A Turbidity-Based CEPT Controller for Primary Clarifiers: Model-Based Development and Full-Scale Implementation

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INTRODUCTION

As many other urban rivers, the Saint-Charles River which runs across Quebec City (Quebec, Canada) has been struggling with combined sewers overflows (CSO) for many years. In the early 2000's, in the framework of a program aiming to improve the river water quality to restore recreational uses for the public, fourteen combined sewer retention tanks (RT) for over 150,000 m³, were constructed. With the current water quantity based control RT emptying strategy, the RTs are emptied at the maximum flow rate that the water resource recovery facility (WRRF) can handle, the aim being to recover the storage volume as fast as possible in view of forthcoming rain events. As a result, during and after each major rain event, the WRRF has to operate at maximum capacity for extended periods of time. Such conditions can deteriorate treatment performance, especially primary treatment, which induces clogging of the subsequent biofilter-based secondary treatment stage, leading to possible bypass of partially treated wastewater. To respect the effluent permits, the primary treatment has thus been enhanced by chemical addition.

A preliminary lab study, confirmed by one full-scale test, recommended dosing 70 mg/L of alum on a dry basis and 0.2 mg/L of a particular polymer (Lajoie and Collin, 2008). However, other experiments have shown that in many cases such dosage is excessive, resulting in operational problems and economical loss. In view of optimizing the dosage, experiments have been performed to model the primary clarifier (PC) behaviour without and with different levels of alum addition. The objective was to propose a real-time control system that would adjust dosage in view of achieving a desired effluent turbidity.

MATERIALS AND METHODS

Fieldwork

To get a good understanding of the system's behaviour and to identify key parameters of the PC model (see below), extensive field campaigns were carried out. Total suspended solids (TSS) lab analyses are time consuming, and high frequency time series are needed for model development and controller evaluation. In that sense turbidity data recorded by an on-line sensor are thus very interesting. Furthermore, unlike TSS, turbidity data are immediately available, allowing a real-time controller to be developed around it.

The possibility to monitor influent and effluent quality of the PC has been evaluated, resulting in the permanent installation of turbidimeters (Hach Solitax®). From an operational point of view, the long-term in-situ experiments which were conducted revealed that to ensure proper operation, the sensors' maintenance can be limited to one manual cleaning per week, which is an acceptable effort (Alferes et al., 2013).

The CEPT-chemicals used are alum as coagulant (added at the inlet of the grit chamber) and an anionic polymer as flocculent (added at the inlet of the PC). Jar-test were carried out to determine the optimal dosage. Since the main chemical supply cost comes from the coagulant it was decided to use a relatively high polymer concentration (0.15 mg/L) and to modulate alum concentration to achieve the desired turbidity in the supernatant. Dosing between 25 and 60 mg/L of alum on a dry basis was found optimal.

Several tracer tests using rhodamine WT, which is an innocuous soluble and inert product which can be detected down to very low concentrations by fluorimetry, have been performed to determine the hydraulics of the grit chamber and PC under different incoming flow rates. The average hydraulic retention time in each unit process have been determined.

Model development and controller design

The model was implemented in the WEST® modelling software (mikebydhi.com). A PC model taking into account the possibility of CEPT was proposed by Tik *et al.* (2013). The effect of alum addition on sedimentation is simulated by increasing the particle settling velocity and decreasing the fraction of non-settleable suspended solids with the concentration of alum. The hydraulic configuration was reproduced using a series of completely mixed reactors. It was indeed essential to accurately represent the hydraulic retention time of the system since the delay between the injection of chemicals and its actual effect has an important impact on the controller design.

Different control strategies were tested on the model. A PI-feedback controller based on the PC's outlet turbidity was retained, with an anti-windup component to deal with controller saturation. This choice of control strategy also agrees with operational limits, such as the efforts required to properly maintain the sensors (primary effluent turbidity is asking much less maintenance than raw wastewater turbidity measurements). To calculate the amount of alum to be added to achieve the requested alum concentration in the wastewater, a feed-forward component using the incoming flow rate was added. The model configuration is represented in Figure 1.

A preliminary simulation study predicted incentive savings of about 30% on chemical's supply when using the turbidity-based controller, compared to the constant dosage which was the reference for the study (Tik *et al.*, 2013).

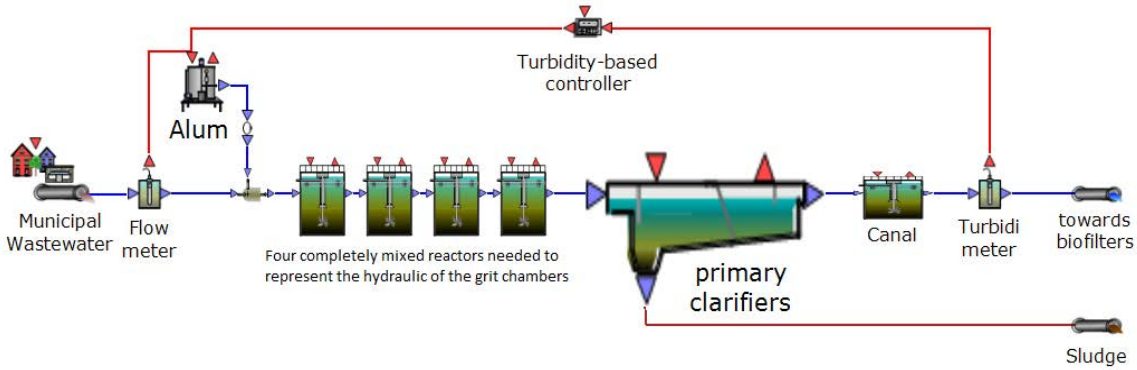

Figure 1 Model configuration of the Quebec City water resource recovery facility (WRRF) grit chamber and primary clarifier in WEST® (mikebydhi.com)

