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Predictive Control of Decantation in Batch Sedimentation Process

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Introduction

Decantation of clarified liquid in batch sedimentation[1] is considered in this article. Little attention has been paid in the literature cited to the actual control strategy for the decanting process. It is only stated, that the rate of clarified liquid removal can be adjusted to the actual sedimentation characteristics of the sludge.[2] A simple on-off control strategy controlling the pump with respect to turbidity measured below the decanting device may cause frequent switching of the pump as demonstrated in this article. Therefore, an algorithm is needed that will adapt itself to changing process parameters and will be simple enough for implementation using industry standard programmable logic controllers (PLCs).

Problem of the time-reducing decanting process

The problem of time-reducing control of decantation is based on the fact that the removal of clarified liquid may and should start before the settling process is complete. In such a case, two different possibilities may be distinguished:

(a) rate of sludge blanket descend v_{SB} is greater than the removal rate of liquid v_{LV} (Figure 1a), and removal of liquid as soon as possible is fully justified,

(b) the removal rate of clarified liquid v_{LV} is greater than the sludge blanket rate of descend v_{SB} (Figure 1b). In this case, although the late commencement of the removal process may not be as critical, it may still be beneficial to start decantation as soon as possible, especially when the clarified liquid must be processed.

An example of such a post processing is treatment of municipal or industrial wastewater effluent by ozone, UV or microfiltration in order to enhance the effluent quality.[3–5] In such cases, early commencement of decantation will most likely result in lower costs (smaller maximum inflows and smaller buffer tanks).

It is assumed in this article, that the sludge blanket level cannot be measured directly. However, during removal of clarified liquid, at some point the pump is switched off due to high value of suspended solids concentration as indicated by the turbidity sensor. At this time, since the distance between the turbidity sensor and the surface of liquid (the level in the settler is measured and the suction nozzle together with the turbidity sensor are mounted on a float) is constant, the current sludge blanket level may be determined.

Materials and Methods

An experimental installation[6] (Figure 2) consists of a settler having a diameter of 20 cm, with a maximum level of 90 cm. A mineral suspension (halloysite, density approximately equal to 2.0 g/cm^3) is used. Level of liquid in the settler is measured by a pressure transducer (y_2). Clarified water is removed from the settler by a Masterflex peristaltic pump (u_2, on-off control, $Q_P = 1.73$ L/min), and the suction nozzle is mounted on the float. A turbidity sensor (y_1) is mounted on the same float and is calibrated to indicate sludge concentration X g/L within the range of 0.0 – 4.0 g/L. An on-off stirrer (u_1) is provided. Measurement signals and control variables are accessed in a National Instruments FP-2010 controller in which control algorithms implemented using the LabVIEW environment are embedded and executed in a real-time operating system. A PC computer is used for monitoring.

The on-off control strategy

The simplest and most intuitive control strategy is a simple on-off algorithm. Two threshold values are specified:

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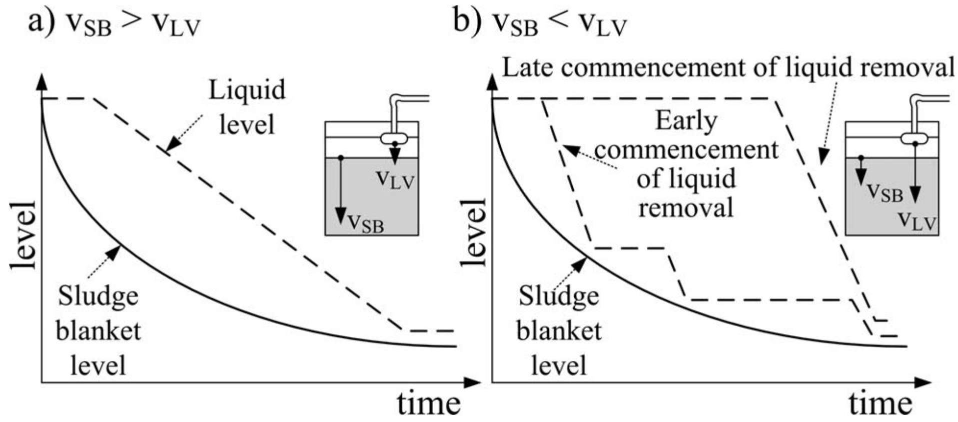

Figure 1. Different cases of clarified liquid removal.

