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Sludge settling prediction in sequencing batch reactor plants

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ABSTRACT

Sequencing batch reactors are widely applied in domestic and industrial wastewater treatment facilities. Their use relies on the possibility of separating the sludges from the liquid phase by settling in an acceptable time. The aim of this work has been to develop a simple method for predicting the settling curve in pilot and industrial plants from the results obtained at laboratory scale. For this purpose, jar test settling experiments were carried out in a one-litre cylinder tube together with sludge volume index and volatile suspended solids determinations. For sludges with low content of filamentous microorganisms, a simple method consistent in obtaining settling velocities as a function of the relative height of the sludge blanket was developed. Additionally, a more general correlation between the sludge volume index and the ratio (settling velocities at pilot plant scale)/(settling velocities in the laboratory tests) was obtained. Having estimated the settling velocity, the necessary settling time may be calculated and the industrial equipment units can be dimensioned. The method yields good results for the values of sludge volume index between 30 and 240 mL/g.

1. Introduction

In the last few decades there has been an increase in the number of discontinuous processes, in particular the introduction of sequencing batch reactors (SBR) that are becoming a common technology used in industrial processes (Wilderer et al., 2001; NEIWPCC, 2005). SBR plants are particularly important in the industrial and domestical wastewater processing (Rodríguez-Caballero et al., 2015; Sun et al., 2013; Wood et al., 2000). Continuous operation in an SBR consists in a cyclic process that typically involves the following stages: filling the device, reaction in the completely mixed reactor volume, settling of the suspended solids, drawing off the settled sludge and idle. SBR, with different technological variants, are widely used for wastewater treatment (Krishna Mohan et al., 2016; Puay et al., 2015; Singh and Srivastava, 2011). SBR systems are a good technological alternative to the conventional activated sludge process for the removal of toxic, inhibitory compounds or operation in extreme environments (Tomei et al., 2016; Zheng et al., 2016; Jiang et al., 2016). In addition, Sequencing Batch Reactors can also easily change the sequence and time of the different processes carried out in the devices and also exhibit an important degree of flexibility for processes with large variations in flow rate and composition (Mata et al., 2015). Frequently, BOD_5 (5-day biochemical oxygen demand) degradation is not a problem in many activated sludge processes, the most important difficulty being the removal of sludges from the treated water. Consequently, the time necessary for the settling period is a quantitatively significant parameter in the SBR cycle (Qiu et al., 2016; Zheng et al., 2016). This time must be as long as necessary to allow sludges to settle before the treated water is drawn-off but should not be excessive in order not to impair the performance and effectiveness of the whole process. The total available time has to be distributed mainly between settling and biodegradation according to the needs for disposal. The prediction of the settling velocities of concentrated dispersions is laborious even for homogeneous particles (Baldock et al., 2004; Cuthbertson et al., 2008; Koo, 2009) and far more complicated is the prediction of the settling behaviour for the activated sludges, with a wide range of particle sizes and shapes as well as with a very complex liquid matrix. While in real scale traditional water treatment systems the settling operation is carried out in continuous, most of the previous theoretical work on settling in the last decades has been devoted to the prediction of continuous settling from data in the laboratory, but no interest has been given to the prediction of discontinuous settling in SBR from the laboratory results. No previous proposal appears in the literature to directly apply the results of settling in the laboratory to the

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design of discontinuous settling processes. This work presents a procedure to help in the design of discontinuous real scale settling operations.

For prediction of discontinuous settling, most studies were carried out on activated sludge settling behavior prediction and modeling. Such works aimed to correlate the settling velocity and the sludge concentration, these correlations being applied in the settling flux theory for the conventional activated sludge process. In this way, Vesilind (1968) correlated those variables through a very simple equation that has been widely used:

$$V_s = V_0 e^{-KX} \quad [1]$$

where:

V_s is the zone settling velocity,
X is the microorganisms concentration,
V_0, K are the parameters of the model.

From that time on, several authors have proposed various correlations between the parameters of the model and the sludge volume index, SVI (Bye and Dold, 1999; Giokas et al., 2003). This resulted in expressions for the prediction of the settling velocity as a function of the SVI and the microorganisms concentration that have been applied in the design of clarifiers. Table 1 shows expressions for the prediction of the zone settling velocities according to different authors. Other expressions for the settling velocity have been given in the work of Cho et al. (1993). In that paper, these expressions were compared with others found in the literature, in order to find the best fit for the experimental data, this study being applied to conventional activated sludge treatment.

