A CEPT model based on particle settling velocity distributions

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Abstract: Chemically enhanced primary treatment (CEPT) can be used to improve total suspended solids (TSS) removal but the lack of insight in this highly dynamic process can lead to non-optimal chemical dosing, resulting in high operational cost. Based on numerous lab, pilot and full scale experiments, a CEPT model using particle settling velocity distributions (PSVD) is proposed, leading the way to cost-saving process control.

Keywords: Chemically Enhanced Primary Treatment; Mathematical modelling; Particle settling velocity distribution.

Introduction

Adding chemically enhanced primary treatment (CEPT) to a wastewater treatment plant (WWTP) is to increase total suspended solids (TSS) removal performance, especially under wet weather conditions. In that context, to describe the underlying phenomena of the settling process, a primary clarifier model based on particle settling velocity distribution (PSVD) has been proposed by Bachis *et al.* (2015). Here, this model is extended to describe CEPT using the same approach. This outline paper presents this CEPT model developed on the basis of lab and pilot-scale experimental data collected at the Québec (Canada) WWTP. The model has then been confronted with full-scale data to evaluate its performance.

Modelling approach

Maruéjouls *et al.* (2012) demonstrated that the ViCAs protocol (Vitesse de Chute en Assainissement, French for settling velocity in sanitation) developed by Chebbo and Gromaire (2009) is an appropriate tool to characterize wastewater in terms of particle behaviour. This quite simple lab experiment, only requiring a settling column and the lab equipment for TSS analysis, leads to the determination of the PSVD curve of a water sample. Figure 1 shows an example of a PSVD curve and the corresponding TSS fractionation in particle classes, each class being defined by a settling velocity. Based on a large number of ViCAs experiments performed on raw wastewater sampled at the inlet of the Québec primary clarifier, Bachis *et al.* (2015) could conclude that all measured PSVD curves were contained in a relatively restricted zone located in this settling velocity distribution figure. Furthermore, it was noticed that the PSVD curve of a water sample is related to its TSS concentration (the higher the TSS concentration, the lower the curve is located).

These observations were used to develop a primary clarifier model composed of a number of layers that allow representing the vertical TSS gradient in the clarifier. In each layer, mass balances are constructed for each particle class and the transport of the particles in and out of the layer are calculated. Particles are subject to advection depending on the vertical flow rate (leading to an up or down bulk flux depending on the location in the clarifier) and to settling according to the settling velocity, depending on the particle class considered (Bachis *et al.*, 2015). To extend this model for use in a CEPT context, the idea is to change the location of the PSVD curve depending on the chemicals addition, i.e. to progressively increase the fractions of particles with high settling velocities.

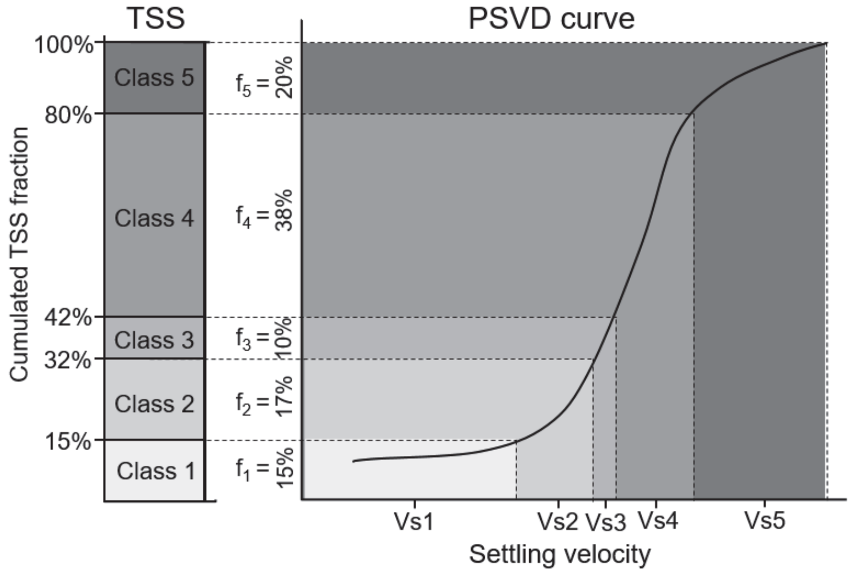

Figure 1 An example of TSS fractionation in five particle classes (class delineation with dashed lines). Each particle class, characterized by a mean settling velocity (Vs1 to Vs5) is associated with its TSS mass fraction (f_1 to f_5).

