Modelling and optimisation of continuous clarifier operations from batch jar test data

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Abstract

The conventional laboratory jar testing procedure which is utilised in the design and process description of the rapid mix and flocculation processes of water clarification may be adapted to describe the operation of a full-scale continuous shallow depth sedimentation unit process. It was found that in analysing the flocculation kinetics of the jar test, the floc break-up rate and floc aggregation rate constants are statistically correlated to the floc settling velocities. The constants in the correlation are typical for the particular type of water and provide a link between the batch jar test and the continuous sedimentation process.

The laboratory jar test is also useful in evaluating the effect of clarifier hydraulic characteristics, such as short circuiting and back mixing. Such a study done on a lamella settler showed that the clarifier will not perform satisfactorily without a flocculation basin preceding the plate pack, since the velocity gradients are low and of too short a duration. The jar test may also be used to optimise a clarifier configuration instead of resorting to pilot-plant studies.

Introduction

The mechanism for the removal of colloidal particles in suspension in water has been extensively researched and modelled around the coagulation, flocculation and sedimentation unit processes. Coagulation involves the neutralising of electrical charges on the particles, which for clay particles result from imperfections in the crystal lattice structure. Metal salts such as $Al_2(SO_4)_3$ and $Fe_2(SO_4)_3$ are used to neutralise these charges. Typical relationships between residual turbidity, colloid concentration and coagulant dose for the coagulation process have been presented by Benefield et al. (1982). Once the optimum coagulant dosage, pH and rapid mix conditions have been established, the water is transferred to a flocculation tank in which gentle agitation produces particle contact between destabilised colloids, so that larger aggregates can form which are large enough to be removed by sedimentation.

Different waters, however, have different treatment requirements and what the design engineer requires is a relatively simple tool around which he can model the coagulation, flocculation and sedimentation unit processes. This model should ideally incorporate all design variables which need to be considered in practice. The most widely used method in evaluating the coagulation-floccuation processes to date is the laboratory jar test. Hudson (1981) has presented an in-depth summary of the variables involved and the equipment needed to run the jar test to obtain meaningful results.

Argaman and Kaufman (1970) have presented a model for turbulent flocculation comprising 2 components, namely the floc aggregation and floc break-up rate of primary particles (or turbidity). The effectiveness of the removal of primary particles or colloids by their conversion into flocs for a system consisting of completely mixed flocculator compartments in series of equal volume with a total residence time of T was given as:

$$\frac{n_0}{n_i} = \frac{\left(1 + k_A GT/i\right)^i}{1 + k_B G^2\, T/i \left[\sum_{m=0}^{i-1} \left(1 + k_A GT/i\right)^m \right]} \quad (1)$$

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where:

- n_0 - initial concentration of primary particles (or turbidity) at time t = 0
- n_i - concentration of primary particles (or residual turbidity) after flocculation for a time t = T followed by "infinite" settling
- k_A - floc aggregation rate constant
- k_B - floc break-up rate constant (s)
- G - root mean square velocity gradient (s^{-1})

Bratby et al. (1977) showed that the constants k_A and k_B remain the same for a batch jar test and for a continuous flow operation. The equivalent flocculation equation for a batch system is given as:

$$\frac{n_0}{n_1} = \left[\frac{k_B}{k_A} G + \left(1 - \frac{k_B}{k_A} G \right) e^{-k_A GT} \right]^{-1} \quad (2)$$

Argaman (1971) has shown that k_A and k_B are the same for small and large-scale plants treating the same effluent. Therefore Eqs. 1 and 2 may be used to obtain a first estimate in the laboratory of parameters affecting the design of flocculation basins. The constants k_A and k_B have also been shown to be characteristic of a specific water (Janssens and Beukens, 1987) and need to be evaluated every time a different water is treated.

The information obtained from performing a series of jar tests has, however, been limited to the upscaling of the coagulation and flocculation unit processes. What is required is an idea of whether the laboratory jar test is of any use in the design and optimisation of the sedimentation tank which follows the flocculation basin. The direct scale-up of settling data from the jar test to a conventional settling basin is viewed with some scepticism since the settling depth in the jar is much less than that of a full-scale plant. This usually results in large plants producing superior effluent qualities since additional flocculation takes place as flocs settle through the greater vertical settling distance, entrapping smaller particles in their passage to the tank bottom. This is commonly known as "sweep" or vertical flocculation.

In Eqs. 1 and 2, n_i is taken as the residual turbidity measured