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Effects of integrated fixed film activated sludge media on activated sludge settling in biological nutrient removal systems

Hyun-su Kim[a], James W. Gellner[b], Joshua P. Boltz[c], Robert G. Freudenberg[d], Claudia K. Gunsch[e], Andrew J. Schuler[f,*]

[a] Korea Institute of Geoscience and Mineral Resources, 92 Gwahak-ro, Yuseong-gu, Daejeon 305-350, Republic of Korea
[b] Hazen and Sawyer, 11311 Cornell Park Dr., Suite 135, Cincinnati, OH 45242, USA
[c] CH2M Hill, Inc., 4350 West Cypress St., Suite 600, Tampa, FL 33607, USA
[d] Entex Technologies Inc., 400 Silver Cedar Court, Chapel Hill, NC 27514, USA
[e] Department of Civil and Environmental Engineering, Duke University, Durham, NC 27708, USA
[f] Department of Civil and Environmental Engineering, University of New Mexico, Albuquerque, NM 87131, USA

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ABSTRACT

Integrated fixed film activated sludge (IFAS) is an increasingly popular modification of conventional activated sludge, consisting of the addition of solid media to bioreactors to create hybrid attached/suspended growth systems. While the benefits of this technology for improvement of nitrification and other functions are well-demonstrated, little is known about its effects on biomass settleability. These effects were evaluated in parallel, independent wastewater treatment trains, with and without IFAS media, both at the pilot (at two solids residence times) and full scales. While all samples demonstrated good settleability, the Control (non-IFAS) systems consistently demonstrated small but significant ($p < 0.05$) improvements in settleability relative to the IFAS trains. Differences in biomass densities were identified as likely contributing factors, with Control suspended phase density > IFAS suspended phase density > IFAS attached phase (biofilm) density. Polyphosphate content (as non-soluble phosphorus) was well-correlated with density. This suggested that the attached phases had relatively low densities because of their lack of anaerobic/aerobic cycling and consequent low content of polyphosphate-accumulating organisms, and that differences in enhanced biological phosphorus removal performance between the IFAS and non-IFAS systems were likely related to the observed differences in density and settleability for the suspended phases. Decreases in solids retention times from 8 to 4 days resulted in improved settleability and increased density in all suspended phases, which was related to increased phosphorus content in the biomass, while no significant changes in density and phosphorus content were observed in attached phases.

1. Introduction

Stable and efficient removal of the biological solids produced in biological reactors is critical to the operation of biological wastewater treatment systems for the production of high quality effluent. Activated sludge is the most common biological wastewater treatment technology used in industrialized countries, and in this process biological solids are

* *Corresponding author*. Tel.: +1 505 277 4556; fax: +1 505 277 1988.
E-mail address: schuler@unm.edu (A.J. Schuler).
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removed by sedimentation. Poor settling of biological solids remains one of the most common operational problems in activated sludge wastewater treatment systems around the world (Martins et al., 2004). This can lead to increased solids treatment costs, increased effluent solids concentrations, decreased disinfection efficiencies, and increased risks to downstream ecosystems and public health.

Considerable research effort has focused on the effects of morphological characteristics, such as floc size (Knocke, 1986) and shape (Banadda et al., 2005; Eriksson and Hardin, 1984; Grijspeerdt and Verstraete, 1997; Jenne et al., 2006), on activated sludge settling. In an effort to achieve ideal floc morphology for better settling, aerobic granular sludge (AGS) technology was developed in sequencing batch reactor systems (Morgenroth et al., 1997). AGS has been proven to be effective in enhancing settling velocities (Nor Anuar et al., 2007) and providing phosphorus removal (Cassidy and Belia, 2005). Also, the negative effects of excessive filamentous bacteria content on settling are particularly well documented (reviewed in Jenkins et al., 2003 and Martins et al., 2004). Biomass density (defined here in the classical sense of mass per volume of biomass, not including voids) has received much less attention, although the gravitational force that drives sedimentation is a linear function of the difference between biomass density and the density of surrounding fluid (commonly termed the buoyant density), according to Archimedes principle. Density effects on solids settling have only recently been studied in detail, possibly because activated sludge density has generally been assumed to be relatively constant (e.g., Tchobanoglous et al., 2003). However, recent research has demonstrated this assumption is incorrect: for example, biomass densities were demonstrated to vary from 1.02 to 1.06 g/mL in samples from full scale wastewater treatment systems (Schuler and Jang, 2007a), indicating the sedimentation driving force varied by a factor of 3 in this data set (buoyant density ranged from 0.02 to 0.06 g/mL). Similarly, density varied from 1.02 to 1.04 g/mL in another full scale system data set (Dammel and Schroeder, 1991), and from 1.015 to 1.055 in samples from bench scale sequencing batch reactors (Schuler et al., 2001). This variability in density has been demonstrated to significantly affect settleability in both bench and full scale systems, and this effect was greatest in systems with at least moderate filament contents, as measured by the commonly-used sludge volume index (SVI) parameter (Schuler and Jang, 2007a,c). Increasing density also increases zone settling velocities, an alternative measure of settleability (Schuler and Jang, 2007b). Major factors demonstrated to affect density include polyphosphate content, which can vary with enhanced biological phosphorus removal (EBPR) activity, the related parameter non-volatile suspended solids (NVSS) content, and the operational parameter solids residence time (SRT) (Schuler et al., 2001; Schuler and Jang, 2007a).