RESULTS AND DISCUSSION

Full-scale implementation of this controller was completed during the winter of 2015 and supervised tests were conducted during the snowmelt period and during rain events. Under more normal conditions, CEPT was not activated. In order to use the turbidity signal as input for the feedback controller, a kernel average smoother was used to remove noise (see Figure 2).

On Figure 2 a demonstration run is illustrated. At the beginning, when the turbidity-based controller is switched on, a constant dosage of alum at 45 mg/L is applied during 1h (Fig. 2, orange line). After 1 hour the alum addition controller is activated, allowing to modulate the dosage to achieve an alum concentration in the influent in the range of 25 mg/L to 60 mg/L. In case the required dosage would drop below 25 mg/L the alum dosage would stop completely as the jar tests have shown that below 25 mg/L no enhancement of settling is to be expected. The controller performance on two set point changes (Fig. 2, dash line) is illustrated on Figure 2 (red line), clearly showing the ability of the controller to modulate alum injection to reach and maintain the set-point despite the considerable time delay in the system. The actual alum pump flow rate results (Fig. 2, pink line) reflect the feedforward of the influent flow rate variations around 15:10 and 16:00.

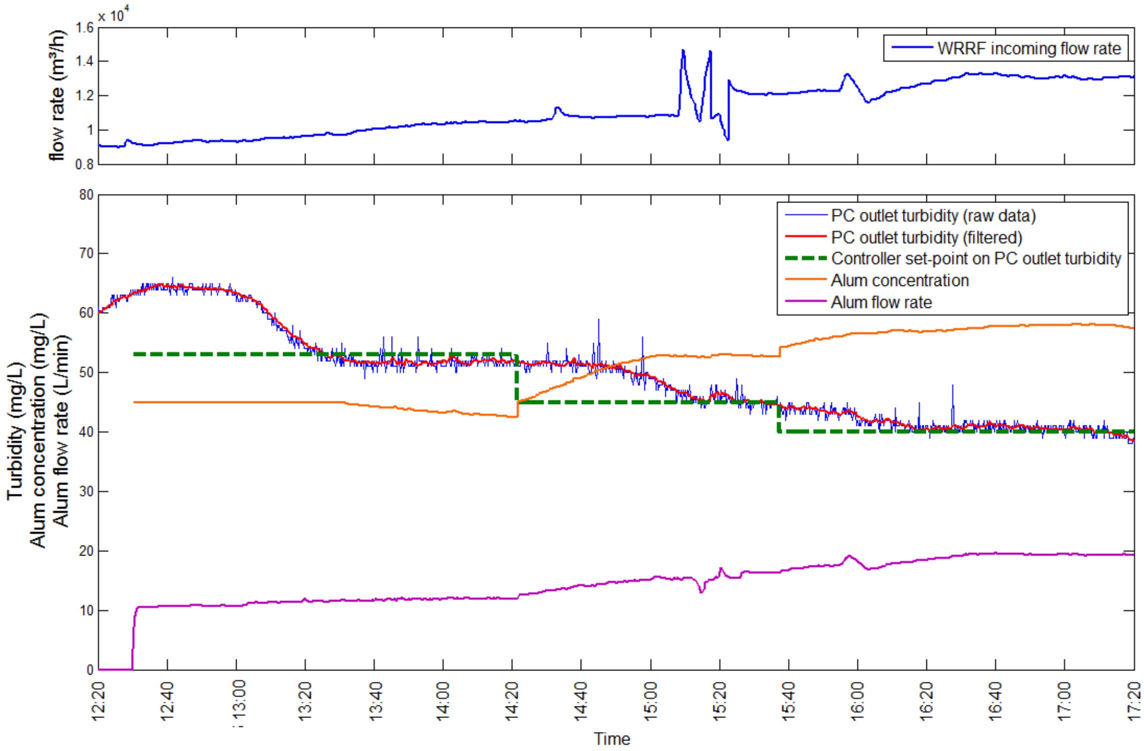

Figure 2 Full-scale experiment performed on April 9th 2015. The turbidity-based control is switched on at 12:30 starting with a 1h-constant dosage of alum, at 13:30, the controller went into action and decreased the amount of alum added. Two set-point changes were imposed: 45 mg/L of TSS at 14:21 and 40 mg/L of TSS at 15:37, which are both reached after a certain delay.

CONCLUSION

A successful collaboration between water utility and university was presented, leading to both scientific and technical progress. On the one hand, the large number of operational data collected led to the development of an innovative model of chemically enhanced primary treatment. On the other hand, operational management ideas have been tested and evaluated on the model before full-scale implementation, resulting in significant resource and time savings. Finally, with only minimal adjustments, an operational system was obtained.

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