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Review

Research advances and challenges in one-dimensional modeling of secondary settling Tanks – A critical review

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ABSTRACT

Sedimentation is one of the most important processes that determine the performance of the activated sludge process (ASP), and secondary settling tanks (SSTs) have been frequently investigated with the mathematical models for design and operation optimization. Nevertheless their performance is often far from satisfactory. The starting point of this paper is a review of the development of settling theory, focusing on batch settling and the development of flux theory, since they played an important role in the early stage of SST investigation. The second part is an explicit review of the established 1-D SST models, including the relevant physical law, various settling behaviors (hindered, transient, and compression settling), the constitutive functions, and their advantages and disadvantages. The third part is a discussion of numerical techniques required to solve the governing equation, which is usually a partial differential equation. Finally, the most important modeling challenges, such as settleability description, settling behavior understanding, are presented.

Contents

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1. Introduction

Biological secondary treatment processes are widely used in wastewater treatment plants to remove organic matter and reduce nutrients such as nitrogen and phosphorus. In most cases, efficient operation requires the biomass to be removed from the wastewater by sedimentation, filtration or other solids-liquid separation processes.

Several types of treatment processes can achieve solids-liquid separation, but secondary settling tanks (SSTs) are most commonly used. SSTs, also known as sedimentation basins or solids-liquid separators, use gravity to separate the biomass from the fluid, and have two similar but distinct functions: clarification and thickening. Clarification is the removal of finely dispersed solids from the liquid to produce a low turbidity effluent; Thickening is the process of increasing the sludge concentration in order for it to be recycled or disposed in less volume. In SSTs, the clarification process occurs in the upper zone while thickening occurs near the bottom. The result is an effluent from the top, low in suspended solids, and a second stream of settled, concentrated biomass from the bottom, suitable for recycling or disposal.

As one of the most important units in wastewater treatment process, the SST is often a "bottle neck," limiting the capacity of the wastewater treatment process (Ekama et al., 1997; Ekama and Marais, 2002). The SST sizing must be combined with the bioreactor sizing to provide the minimum necessary conditions, such as the solids retention (SRT) or food-to-mass (F/M ratio) to meet design conditions, as well as maintaining a safety factor to handle shocks and upsets. If the SST does not produce a highly clarified effluent, or cannot thicken biomass to the required recycle concentration, excessive effluent solids will result, causing effluent permit violations and resultant loss biomass from the reactor. Therefore, two commonly used parameters: overflow rate and solids flux, have been developed for SST design and evaluation.

Since wastewater characteristics vary, such as temperature, flow rate and contaminant concentrations, traditional design procedures for SSTs tend to be more empirical and conservative by introducing averaged parameters with safety factors (Coe and Clevenger, 1916). Therefore SST performance can suffer unanticipated fluctuations, which may cause process control problems and increase the risks of failure. Stringent standards for effluent quality and the need for optimization of WWTP performance have made such variations in effluent quality undesirable, and have encouraged the use of dynamic controls for wastewater treatment process.

A mathematical modeling approach, where the bioreactor models are coupled with SST models, is encouraged in WWTP studies for overall process design and control optimization. Scientific knowledge on characterizing the biomass growth and contaminant removal is well-developed, whereas the various settling behaviors within the SST are still poorly understood, thus causing the difficulty in effluent quality prediction, biomass inventory estimation (Plósz et al., 2011). Great efforts have been made to rigorously predicting the SST performance. According to different practical application purposes, the modeling approaches can be divided into three main categories:

1. One-dimensional (1-D) dynamic model: 1-D model is based mostly on the flux theory and Kynch's assumption that the solids gravity settling velocity is only determined by the local sludge concentration. The hydraulic flow is simplified as downward/upward flow to simulate the recycling/effluent flow and satisfy the 1-D assumption.
2. Two-dimensional (2-D) hydraulic model: compared with 1-D models, 2-D models are developed using computational fluid dynamics (CFD) techniques. Therefore, instead of simplifying or omitting the hydraulic flow impact, 2-D models can incorporate hydrodynamics such as density currents, turbulence, and artifacts unfavorable SST geometry. Flocculation behavior can also be modeled, if coupled with a sub-flocculation model (Zhou and Mccorquodale, 1992a, b). A frequent application of 2-D models is to improve SST geometry design and optimize performance.
3. Three-dimensional (3-D) hydraulic model: the motivation of developing 3-D approaches is to understand non-symmetric features: for example the heat exchange caused by the varying temperatures and wind effects. Very detailed computation grids are now feasible in order to capture geometric features as small as several inches (Gong et al., 2011; Xanthos et al., 2011; Ramalingam et al., 2012). However, the high resolution grids also require strong computing capacity and power which may limit the 3-D models' practicability.

In current engineering practice, 1-D dynamic models are used to predict effluent and recycle solids concentration as well as the sludge blanket height in the SST. Although many 1-D SST models are available and some of them, especially the Takács model (Takács et al., 1991), have been widely utilized in engineering practice, the prediction of the sludge settling characteristics and concentration profiles in and out of a SST is still far from satisfactory, because of the using of empirical functions and unreliable numerical techniques