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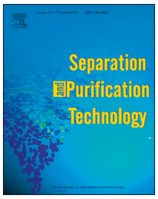

Characterization of activated sludge settling properties with a sludge collapse-acceleration stage

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ABSTRACT

The sedimentability of the activated sludge can be affected by the presence of a large variety of coagulants and polymers from a previous physical-chemical process. In this paper, the activated sludge settling process in industrial wastewater treatment plants where the sludge does not settle in a conventional way is studied. The two observed constant hindered settling velocity stages and the instant the intermediate sludge acceleration period occurs are described. A variation of the Richardson and Zaki model is used to characterize the two stages of constant settling velocity. The concentration of suspended solids, where a sudden decrease of hindered settling velocity was observed, is calculated. Finally, a new hypothesis to explain the processes triggering the collapse of the initial homogeneous sludge structure and the existence of an acceleration period is formulated.

1. Introduction

Many secondary settling tanks design methods are based on the experience acquired in the design of urban wastewater treatment plants. It is also common to use models to simulate settling tanks by calculating the hindered settling velocity from standard values or using empirical formulas obtained from urban wastewater treatment plants. However, in some urban wastewater treatment plants, and especially in industrial ones, the sedimentability of activated sludge can be affected by the presence of coagulants and polymers used in a previous physical-chemical process.

In a batch settling test with activated sludge it is usual to find an initial induction stage of a few minutes. The increase of the settling velocity during the induction stage is due to the dissipation of the turbulence generated in the filling of the settling column [1]. The presence of cationic polymers in the sludge reduces the length of this induction period and increases the hindered settling velocity of the sludge [2,3].

The existence of an induction period in settling tests with flocculate suspensions in the compression range has also been described. This induction period is due to the initial increase in the permeability of the suspension resulting from the formation of channels through which the water rises [4].

Chen et al. [5] studied the activated sludge settling velocity from an industrial wastewater treatment plant in Taiwan. In the settling tests they observed, for certain solid concentrations, two stages with constant hindered settling velocity and an intermediate stage where the acceleration of sludge occurs. They also observed the appearance of large flocs during the speed-up period starting from a homogeneous sludge.

Zhao [6,7] also described the same acceleration process with primary sludge coagulated with aluminium sulphate and with an anionic organic polymer. Zhao [6] observed that the sludge acceleration was higher in the underdose range of the polymer (< 10 mg/l) and that the increase of settling velocity could be due to the sludge flocculation during sedimentation. According to Zhao [6] in the underdose range of the polymer the sludge sedimentability was controlled by the formation of large flocs and by the progressive decrease of the viscosity. While in the overdose range of the polymer (> 10 mg/l) the sludge sedimentability was controlled by the formation of a networked sludge structure surrounded by an excess of polymer. Zhao [7] considered that this networked structure links flocs and seems to cause a packing regime.

An increase in the hindered settling velocity in colloidal suspensions with weak gel structure was also reported. In a weak gel, the excess of unabsorbed polymer generates weak bonds between the colloidal particles due to the attractive forces induced by the depletion mechanism.

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Weak gels present an initial period of no sedimentation, or sedimentation at constant velocity, and a later period of gel collapse with a sudden increase of settling velocity [8]. The gel net undergoes restructuring and weakens over time due to the breakage and the readjustment of the bonds [9]. In these suspensions the delay time in which the collapse of the suspension occurs increases exponentially with the concentration of the unabsorbed polymer due to the increase in bond strength by the depletion mechanism [10]. Kilfoil et al. [10] also showed that an increase in the volumetric fraction of the solids causes an increase in the delay time due to the reduction of the free volume in which the unabsorbed polymer is found.

This form of sedimentation has not been studied in detail in activated sludge. Chen et al. [5] and Zhao [6] did not study the instant in which the process of acceleration of sludge takes place, nor the possible relationship between the different settling stages. However, in this study the two stages with constant hindered settling velocity, as well as the relationship between these two stages and the instant at which sludge acceleration occurs, are described and characterized. The sudden decrease in final hindered settling velocity in a small range of suspended solids concentrations, not previously described in the literature, is also studied. Finally, a mechanism is proposed to describe the collapse of the initial homogeneous sludge structure and the appearance of the stage of sludge acceleration.

2. Materials and methods

Activated sludge samples for the tests were obtained from the industrial wastewater treatment plant Ford Spain located in Almussafes, Valencia (Spain). The plant comprises a set of physical-chemical treatments, as well as a biological treatment with an oxidation ditch. In the physical-chemical treatments a large variety of chemical reagents are used: $Ca(OH)_2$, iron and aluminium salts, and both, anionic and cationic polymers.