X_{LO}-concentration of sludge at which the pump is turned on, and X_{HI}-concentration of sludge at which the pump is turned off. Figure 3 shows experimental results obtained for different initial concentrations of sludge ($X_0 \cong 10$ g/L and $X_0 \cong 20$ g/L). The following threshold values were assumed: $X_{LO} = 0.15$ g/L, and $X_{HI} = 0.25$ g/L. The main disadvantage that may be observed is frequent switching of the pump, especially in later stages of the process. Such behavior is explained by studying the dynamical properties of the sedimentation process and relating it to the control strategy implemented.

Properties of the process

In order to assess properties of the process, concentration of suspended solids has been measured at different levels in the settler without removing the clarified liquid. Figure 4 presents example results for two different initial sludge concentrations ($X_0 \cong 3$ and $X_0 \cong 7{,}5$ g/L). A clear separation of high-concentration region (thickening sludge), and low-concentration region (clarified liquid) exists. Therefore, as the float moves downward due to pumping and the turbidity sensor immerses in sludge, rapid increase of turbidity is observed. For later stages of the process, when the border between clarified liquid and sludge is well defined, it takes a small movement of the sensor to fully immerse it in sludge causing frequent switching of the pump (as seen in Figure 3). At the beginning of the process the sludge blanket descends with a constant rate. However, once thickening of sludge occurs, the rate of sedimentation decreases. It is therefore assumed, that it is impossible for the sludge blanket to increase its rate of descend unless the process is disrupted.

Predictive control strategy

In order to overcome the mentioned disadvantages, a control strategy is proposed that delays' restarting of the pump after it was stopped. Since, however, the sedimentation process may proceed with different rates, the delay time is computed based on the sludge blanket rate of descend. This rate in turn is estimated using the available measurements, namely the level in the settler and the estimated sludge blanket level. Each time the pump is turned off due to high-turbidity reading, a new delay time T_0 is computed to satisfy the assumed conditions. A simplified scheme of the proposed control algorithm is shown in Figure 5.

The presented control strategy requires a timer to measure the time elapsed form the beginning of the sedimentation process. It will be reset to a value of $t = 0$ when stirring currents inside the settler are assumed to have been attenuated.

Sludge Blanket Level Prediction. The last two measured values of the sludge blanket level (the current value $h_{SB}(t_{curr})$, and the previous value $h_{SB}(t_{prev})$) are remembered. Since at time $t = 0$ the sludge blanket level is assumed to be equal to the initial level in the settler, only one additional measured sludge blanket level value is necessary. A linear

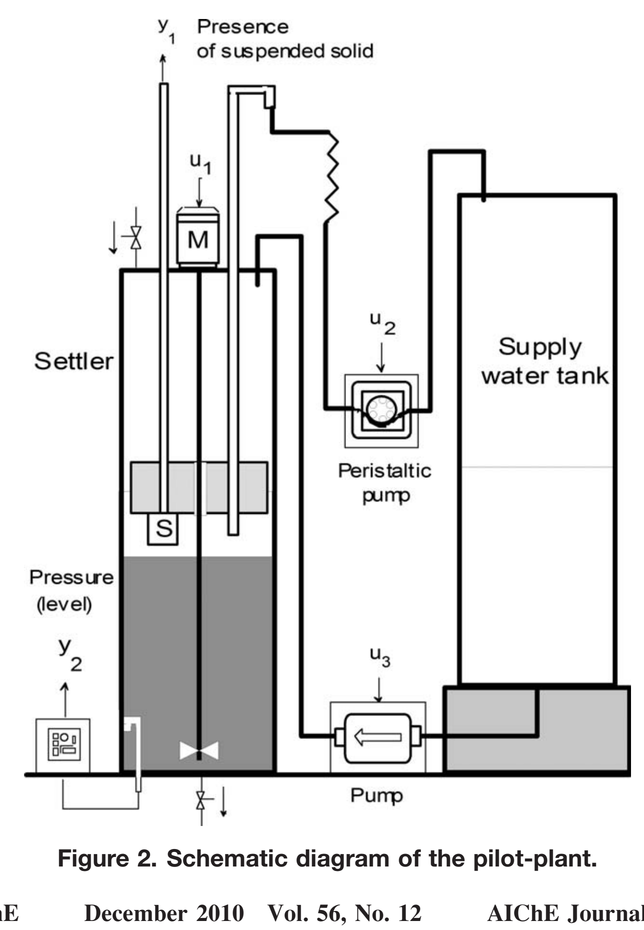

Figure 2. Schematic diagram of the pilot-plant.

