# A MODEL-BASED EVALUATION OF CONTROL STRATEGIES FOR A CLARIFIER AT AN INDUSTRIAL WASTEWATER TREATMENT PLANT

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The aim of this paper is to determine appropriate control strategies for a clarifier at an industrial wastewater treatment plant. This work is part of a larger project aimed at upgrading the control and operational practices of the full treatment plant, including the development of local and supervisory control systems. Five control strategies are proposed, implemented in a simulation environment and evaluated. The strategies used as measured variable, the sludge blanket height, which has been shown to correlate with the control objective, the effluent suspended solids concentration. The manipulated variable was the quantity of polymer added to the system. The strategies were evaluated in terms of their ability to maintain the sludge blanket height below 1.5m, their polymer requirements, their sensitivity to poor tuning and the required control action. The final choice of controller will be based on the ease and cost of implementation.

## KEY WORDS

local control, secondary clarifier, simulation studies

## INTRODUCTION

A 14 000PE industrial wastewater treatment plant located in Belgium will soon undergo a major upgrade in its control system and operational practices. This upgrade includes the development and implementation of local controllers and a supervisory control system. One of the units requiring development of a local control system is the secondary clarifier. It is the aim of this paper to present an evaluation of possible control strategies for the clarifier. To start, the clarifier and its current operation will be described. Then possible control strategies will be proposed. The methodology chosen for evaluating the control strategies was one based on simulation. The results of the evaluation are presented last.

The clarifier under investigation is, on average, critically loaded according to the operating diagrams of Daigger (1995). This means that the clarifier is overloaded during peak flows. In order to prevent massive wash-out of sludge from the clarifier, polymer (Zetag 88N) is currently added continuously at the overflow weir of the aeration tank. Dosing is adjusted according to operator experience. The mean concentration dosed is 13ppm at a rate of 2000 l of pure polymer/month. This costs the plant 10 000Euro/month.

The aim of the control strategy is to minimise the concentration of suspended solids in the effluent whilst minimising the polymer dosing. Development of the control strategy requires that a choice be made regarding the measured variables and the manipulated variables.

Possible measured variables are listed below.

- The effluent suspended solids: feedback control strategies based on this variable can only become active once there is an increase in effluent suspended solids which is obviously too late. Thus, this variable is inadequate for control (Müller and Krauth, 1998).
- The solids flux (the product of the influent flowrate and sludge concentration ($X_{infl}Q_{infl}$)) to the clarifier.
- The sludge volume loading (the product of the influent flowrate and sludge volume ($SSV_{infl}Q_{infl}$)).
- Hydraulic loading (influent flowrate($Q_{infl}$)).
- The height of the sludge blanket (SBH): observations during studies of full-scale clarifiers showed that the effluent suspended solids concentration only rose significantly when the sludge blanket exceeded a critical level (Stowa, 1981a; Deininger, 1994; Nyberg *et al*., 1996; Müller and Krauth, 1998). This level appears to be dependent on the clarifier design. For the clarifier under investigation, simulation studies used to determine the correlation between the sludge blanket height and the effluent height showed that 1.5m was the critical height (Vanderhasselt *et al.,* 1999).

The strategies evaluated incorporated one or more of each of these measured variables except the effluent suspended solids for the reason given above.

The number of manipulated variables that can be used to achieve the control action is limited. There are possibilities for either physical and/or chemical means of control. Possible physical means of control include: manipulating the sludge waste flowrate; manipulating the recycle flow rate; using a step feed, however, this requires retrofitting the plant; and limiting plant influent. The final possibility is the most stringent control action and is only possible if appropriate hydraulic buffering is present or if occasional bypassing of unpurified water is acceptable (Nyberg *et al.*, 1996). The possibility of using these manipulated variables for control is limited.

The alternative is chemical control, that is, the dosage of additives such as organic polymers (Vanderhasselt and Verstraete, 1998) that enhance the settling properties of the sludge entering the settler. If an appropriate additive is used then it can be a promising means of control because it is typically fast acting. Stowa (1981b) successfully used a polymer to prevent the wash out of sludge during wet weather conditions. This is the means of control chosen for the clarifier in question.

It remains now to determine which is the most appropriate measured variable and what control law should be used. The methodology used to evaluate possible control laws is outlined next.

