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Risk Assessment Module of the IWA/COST simulation benchmark: Validation and extension proposal.

Jordi Dalmau

Ignasi Rodríguez-Roda

Jean-Philippe Steyer

Joaquim Comas

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J. Dalmau*, I. Rodríguez-Roda*, J. P. Steyer, J.Comas***
* Laboratory of Chemical and Environmental Engineering, University of Girona. Campus Montilivi s/n, E-17071, Girona, Catalonia Spain (E-mail: jordi/quim/ignasi@lequia.udg.cat).
** Laboratoire de Biotechnologie de l'Environnement, INRA. Avenue des étangs – 11100 Narbonne, France (e-mail: steyer@ensam.inra.fr)

Abstract: The IWA/COST simulation benchmark platform has been widely used to evaluate and compare different activated sludge control strategies. The IWA/COST simulation benchmark provides performance indices like the effluent water quality, operating costs and controller performance (Copp, 2002), all of them quantitative. However, these indices do not take into account the biomass separation related problems which at present cannot be quantitatively modelled. A qualitative *Risk Assessment Module* adaptable to any simulation benchmark platform has been developed for the activated sludge systems. As a consequence, and in order to improve the quantitative performance indices, lately the anaerobic digestion model number 1 (ADM1) has recently been implemented in the benchmark platform, BSM2, (Jeppsson *et al*. 2006) to provide a plant-wide model for simulation. The *Risk Assessment Module* thus needs to be extended to also cope with anaerobic digestion problems of qualitative nature. The proposal and preliminary intentions for both extension and validation are discussed in the present paper.

Keywords: ADM1; benchmark; BSM2; modelling; solid separation problems; validation.

1. INTRODUCTION

1.1 Activated Sludge processes

In an Activated Sludge (AS) process, the wastewater (organic matter, suspended solids and nutrients) is mixed with biomass (sludge), composed by a wide variety of microorganisms. After enough contact time, under the desired reaction conditions: Temperature, Dissolved Oxygen (DO), pH… This mixture is discharged to a secondary settler where the suspended biomass is separated from the treated water.

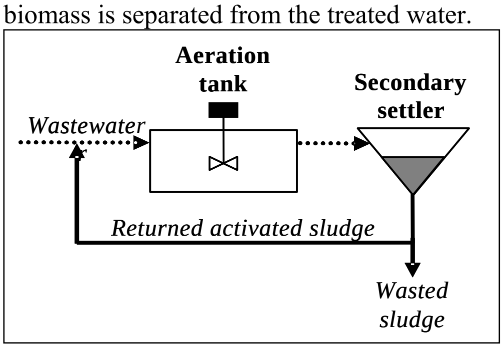

Figure 1. Activated Sludge system

Most of the biomass is recycled into the aeration tank but part is continuously wasted from the system **(Figure 1).** Since the AS process involves a multi-specific microorganisms population constitutes a complex system that often evolves to imbalances causing severe operational problems. The most important biomass related problems are:

i. Filamentous bulking: Mainly caused by low DO in the aeration tank. These conditions favour the growth of filamentous bacteria. This, difficult the separation between the biomass the treated water.

ii. Filamentous foaming: Some filamentous organisms can cause large foams throughout the aeration tank and secondary settlers.

iii. Rising sludge: Due to uncontrolled denitrification in secondary settlers. Nitrogen gas generated inside settlers cause the sludge to rise, leading to biomass lost.

1.2 Anaerobic Digestion (AD) processes

As Lardon L. *et al.* (2004) describe, Anaerobic Digestion (AD) is a set of biological processes that take place in the absence of oxygen and by which organic matter (contained in wasted sludge) is decomposed and converted on one hand into biogas (i.e., a mixture of mainly carbon dioxide and methane) and, on the other hand, into microbial biomass and residual organic matter. AD systems include basically the sludge digestion tank, where the biogas is produced **(Figure 2)**.