Other interesting works have been carried out regarding the possible relationships between the SVI and other sludges characteristics (filament length, settling velocity, floc size). Of particular interest the work of Sezgin et al. (1980) about the possible relationship between filament length and the rest of the settling parameters at large and small scales, and the work also by the same author in 1982 concerning the influence of the filamentous microorganisms on the SVI and the possible relationship between SVI and settling velocity. The correlation of the SVI with the length of filaments has also been reviewed in more recent works (Jassby et al., 2014; Schuler and Jassby, 2007).

However, very little literature is found on the study of the settling process as it occurs in an SBR, only two studies being found on the modelling of the evolution of the sludge blanket (Tenno et al., 1995; Wett and Rauch, 1996). Other authors distinguish three stages in the process (constant velocity, transition stage and thickening stage), giving different expressions for settling velocities in each stage as different functions of the SVI (Bhargava and Rajagopal, 1993).

As will be seen in the Results Section, the SVI has proven not to be a suitable parameter for direct use in secondary sludge tanks modelization and very seldom it can predict the sludge settling characteristics (Li and Stenstrom, 2014).

To date, the approach has been to test data of settling velocity rather than values derived from laboratory experiments (Giokas et al., 2003). The aim of this work is to predict the settling curves in large scale vessels from laboratory scale data. Zone settling tests in a one-litre cylinder tube were monitored for different sludges, it being found that the most important factors affecting the prediction are: inorganic content of the sludges, presence or absence of filaments and geometry of the vessels. In this way, we will distinguish the results for sludges with little or high inorganic content, and in the presence or absence of filamentous microorganisms. From these data, it has been possible to predict settling in large scale reactors quite accurately using a graphical method, mainly when filaments are not present. In addition, a correlation has been found between the ratio of settling velocities in the pilot plant reactor and in the laboratory cylinder and the SVI, which can be used for SVI interval values between 30 and 240 mL/g.

2. Materials and methods

With the aim of determining the role in the settling process of each of the factors mentioned in the preceding section, experiments were carried out in different SBR at pilot plant scale whose characteristics are indicated in Table 2, as well as in a one-litre cylinder tube with a cross-sectional area of 27.4 cm^2. The experiments were always conducted for pilot plant reactors and laboratory scale at the same time and consisted on the monitoring of the height of the sludge blanket both in the laboratory cylinder tube and the pilot plant reactor. The reactors were kept operating for periods of time up to 7 months. The sludge for the laboratory scale settling experiment was taken (in duplicate and with no dilution) from the reactor immediately before every pilot plant settling determination. Both experiments were carried out simultaneously in order to be sure that the characteristics of the sludge were the same in the reactor and in the laboratory cylinder. The reactors were operating under variable conditions (mainly the characteristics of the industrial effluents fed, and different SBR time sequences) and the settling experiments usually required to interrupt the operation for more than two hours. Consequently, it was not always possible to carry out exactly the same experiment twice. These circumstances lead to the fact that the majority of the pilot plant settling experiments could not be exactly replicated.

The sludges used in the experiments were obtained from the treatment of different industrial wastewaters: the high inorganic content sludge (50–60% of inorganic material) was obtained from the treatment of a very salty industrial wastewater, and the low

Table 2
Pilot plant reactors characteristics.

Reactor	Volume	Height	Cross section
Bubble column	1.4 m^3	4 m	0.35 m^2 (squared)
Air-lift	0.15 m^3	4 m	0.038 m^2 (circular)

Table 1
Zone settling velocities from different prediction models.

Model No.	Authors	Expressions[a]
1	Daigger and Roper (1985)	$V_s = 7.8 \bullet e^{-(0.148+0.00210 \bullet SVI) \bullet X}$
2	Wahlberg and Keinath (1988)	$V_s = (15.3 - 0.0615 \bullet SVI) \bullet e^{-(0.426+3.841 \bullet 10^{-3} \bullet SVI - 5.43 \bullet 10^{-5}(SVI)^2) \bullet X}$
3	Akça et al. (1993)	$V_s = 28.1 \bullet (SVI)^{-0.2667} \bullet e^{-(0.177+0.0014 \bullet SVI) \bullet X}$
4	Ozinsky and Ekama (1995)	$V_S = 8.53e^{-0.00165SVI} \cdot e^{-(0.200+0.00091 \cdot SVI) \cdot X}$
5	Daigger (1995)	$V_S = 6.50 \cdot \mathrm{e}^{-(0.165+0.00159 \cdot SVI) \cdot X}$
6	Bye and Dold (1998)	$V_S = (H_0 - H_0 \cdot SVI \bullet X/1000)/t$

[a] SVI [mL/g]; X [kg/m^3]; V_S [m/h]; H_0, initial height [m]; t [h]. Except for Model 6, V_S represents zone settling velocities.