Experimental observations

Series of jar tests have been performed to identify the range of chemical concentrations to focus on. In this study, an anionic polymer was used as flocculant in combination with different coagulants. Since the polymer only represents a minor cost in the total CEPT chemicals budget for Québec's WWTP, the city decided to use a constant concentration leading to a slight excess dose based on jar test data. The chemical that incurs considerable operating costs and is thus used as reference in the results presented below is alum. However, other coagulants have been tested as well and showed similar behaviour. As described in Bachis *et al.* (2015), the characteristics of a water sample change with chemicals addition, lowering its PSVD, i.e. a larger fraction of particles settle faster. Figure 2 shows the PSVD curve of a raw wastewater sample (solid blue line) and of the same wastewater sample after addition of 60 mg/L of alum (dash red line). Different concentrations of chemicals have been added to a wastewater sample which has then been submitted to ViCAs experiments. Experience shows that a minimum concentration of chemicals is needed to observe an effect on the particle settling process. Similarly, when more than a maximum chemical concentration is applied, no further improvement in particle settling is observed, representing a saturation effect. For alum and the considered wastewater, the range in which alum affects settling lies between 20 and 70 mg/L. To represent these observations a sigmoidal change of the PSVD curve with chemical addition is proposed, as illustrated in Figure 3.

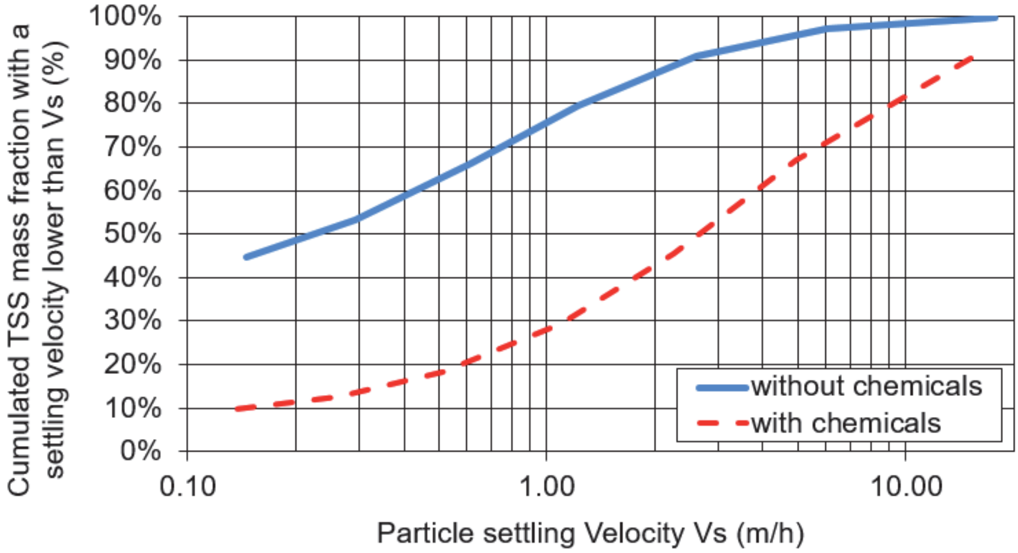

Figure 2 Particle settling velocity distribution of a wastewater sample without (solid blue line) and with (dashed red line) chemicals addition.

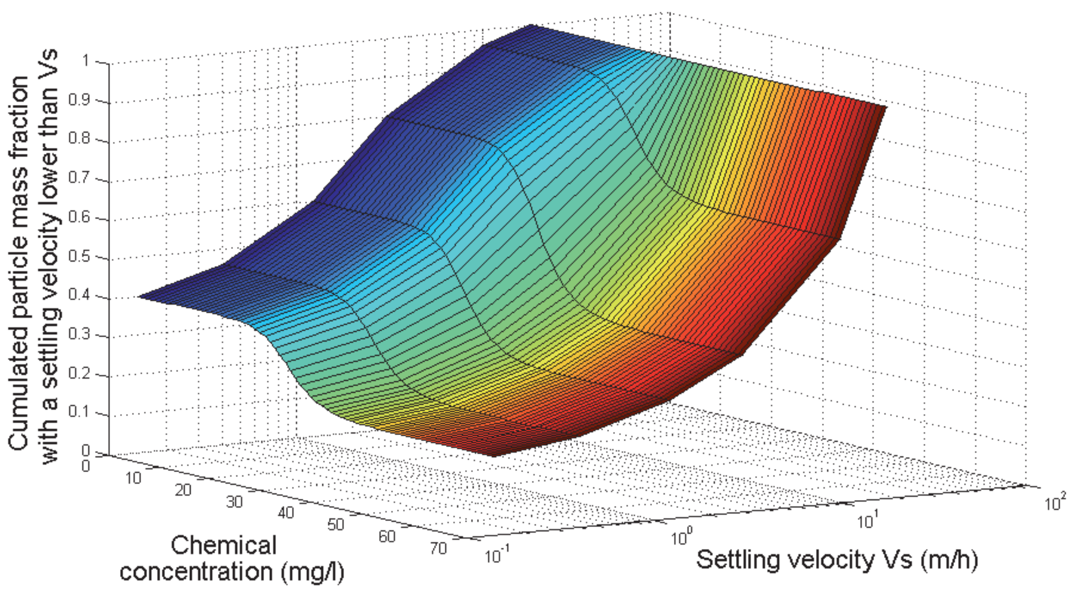

Figure 3 Sigmoidal representation of the particle settling velocity distribution (PSVD) change due to chemical addition. PSVD when no chemical is added is in blue and when saturation is reached is in red.

