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Effect of Sensor Location on Controller Performance in a Wastewater Treatment Plant

U. Rehman*, M. Vesvikar*, T. Maere*, L. Guo, P.A. Vanrolleghem** and I. Nopens***

*BIOMATH, Department of Mathematical Modelling, Statistics and Bioinformatics, Coupure Links 653, 9000 Gent, Belgium. (E-mail: usman.rehman@ugent.be, mehul.vesvikar@ugent.be, thomas.maere@ugent.be, ingmar.nopens@ugent.be)
** model*EAU*, Département de génie civil et de génie des eaux, Université Laval, Québec, QC, Canada. (E-mail: lisha.guo.1@ulaval.ca, peter.vanrolleghem@gci.ulaval.ca)

Abstract: Complete mixing is hard to achieve in large bioreactors in wastewater treatment plants. This often leads to a non-uniform distribution of components such as e.g. dissolved oxygen and the process rates depending on them. Furthermore, when these components are used as input for a controller, the location of the sensor can potentially affect the control action. In this contribution, the effect of sensor location and the choice of setpoint on the controller performance were examined for a non-homogeneous pilot bioreactor described by a compartmental model. The impact on effluent quality and aeration cost were evaluated. It was shown that a dissolved oxygen controller with a fixed setpoint performs differently as function of the location of the sensor. When placed in a poorly mixed location, the controller increases the aeration intensity to its maximum capacity leading to higher aeration costs. When placed just above the aerated zone, the controller decreases the aeration rate resulting in lower dissolved oxygen concentrations in the whole system, compromising effluent quality. In addition to the location of the sensor, the selection of an appropriate setpoint also impacts controller behavior. This suggests that mixing behavior of bioreactors should be better quantified for proper sensor location and controller design.

Keywords: Activated sludge process; Compartmental modelling; Instrumentation; Process control

INTRODUCTION

Control strategies have become state of the art in wastewater treatment plants (WWTP) to achieve cost-effective and optimized operational system behavior (e.g. Olsson et al., 2005; Olsson, 2012). Hereby, on-line sensors are used to gather process information and action is undertaken depending on the system's state (feedback control). The location of sensors is discussed in previous studies (e.g. Waldraff et al., 1998), but it often concerns the development of observers that are used as an input to controllers. Controllers are typically designed based on process models that are mostly approximated by a tanks-in-series approach. Hence, at most the effect of sensor location along the advective flow direction (1D) can be simulated. However, the number of tanks is usually chosen small (for computational reasons) and all tanks are considered completely mixed. In this way they average out local variations occurring in the other 2 dimensions. In reality perfect mixing never occurs: inefficiently mixed reactors possess less well mixed regions or even dead zones resulting in a non-uniform environment.

The current main driver for choosing the location of on-line sensors is easy accessibility for maintenance. The fact whether the sensor is located in a place that severely deviates from the average value in that section is usually not considered. However, since this local value provides the input to the controller, it directly impacts its behavior and success. This contribution illustrates this impact for an ill-mixed system of which a compartmental model was derived based on a CFD model.

MATERIALS & METHODS

The compartmental model of a pilot-scale channel reactor (Figure 1) giving a good representation of real mixing behavior (Le Moullec et al., 2010, 2011) was adopted. Controller performance was evaluated in terms of aeration cost and effluent quality. The model was implemented in the modelling and simulation platform WEST® (mikebydhi.com) and used the Benchmark Simulation Model No.1 (BSM1) dry weather influent with dynamic diurnal effects (Gernaey et al., 2013). The reactor was divided into six slices along the length and each slice was further divided into four compartments depending on mixing behavior and occurrence of aeration input (24 compartments in total; Figures 2 & 3). Compartments are coupled by bidirectional fluxes. For clarity, each compartment in a slice is labelled as GR, RL, CR and CN (Figure 2). These labels are accompanied by the numbers 1 to 6 where 1 represents the first slice at the entrance and 6 is the last slide near the outlet (Figure 3).