## METHODOLOGY

Two methodologies were considered for use in evaluating an appropriate control strategy. Firstly, the control laws could be tested using the clarifier itself. This would require the acquisition of a number of sensors to measure the variables listed above, development of controllers and controller tuning, evaluation for a prolonged period of time to eliminate inherent variation, and consequently, would be expensive. Also, testing on the full-scale installation might jeopardise its operation. The other disadvantage of such a methodology is that each of the control strategies would be tested under different disturbances, possibly giving biased results. The second alternative is the more appropriate. It is to use a simulation environment with a model of the clarifier to develop and test the control strategies. It is less expensive, does not intrude on the operation of the plant and the same disturbances can be simulated for each of the control strategies. This was the methodology chosen.

A one-dimensional settler model was constructed in West++®[1]. It consists of ten layers with the inlet in the fourth layer from the top. The sedimentation velocity describing the propagation of the flocs through the settler as a function of the local floc concentration was described by the Vesilind (1968) equation. It was assumed that the polymer attaches to the flocs and propagates through the settler. Thus, mass balances on the polymer were required for each layer and the propagation of the polymer modelled proportional to the

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[1] West++® is an environment for the dynamic modelling and simulation of wastewater treatment plants (Hemmis, Kortrijk, Belgium http://www.hemmis.be/en/default.htm)

floc propagation. This model was shown to be a satisfactory representation of the settler (Vanderhassalt *et al.*, 1999).

The data set used to evaluate the controllers was a 2500 hour full-scale data set of on-line clarifier influent flow rate measurements (averaging 175m$^3$/hour) and off-line sludge concentration measurements in the previous unit. The recycle flow was kept constant at 60m$^3$/hour.

## RESULTS

The aim of the control strategy was to minimise the polymer cost whilst maintaining the sludge blanket height below the critical level of 1.5m. An optimisation algorithm available in West++® was used to tune the controllers where possible and trial-and-error used when reasonable results were not obtained. The best control strategies were evaluated according to the following criteria: maintain sludge blanket height below 1.5m, use minimal amount of polymer, be insensitive to poor tuning, and require a smooth control action.

All of the control strategies tested satisfactorily controlled the sludge blanket height and resulted in effluent suspended solids concentrations of less than 6mg/l. They all required considerably less polymer per month than the 2000l/month current dosage (Table 1). This difference can be attributed partially to density currents in the settler due to its design which erode the sludge blanket and require the operators to maintain the sludge blanket at 0.5m (the model predicts that this requires 30 times more polymer than that given in Table 1); the poor positioning of the polymer dosing point resulting in poor mixing and, hence, low effectiveness of the polymer; the current manual control of the sludge blanket height. The amount of polymer required was in the same order of magnitude for each of the strategies with the exception of the one using feedforward control and based on the hydraulic loading only (strategy 2).

Table 1 Evaluation of the different control strategies based on their polymer requirements, control action and sensitivity

| | **Type of control** | **Control law** | **Pure polymer requirement per month (l)** | **Control action required**[*] | **Sensitivity to poor tuning**[**] |
|---|---|---|---|---|---|
| | Reference (no polymer) | | 0 | | 672.3 |
| 1 | Feedback | $Q_{pol} = 4.1\times(SBH-1.5)$ | 6.5 | + | 14.32 |
| 2 | Feedforward | $Q_{pol} = 10^{-3}\times(Q_{infl}-140)$ | 18.6 | - | 166.5 |
| 3 | Feedforward | $Q_{pol} = 1.5\ 10^{-7}\times(X_{infl}Q_{infl}-800000)$ | 7.0 | - | 564.85 |
| 4 | Feedforward/Feedback | $Q_{pol} = 10^{-7}\times(X_{infl}Q_{infl}-775000) + 10(SBH-1.5)$ | 6.8 | + | 6.40 |
| 5 | Feedforward | $Q_{pol} = 2\times10^{-6}\times(SSV_{infl}Q_{infl}-85000)$ | 9.3 | - | 554.06 |
| 6 | Feedforward/Feedback | $Q_{pol} = 7.2\times10^{-4}\times(SSV_{infl}Q_{infl}-90000) + 8.7(SBH-1.5)$ | 6.7 | + | 7.81 |

[*] Excessive control action required (+), excessive control action not required (-)

[**] measured as cumulative exceeding of the critical SBH (m.h)

With respect to the control action, the strategies that used the sludge blanket height as a measured variable (1, 4 and 6) resulted in excessive control action, which is undesirable, as it results in wear on the actuator. This behaviour is illustrated in Figure 1 and can be compared with the smooth action of a control strategy that does not control the sludge blanket height in Figure 2.