Model simulation results

The proposed CEPT model thus simultaneously considers the raw wastewater characteristics in terms of TSS concentration (converted in PSVD, see Bachis *et al.*, 2015) and chemicals concentration allowing to modulate the change in settling with regards to both concentrations.

The model was shown to be able to properly simulate full-scale behaviour of the CEPT installed at Québec's Eastern WWTP. Figure 4 presents the model's performance for an experiment during which step changes in alum addition were performed. Automatic samplers (15-min composite samples) were installed at the inlet and at the outlet of the primary clarifier to measure TSS concentration. Good agreement between data and model can be observed.

Straightforward application of this model is to design and optimize a process control system of chemical dosage (Tik *et al.*, 2013). The model can also be included in a whole plant model or even in an integrated wastewater collection and treatment model that allows studying extended control possibilities for improved wet weather operation where first flush phenomena are often critical in terms of TSS load (Tik *et al.*, 2014). Since not only the TSS concentrations at the outlet of the primary clarifier can be better predicted but even the PSVD can be obtained, models that consider particle properties to describe for instance hydrolysis rates or biofilter clogging in secondary treatment become possible (Maruéjouls *et al.*, 2014; Tik *et al.*, 2015).

Further experiments, including jar tests and ViCAs tests, are planned to further validate the model and to evaluate whether generalization to other chemicals is possible.

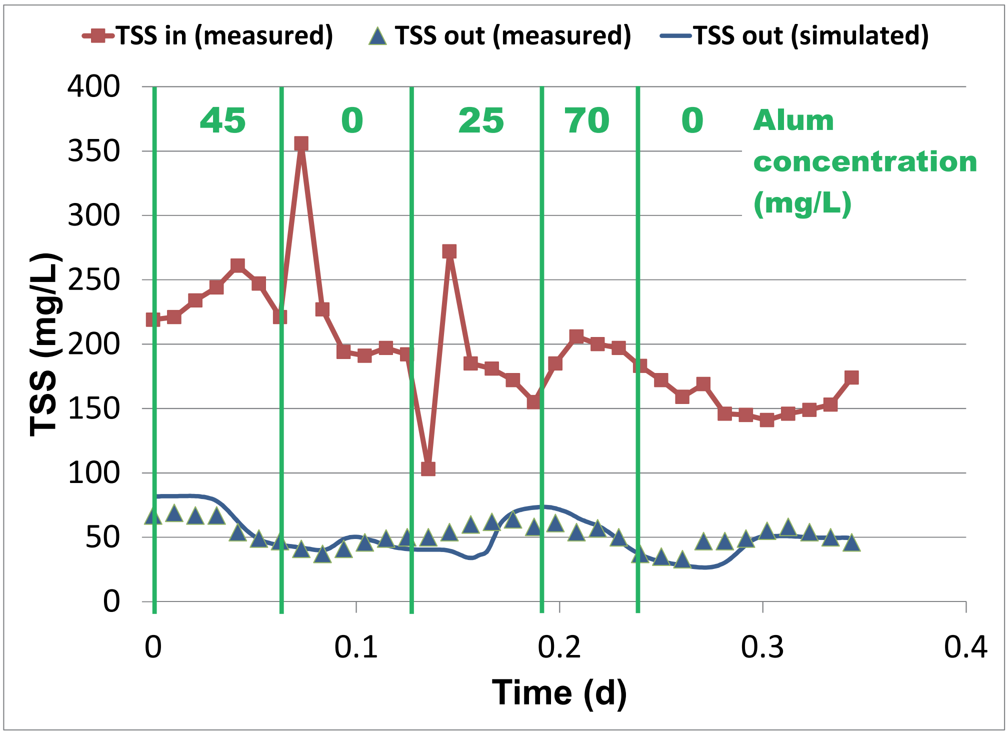

Figure 4 Experimental and simulated TSS results of a full-scale experiment performed on Québec's Eastern WWTP. The flow rate was approximately constant at 9,300 m^3/h, a typical rainy day situation. The alum concentrations (mg/L) applied at each step change are given on top.

Conclusions

A model for primary clarifiers based on particle settling velocity distributions and allowing modulation to represent CEPT has been presented. This model not only allows predicting TSS concentrations at the outlet of the primary clarifier but also of the particle settling velocity distribution (PSVD), which could be a useful information for the subsequent treatment process. Only simple lab experiments (TSS analyses, ViCAs and jar tests) are needed to calibrate the model, which can then be used to optimize the chemical dosage, and ensure appropriate process operation of the WWTP, possibly generating cost savings on chemical supply.

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