RESULTS & DISCUSSION

The objective is to design a DO controller for cost-effective system performance. Different PI controllers were tested differing with respect to the placement of the sensor (GR1, GR3, GR6, RL6 and CR6). These locations were selected based on the fact that usually DO is measured near the bioreactor outlet and at the water surface (easy access for maintenance). Controller settings have been kept fixed for each sensor location to only see the impact of the location. The setpoint was chosen as 1.5 g/m^3. The effluent regulations in BSM1 impose constraints for BOD, NH_4-N and total nitrogen, 10 g/m^3, 4 g/m^3 and 18 gN/m^3, respectively (Gernaey et al., 2013). Effluent quality and DO in the effluent was measured in the final compartment named RL6 as this is the actual outflow from the reactor. Results in the form of effluent quality and aeration cost per day are shown in Figure 4. It is evident from the figure that when the sensor is placed in the GR compartments where aeration is actually taking place, BOD and ammonia concentrations in the effluent are quite high. Indeed, aerated GR compartments have higher DO concentrations as compared to other compartments where oxygen is transferred only by advection with the liquid phase in absence of air bubbles. The DO setpoint is easily reached by local higher values of DO in GR compartments. As a result the controller reduces the aeration rate, which leads to low DO levels in the other non-aerated compartments. This explains the higher BOD and NH_4 levels in the effluent for these cases as lower reaction rates occur due to low DO levels in the non-aerated zoned. Changing location between GR1, 3 and 6 did not result in significantly different behavior.

When the sensor is placed in the RL and CR zones with low DO values, the controller keeps on increasing aeration (within the blower specs) to achieve the setpoint. In these poorly mixed zones the setpoint is hard to reach and the maximum capacity of aeration is attained before the setpoint is achieved, resulting in good effluent quality in terms of ammonia removal, but at very high aeration cost. The DO concentration in GR zones is found to be as high as 7 g/m^3. This analysis leads to the obvious control optimization of changing the setpoint to higher values when the sensor is placed in GR zones or lowering it when placed in RL zones.

Three different setpoints were applied in both GR6 and RL6 compartments. The results of these six simulations are shown in Figure 5 (RL6-1.5 corresponds to the sensor being placed in the RL6 compartment with a DO setpoint of 1.5 g/m^3). It is observed that increasing the DO setpoint in the GR zones causes an increase in aeration and better oxygen transfer to the other compartments resulting in lower BOD and ammonia concentrations in the effluent, however at higher aeration cost. Also, the gain from 1.5 to 2 g/m^3 is larger than from 2 to 2.5 g/m^3. Decreasing the setpoint in RL zones resulted in lower aeration costs while maintaining good effluent quality. It is to be noted that the aeration cost in the case of RL6-0.5 is still two and a half times higher compared to GR6-2.5.

CONCLUSIONS

Due to the complex mixing behavior of full-scale reactors, tanks-in-series models usually used in models for development of controllers are not very realistic because they are severely oversimplifying real mixing behavior. A compartmental model that refines the mixing behavior showed that in order to achieve cost-effective DO control the sensor location and setpoint are of importance. Hence, this should be embedded in a control design protocol. Another path forward is to redesign reactors and embedded aerators to better achieve completely mixed conditions. However, it must be investigated whether this does not lead to reduced process efficiency or increased construction costs.

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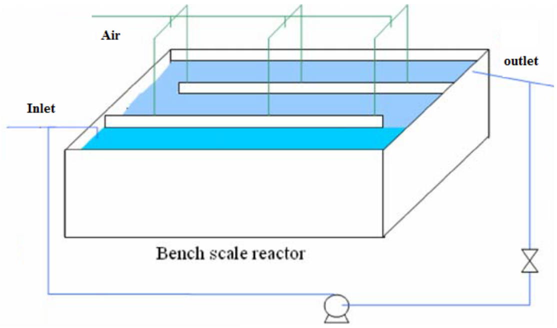

Figure 1: Pilot-scale reactor (Le Moullec et al., 2010)

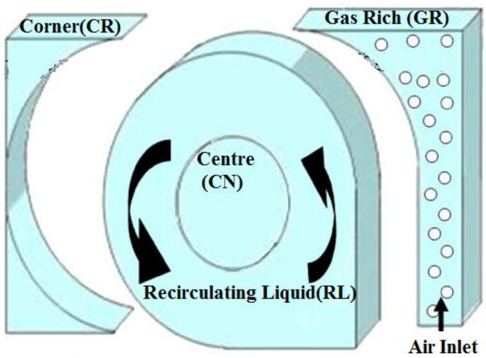

Figure 2: Cross-sectional compartments (Le Moullec et al., 2010)