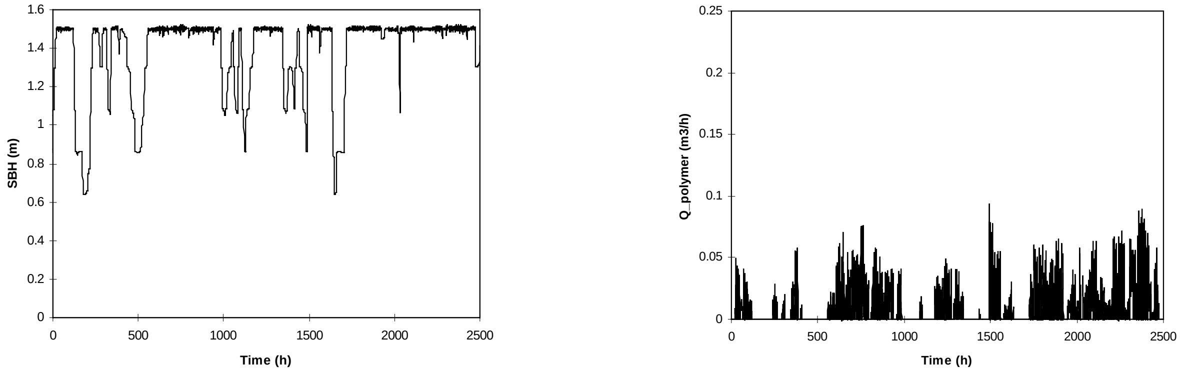

Figure 1. The resulting sludge blanket height and the required polymer for strategy 1 showing the excessive control action

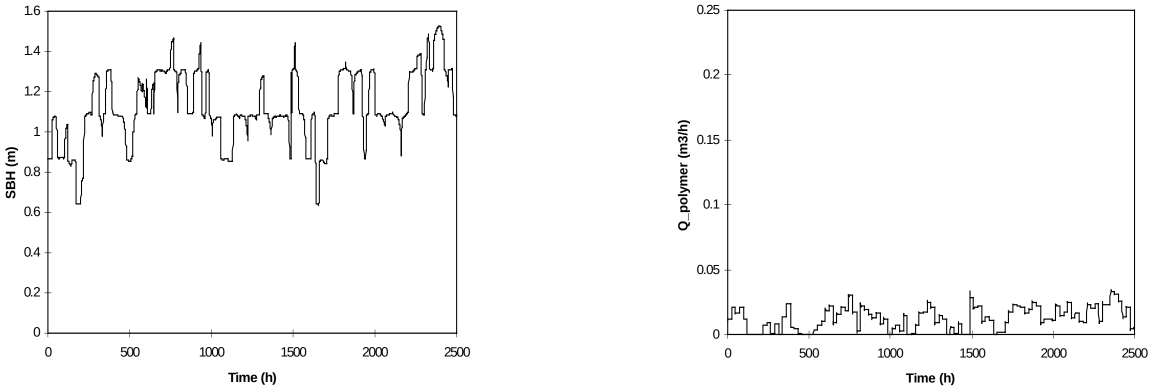

Figure 2. The resulting sludge blanket height and the required polymer for strategy 4 showing the smooth control action

In order to evaluate the sensitivity of the different strategies to suboptimal parameters, the effect of erroneous tuning was measured. For each control strategy, setpoints were increased by 10% and proportional factors were decreased by 10%. The cumulative exceeding of the critical sludge blanket height is given in the last column of Table 1. There is a clear difference in the sensitivity of strategies using the sludge blanket height as compared to those without it, as is to be expected. The best strategy with respect to suboptimal tuning and model mismatch is strategy 4.

The final selection of which control strategy to implement will be based on the ease and cost at which this can be achieved.

## CONCLUSIONS

In this paper, five strategies for the control of a clarifier at an industrial wastewater treatment plant have been evaluated. The aim of these strategies was to minimise effluent suspended solids by maintaining the sludge blanket below a critical height. Each strategy uses the polymer addition as manipulated variable. The difference in the strategies is the type of controller and the combination of measured variables. The polymer requirements for the different control loops are in the same order of magnitude with the exception of strategy 2, the feedforward controller based on the hydraulic loading. A sensitivity study showed that strategies 3 and 5, the feedforward controllers based on the solids loading and the sludge volume loading are not robust towards sub-optimal tuning. This suggests that the most appropriate controllers are 1, 4, and 6, that is, those based on the SBH or a combination of SBH and another measured variable. The final selection should be made on the ease and cost of implementation.

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