Sludge was collected from the oxidation ditch after the surface aerators were activated to obtain a homogeneous sludge sample. The supernatant used to make the sludge dilution was collected from the secondary clarifier effluent.

2.1. Settling tests

The hindered settling tests were performed using two cylindrical columns, 1.1 m in height and 0.12 m in diameter. Preliminary studies (Fig. S1 in the Supplementary material) showed the need of an initial rapid stirring of the sludge for ten minutes to reproduce the settling curves and eliminate the memory effect of the sludge described by Chen et al. [5]. The initial rapid stirring of the sludge allows reproducing the hydrodynamic conditions of the treatment plant [11] where sludge is subject to high turbulences in mechanical aerators of the biological reactor before reaching the secondary clarifier.

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.seppur.2018.07.006.

The height of the interface in the settling test was determined as a function of time at the end of the stirring phase. A slow stirring of the sludge was not performed during the settling test to avoid interfering with the possible flocs aggregation process [5], or with the collapse of the initial sludge structure causing the acceleration stage. The sludge concentration (*X*) was determined from the concentration of total suspended solids using the Standard Method 2540 D [12]

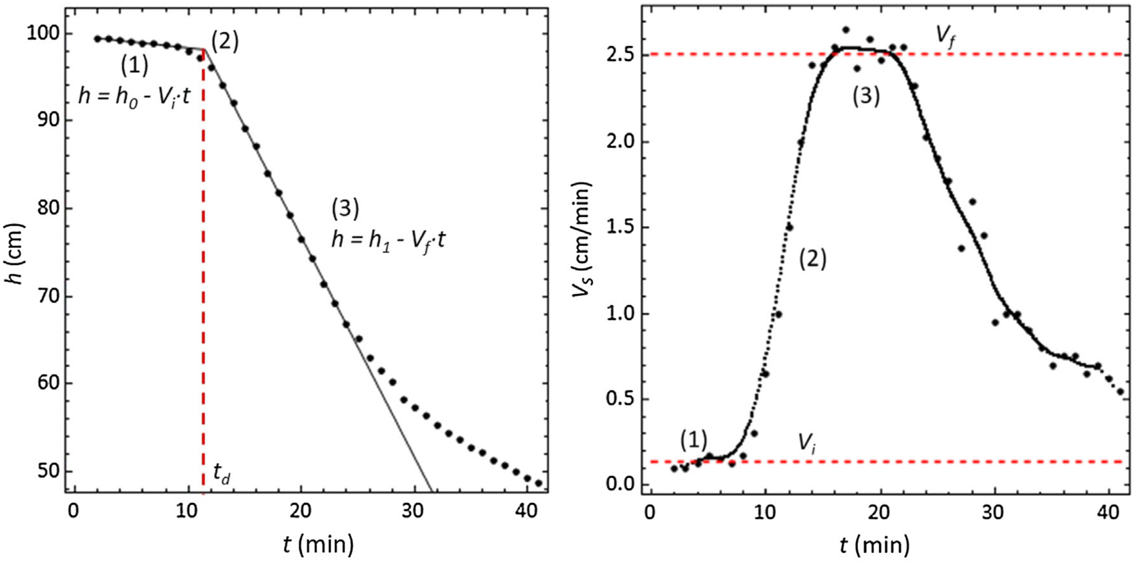
To consider the effect of the chemical reagents used in the wastewater treatment plant, two sets of settling tests were performed with different composition of the supernatant. In experiment A, the dilution of the sludge was performed using the supernatant of the secondary clarifier and in experiment B with the supernatant diluted to 75%. Settling tests were also carried out by adding during the fast agitation phase, coagulants and polymers used in the physical-chemical process.

2.2. Density and size of flocs

Sludge samples were taken during the initial stirring process from the settling column. The flocs in this stage are called primary flocs to distinguish them from those generated during the settling process. The density and size of the primary flocs was also determined.

The density of the dry sludge (ρ_s) was determined using a pyknometer method [13] and the primary floc density (ρ_p) with a method based on centrifugation in homogenous density solutions [14].

Image analysis techniques were used to determine the distribution of floc size. Images were acquired by light field microscopy using an optical microscope and a digital coupled camera with a resolution of 10 megapixels. A minimum of 120 images were taken in each test to have a sample of floc images large enough to be able to perform a statistical analysis later. The analysis and processing of images was performed with a program developed with MATLAB (MathWorks®) following the



(a) (b)

Fig. 1. Typical settling curve *h*(t) and settling velocity V_S(t) of settling tests.