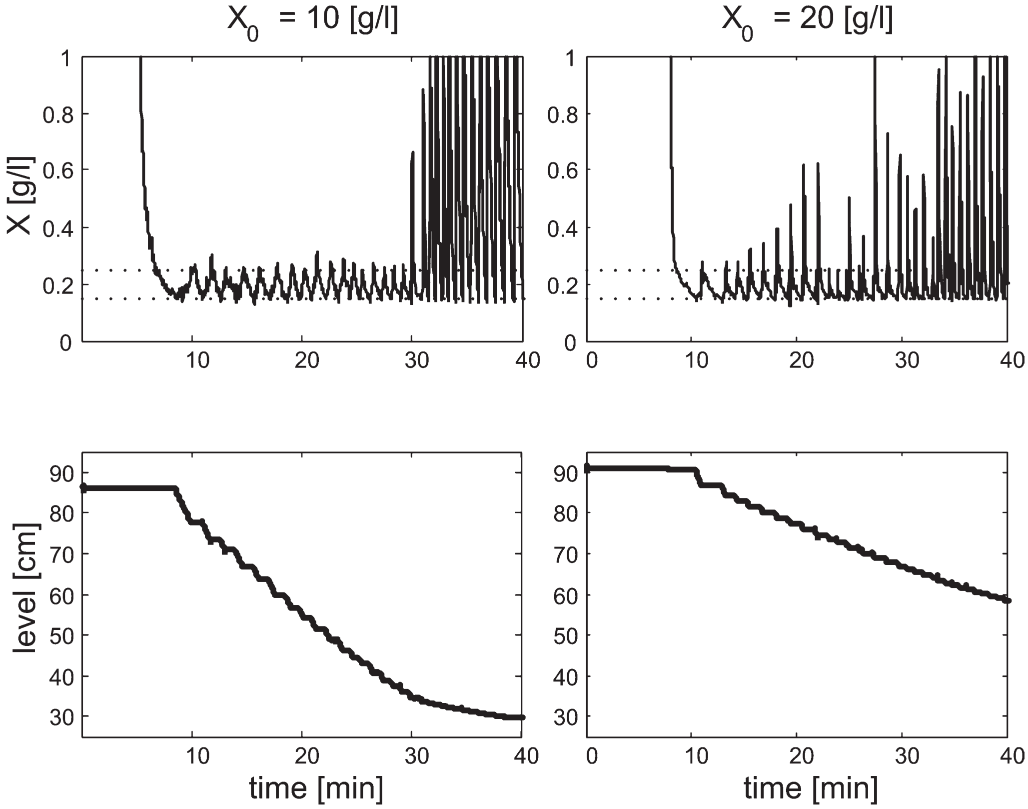

Figure 3. On-off control strategy for different X0.