Integrated fixed-film activated sludge (IFAS) is an increasingly popular modification of conventional activated sludge, in which solid media (typically suspended plastic pieces or fixed synthetic mesh) are added to suspended growth reactors to provide attachment surfaces for biofilms, thereby increasing microbial concentrations and rates of contaminant degradation. IFAS is an attractive option for retrofitting many existing facilities, in part because the inclusion of an attached biomass phase enriches for the slow growing autotrophs responsible for ammonia and nitrite oxidation (nitrifying bacteria), which are central to nitrogen removal processes in wastewater treatment, thus providing improved nitrification capacity without construction of new reactors. (Randall and Sen, 1996).

Data on the effects of IFAS systems on biomass settleability are scarce and inconsistent. McQuarrie et al. (2004) reported lower SVI values, indicating improved settling, after addition of IFAS media to a full scale EBPR system (median values decreased from about 150 to about 135 mL/g). In contrast, Stricker et al. (2007) reported higher SVI values in a full scale IFAS system (median SVI = 113 mL/g) relative to a parallel non-IFAS system (median SVI = 86 mL/g). Sriwiriyarat et al. (2008) reported no significant difference in the average SVI values of parallel pilot scale systems with and without IFAS (both were poorly settling systems with average SVI values > 250 mL/g).

Given the importance of settling to activated sludge performance, the increasing use of IFAS systems, and uncertainties about IFAS effects on settleability, there is a research need to determine the effects of IFAS systems on biomass settling. This study focused on settling in IFAS/EBPR systems in particular.

It was hypothesized that (1) inclusion of IFAS media affects biomass density in EBPR systems by altering the amount of polyphosphate stored in the suspended phase biomass, (2) the relatively high SRT occurring in attached growth will lead to increased density because of increased NVSS content, and (3) changes in density due to addition of IFAS are large enough to significantly affect settleability.

The objectives of this study were to determine how IFAS media installation affects biosolids settling characteristics, including effects on biomass density and parameters known to affect density. The research approach was to study settling and biomass characteristics in pilot and full-scale systems that included IFAS trains and independent, non-IFAS controls, including analyses of the biomass in the attached and suspended phases, to provide the first such direct comparisons and the first measurements of biomass densities of biomass (both suspended and attached) in IFAS systems.

2. Materials and methods

2.1. Pilot systems

Parallel pilot wastewater treatment systems were located at the South Durham Water Reclamation Facility (SDWRF) at Chapel Hill, North Carolina, with one train containing IFAS media and the other operated as a non-IFAS control. Both systems were operated in an anaerobic–anoxic–aerobic (A_2O) configuration for enhanced biological phosphorus removal (EBPR), denitrification, and nitrification (Fig. 1), with primary effluent as feed. Each train included an anaerobic (0.68 m^3), two anoxic (0.68 m^3 each) and two aerobic (1.37 m^3) reactors and a clarifier. Influent wastewater primary effluent pumped directly from the SDWRF. The flow rate (Q) was 18.0 ± 0.7 m^3/d to each train, resulting in a total hydraulic residence time (HRT) of 6.4 ± 0.25 h. Internal recycle flows for denitrification were pumped from the final aerobic reactors to the first anoxic reactors, with flow rates of 3.8 to 4Q. Return activated sludge was pumped from the clarifier to the anaerobic reactor (flow rate = 0.8 to 0.9Q). IFAS media