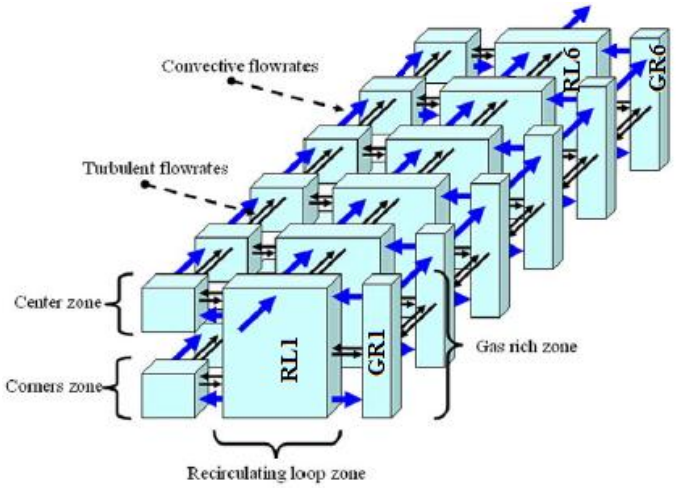

Figure 3: Compartmental model layout

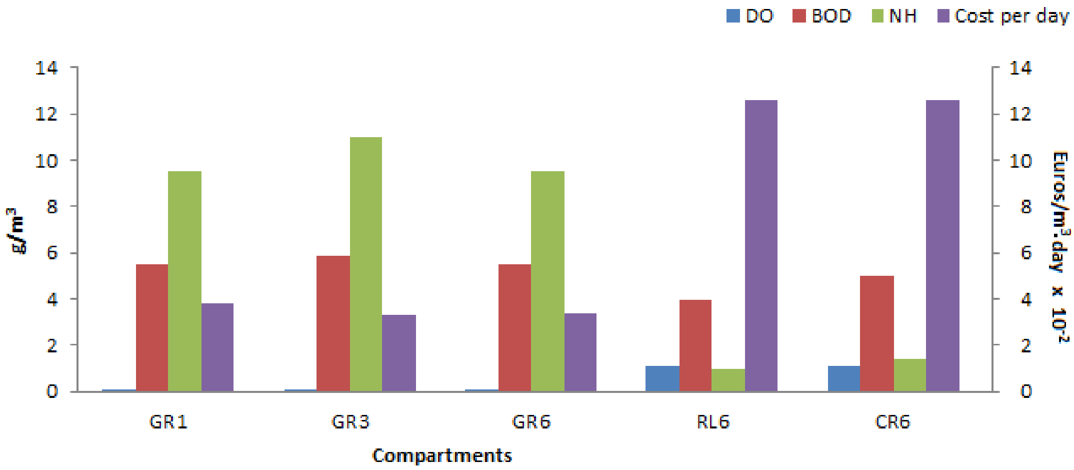

Figure 4: Effluent quality & aeration cost per day with a fixed DO setpoint of 1.5g/m^3

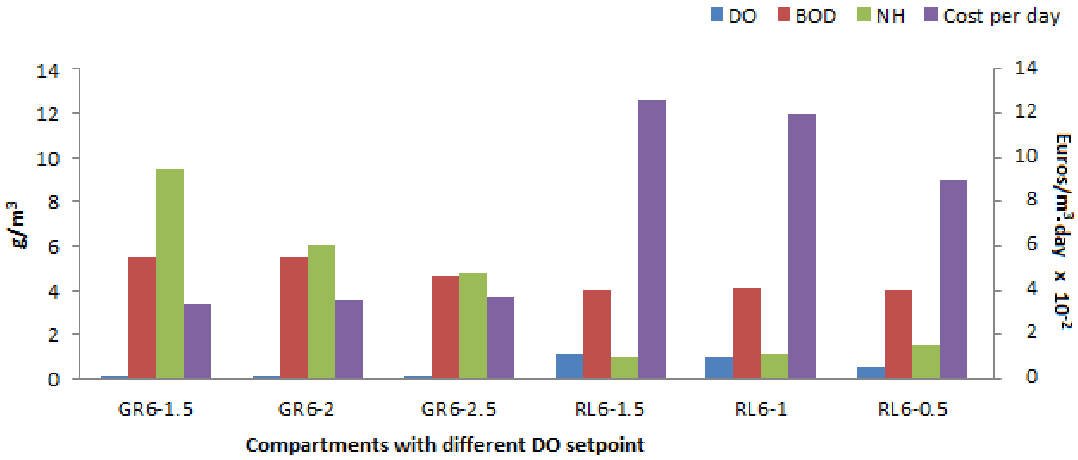

Figure 5: Effluent quality & aeration cost per day with varying DO setpoints