function is used to describe the predicted behavior of this process

$$h_{SBpred}(t) = at + b \tag{1}$$

where

$$a = \frac{h_{SB}(t_{curr}) - h_{SB}(t_{prev})}{t_{curr} - t_{prev}} \tag{2}$$

$$b = h_{SB}(t_{prev}) - at_{prev} \tag{3}$$

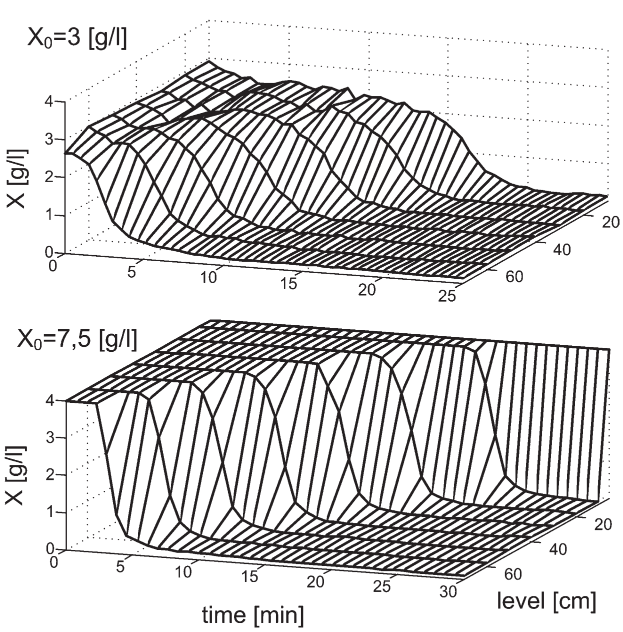

Figure 4. Changes in X at different levels of the settler.

Control action determination

Based on the prediction the time period T_0 for which the pump should be switched off is determined (Figure 6).

First working regime. In the first phase of the settling process it is assumed that the controller works in cycles of a given period T_C (the first tuning parameter of the proposed control strategy). At time t_{curr}, the controller computes T_0 so

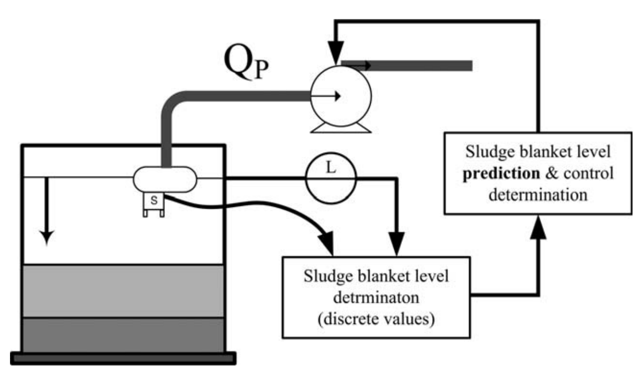

Figure 5. Simplified diagram of the proposed control strategy.

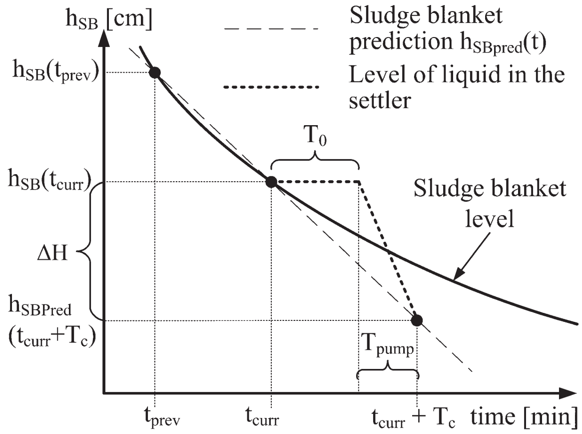

Figure 6. Process prediction and control action determination.

that the pump will be switched off at $t = t_{curr} + T_C$ (hence, the controller expects to "meet" the sludge blanket at time $t_{curr} + T_C$). Therefore, the expected decrease of level in the settler for period T_C can be determined as

$$\Delta H = h_{SB}(t_{curr}) - h_{SBpred}(t_{curr} + T_C) = h_{SB}(t_{curr}) - a(t_{curr} + T_C) - b \quad (4)$$

If the resulting decrease of level ΔH is equal to or greater than an assumed minimum value of level decrease ΔH_{min} (the second tuning parameter of the proposed control strategy) the controller works in the first regime. The time needed to decrease level by ΔH equals

$$T_{pump} = \frac{\Delta H \cdot A}{Q_P} \quad (5)$$

where A is the cress sectional area of the settler. Since it is assumed that the sludge blanket rate of descend is lower than the efficiency of the pump (Figure 1b), time T_0 can be expressed as

$$T_0 = T_C - T_{pump} \quad (6)$$

Second Working Rregime. If, however, the predicted decrease of level (Eq. 7) is lower than the given minimum value ΔH_{min}, a new value for the working cycle is determined. In other words, it is now desirable to achieve at least the minimum decrease of level. Hence, the extended time period is given as

