynamics and environmental parameters is too limited. The temperature effect on growth according to the Arrhenius equation is not adapted, and the pH effect is ignored. In addition, the reverse relationship of biological activity on pH and temperature is not represented.

Toxicity processes and biomass acclimatization are not represented. In winery effluents possible inhibition sources are intermediate biodegradation products and influent pollutants (such as accidental pesticide or chemical product input). This is because aerated storage of winery effluent works under much less stabilized biological and environmental conditions than municipal activated sludge systems.

Even though the predictions must be used with a safety factor; as biodegradation rate and influent fractionation fluctuations are not taken in account in the simulations, they still give indicative answers to questions which could not have been answered easily based on the sole on-site monitoring data and standard calculation tools. The practical simulation benefits for improvement of treatment plant design and operation show that it would be worthwhile to develop a specific modelling tool for aerobic pure winery effluent treatment. The ASM1 reduced to its COD part could be used as a base. The shortcomings were identified based on on-site studies, but to extend the model in the suggested directions, some intensive lab and development work would be necessary.

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References