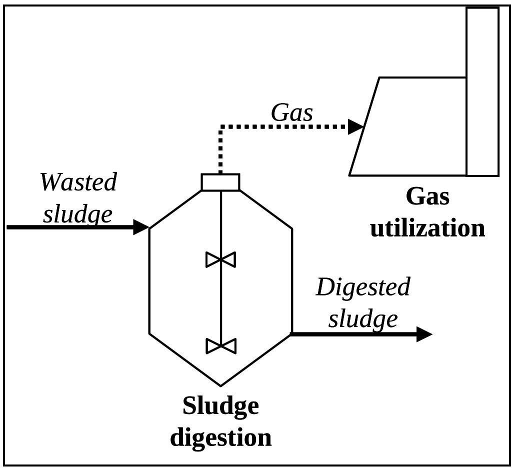

Figure 2. Anaerobic Digestion system

Several advantages are recognised to AD processes when used as WWTPs: high capacity to treat slowly degradable substrates at high concentrations like wine vinasses or aerobic sludge, very low sludge production, potentially for valuable intermediate metabolites production, low energy requirements and possibility for energy recovery through methane combustion. AD is indeed one of the most promising options for delivery of alternative renewable energy carriers, such as hydrogen, through conversion of methane, direct production of hydrogen, or conversion of by-product streams.

1.3 The IWA/COST simulation benchmark

The IWA/COST simulation benchmark has been often used by the wastewater research community as a standardized simulation protocol to evaluate and compare different control strategies for a biological nitrogen removal process. It includes a plant layout, simulation models and parameters, a detailed description of the influent disturbances (dry weather, storm and rain events), as well as performance evaluation criteria to determine the relative effectiveness of proposed control strategies (Copp, 2002). The plant layout consists of five completely mixed reactors, including a pre-denitrification section. The activated Sludge Model (ASM1) was selected to model the biological processes (Henze *et al.* 1987) while Tákacs ten-layer model was chosen to describe the settling processes (Takács *et al.* 1991). Several applications of the IWA/COST simulation benchmark can be found in literature demonstrating the performance of different control strategies when tackling the influent disturbances (see for example, Vrecko *et al.*, 2002; Zarrad *et al.*, 2004).

The absence of basic knowledge about the interactions mechanisms between the microorganisms communities and operational parameters, which are not described by standard models, is an obvious limitation when evaluating control strategies via simulation. Experience show that mechanistic models sometimes have limitations at predicting some real behaviours of the process once the model is confronted with reality (Sin *et al.*, 2005). For this reason, an extension of the IWA/COST simulation benchmark was developed, which includes expert reasoning for the system performance evaluation. In this context, an expert reasoning module called *Risk Assesment Module* was developed to detect favouring conditions for filamentous bulking, foaming, rising and, later, deflocculation (Comas *et al.*, 2006).

Plant-wide modelling in the wastewater treatment field is attractive to many researchers as it provides a holistic view of the process and it allows for a more comprehensive understanding of the interactions between the various unit processes. Plant-wide modelling is also an important tool for development and testing of new control and monitoring schemes for wastewater treatment (Rosen *et al.*, 2005). So the ADM1 model (Batstone *et al.* 2002) has been included into the BSM2 benchmark in order to provide a plant-wide simulation platform which considers primary and secondary settlers, thickener, and anaerobic digester in addition to the activated sludge process (Jeppsson *et al.*, 2006).

This evolution of the IWA/COST simulation benchmark and the several platforms (BioWin™, EFOR™, GPS-X™, Matlab/Simulink™, Simba®, STOAT™, WEST® and user defined FORTRAN code), where it is implemented, leads to additional operating conditions and control strategies that have to be qualitatively evaluated, in addition to the existing evaluation criteria. It is therefore, was necessary to develop and to implement the *Risk Assessment Module* to all the platforms in which the IWA/COST simulation benchmark is implemented. Moreover, the *Risk Assessment Module* has to be validated in order to ensure its reliability for the activated sludge systems. Finally, an extension for the *Risk Assessment Module* considering AD model has to be proposed, according to the inclusion of ADM1 to the BSM2.