$$T_{Cext} = \frac{-\Delta H_{min}}{a} \quad (7)$$

The time needed to decrease level by ΔH_{min} can be expressed as

$$T_{pump} = \frac{\Delta H_{min} \cdot A}{Q_P} \quad (8)$$

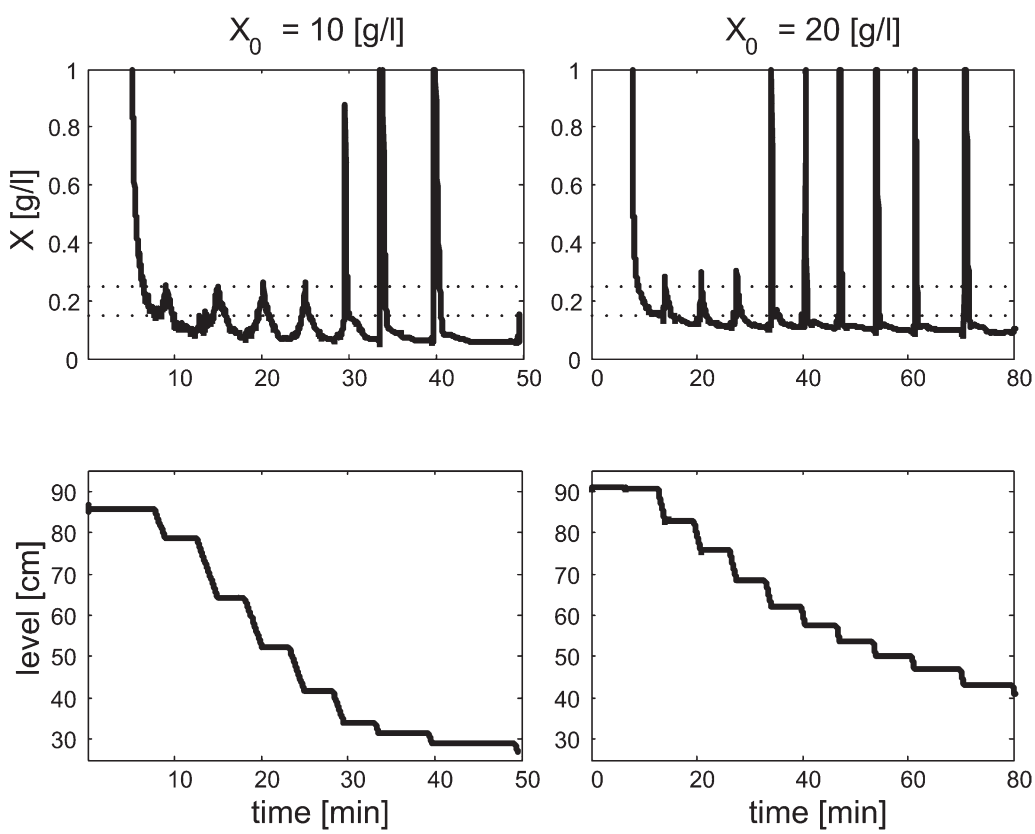

Figure 7. The proposed control strategy for different X0.

and the off-period is simply given by

$$T_0 = T_{Cext} - T_{pump} \quad (9)$$

Figure 7 presents experimental results obtained for the proposed control strategy. Evidently, the pump is not restarted just after it was stopped. Additionally, in later stages of the sedimentation process, when the sludge blanket descends with a slower rate, the delay time T_0 is being prolonged accordingly.

Concluding Remarks

The proposed predictive control strategy is simple enough for easy implementation in most programmable logic controllers (PLCs), but still ensures a time-optimal control of the decanting process regardless of the process conditions. At the same time it ensures that the pump is not switched on and off frequently. Mineral suspensions sometimes contain a fraction of small solid particles having a very small settling velocity, making the clarified liquid appear cloudy. Because the pump is being switched on less frequently, the proposed control strategy also ensures that a smaller amount of those particles is removed with the clarified liquid. Additionally, the proposed control strategy provides means of monitoring the settling qualities of the medium. The estimated sludge blanket rate of descend (parameter a) may be directly used to assess the rate of sedimentation. For example, a rapid decrease of this parameter with respect to a previous batch may indicate that either the initial concentration of solids greatly increased or the settling properties deteriorated. On the other hand, the large values of the computed T_0 time may be used to indicate finalization of the sedimentation process. Hence, the proposed predictive control strategy provides clear and easy to understand parameters informing the process operator about conditions existing in the settler.

Acknowledgments

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