1.4 Risk Assessment Module

The *Risk Assessment Module* has been developed following the basis set in Cortés *et al.* (2000) and Poch *et al.* (2004). It has been done through a careful analysis at the biomass separation related problems and by collecting experimental data and acquiring the knowledge of the process from the experts and manuals. The most common biomass separation related problems are represented (i.e.: filamentous bulking, filamentous foaming; rising sludge and deflocculation). The most important element in this module is the knowledge base. It consists in a set of rules for each biomass related problem. **Figure 3** shows an example of a set of rules used by the system. The inference of the *Risk Assessment Module* is performed by a rule-based fuzzy system. This knowledge base is presently being verified by a group of international experts.

2. EXTENSION OF THE RISK MODULE

In order to extend the *Risk Assessment Module* to the overall plant-wide BSM2 benchmark, a proposal for the development of the *Risk Assessment Module* using standard modelling and equations has been developed. This proposal allows the different benchmarking groups to have at their disposal the *Risk Assessment Module*, which was first developed using Matlab, in their own software simulation platforms.

Another extension of the *Risk Assessment Module* is to include detection of different problems related to anaerobic digestion; Volatile Fatty Acids (VFA) inhibition, toxicant presence, hydrolic and organic overload (Lardon *et al*, 2004). Uncertainty wihin these problems will be studied to be faced with using the evidence theory (Lardon *et al.*, 2004).

Once this *Risk Assessment Module* is extended and validated, it will provide very helpful qualitative evaluation criteria that will efficiently complement quantitative criteria. It will include most of the main operational problems for the plant-wide BSM2 evaluation of the control strategies.

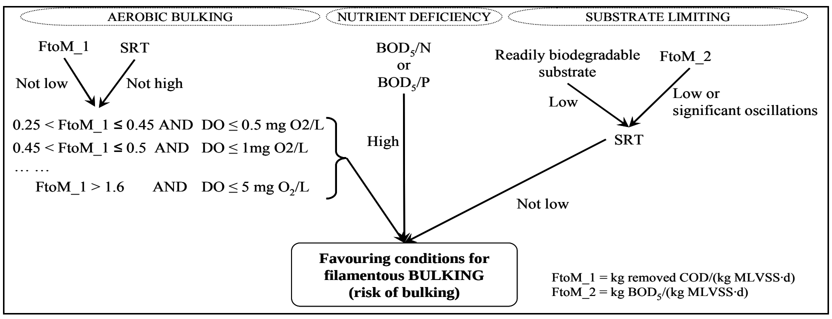

Figure 3. Flow diagram developed to evaluate the risk of filamentous bulking.

3. VALIDATION

The *Risk Assessment Module* for the IWA/COST simulation benchmark performance has to be evaluated with real data from pilot or full-scale plants which have experienced operational problems of qualitative nature. The validation has thought to be performed by following a 5-step procedure: (i) taking real data from pilot or full-scale plants; (ii) run the *Risk Assessment Module* using the real data as input; (iii) analyze and compare the *Risk Assessment Module* results with the real ones concerning operational problems of microbiological origin; (iv) modify the knowledge base of the *Risk Assessment Module* according to the results of step iii; (v) if a mechanistic model of the pilot plant or full-scale plant is available, run the *Risk Assessment Module* with the simulated data of this model in order to detect microbiologically-related operational problems. Although a mechanistic model would not be able to predict the separation problems, the *Risk Assessment Module* would have to do it with the same simulated data. On the other hand, it could be interesting to validate the *Risk Assessment Module* with normal operational data from a real plant. Likewise, it can be assured that the system will not detect problems which are not there.

However full-scale plant real data can have a limitation because all the needed data to run the *Risk Assessment Module* is not always available in real plants. In this case the gaps in the real data files will represent a problem. For this reason it is interesting that the plant had been modelled because in some cases the real data files can be filled with simulated data.

4. FUTURE WORK

To sum up, the first set of rules of the *Risk Assessment Module* for the activated sludge part of the IWA/COST simulation benchmark is going to be validated with real data from a SBR pilot plant. Soon the rest of rules will be validated.

Interviews with anaerobic digestion experts have to be arranged shortly to begin with the extension of the *Risk Assessment Module*.

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