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Technical Note

Development of pseudo-amphoteric sponge media using polyalkylene oxide–modified polydimethylsiloxane (PDMS) for rapid start-up of wastewater treatment plant

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Abstract

Hydrophobic sponge media require a relatively long start-up period, as they just float on the surface of aeration tanks due to their little tendency to adsorb water, which causes a delay in the initiation of bacterial attachment. In order to overcome this difficulty, a new pseudo-amphoteric BioCube media (a standard BioCube is hydrophobic) using polyalkylene oxide–modified polydimethylsiloxane (PDMS) as a surfactant was developed. Of the many evaluated hydrophilizing agents, polyalkylene oxide–modified PDMS was found suitable. Among the diverse types of modified PDMS, the non-reactive polyethylene oxide–modified PDMS was found to be optimum agent. Pseudo-amphoteric BioCube media are readily immersible, but after complete immersion, they gradually become hydrophobic, as the polyethylene oxide–modified PDMS is designed to alienate from polyurethane backbone of BioCube to provide hydrophobic surfaces exhibiting more affinity for bacterial attachment. Clearly, the pseudo-amphoteric BioCube showed faster bacterial attachment during the early stage due to chances of enhanced contact between the bacteria and media surfaces, but the extent of attachment between the hydrophobic and pseudo-amphoteric BioCube was similar at the steady state because the former (pseudo-amphoteric BioCube) had already changed to hydrophobic. Fluorescent *in situ* hybridization result showed 14% occupation by ammonia oxidizing bacteria, 13% by nitrite oxidizing bacteria and 73% by others in pseudo-amphoteric BioCube, respectively.

Keywords: Bacterial attachment; FISH; Hydrophobic; Pseudo-amphoteric; PDMS; Sponge media

1. Introduction

In order to remove nutrients to meet new standards, many existing municipal wastewater treatment plants in South Korea are in brisk upgrading and retrofitting. Due to space constraints, upgrading concepts should provide a compact solution, as well as fully utilize the existing processes and structures. In order to fulfill these requirements, the sponge media processes are frequently selected as upgrading methods, as they consist of simple units and require no additional civil works, with the exception of filling the media (Morper, 1994; Reddy et al., 1994; Chae et al., 2004).

The rapid and stable attachment of microorganisms to a porous media surface is most important for the successful application of media processes. In nature, most bacteria do not exist as suspended cells, but rather attached to a surface and develop biofilms. Attachment is a complex process that is influenced by the diverse characteristics of the substratum, growth medium and the bacterial cell surface. Microbial attachment appears to increase as the surface roughness increases, because shear forces are diminished, and more substratum surface area is available

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for adsorption (Pasmore et al., 2002). The surface hydrophobicity of the substratum plays an important role in the rate and extent of bacterial attachment. Many researchers have reported that microorganisms attach more rapidly to hydrophobic than hydrophilic materials (Hood and Zottola, 1995; Parkar et al., 2001; Pasmore et al., 2002). However, the influence of the surface hydrophobicity on bacterial attachment is still controversial. Chavant et al. (2002) reported that the biofilm formation was faster on the hydrophilic substratum. In addition, the bacterial cell surface characteristics such as cell surface hydrophobicity, extracellular polymeric substances production, and presence of fimbria and flagella also influence the rate and extent of bacterial attachment (Zita and Hermansson, 1997; Donlan, 2002). The surface hydrophobicity of bacteria is important in the adhesion by overcoming the initial electrostatic repulsion barrier that exists between the bacterial cell and substratum.

When considering a sponge media process, hydrophobic sponge media are generally used, as they are physically and/or chemically more stable in water than hydrophilic media. They especially have more affinity for microbial attachment and adhesion than hydrophilic media. When sponge media are put into aerobic tanks, at first, they float in aeration, but after some weeks the media circulate in aeration tank with growing microorganisms inside them. From an operational standpoint, it is important to keep the sponge media well-mixed and distributed throughout the aerobic reactor volume for a short time during the start-up period. According to numerous experiences, however, hydrophobic media required a long start-up period, as they took a long time to become completely immersed in the aeration tanks due to their little tendency to adsorb water. Especially, when hydrophobic media were applied to municipal wastewaters with low organic contents, even distribution throughout the reactor took a very long time due to the slowly increasing media density with the biomass attachment.

Municipal wastewaters from specific provinces in South Korea have relatively low organics compared to nitrogen compounds content (namely low C/N ratio), as a considerable part of the carbon loading is removed by septic tanks prior to the wastewater being routed to a wastewater treatment plant through the sewer system. In these cases, the immersion time of the sponge media is the rate-limiting step for the start-up. Obviously, the first step of microbial attachment in porous sponge media is the contact between the bacteria in the wastewater and the media itself by its immersion in water, although increased surface hydrophobicity enhances bacterial attachment. This implies that the media material must be very hydrophilic to initiate the bacterial contact with media. Therefore, a free-floating pseudo-amphoteric polyurethane foam cube was developed to minimize immersion time during the start-up period, and has been employed since January 2003 for the upgrading of many municipal wastewater treatment plants in South Korea.

The hydrophilic condition of the BioCube enhances the immersion speed (wettability), but reduces the microbial attachment potential. Therefore, a pseudo-amphoteric BioCube was developed that would satisfy these two aspects. In order to produce a pseudo-amphoteric BioCube, a hydrophilic functional group with modified polyalkylene oxide–modified polydimethylsiloxane (PDMS) as a surfactant was added in the manufacture of a polyurethane foam cube. The purpose of this paper was to present our investigations on diverse hydrophilizing agents for the pseudo-amphoteric BioCube development, the microbial attachment potential of pseudo-amphoteric compared to hydrophobic media, and the application results to municipal wastewater treatment plants.

2. Materials and methods

2.1. Pseudo-amphoteric BioCube media

A BioCube is a highly porous polyurethane foam cube, which acts as a mobile carrier for active biomass. The use of BioCube media allows a process to retain microorganisms by incorporating both their attached and suspended-growth, named the hybrid growth system. BioCube has more than 95% void space, with a large surface area for biomass attachment and entrapment. The cube has a dimension of $15 \times 15 \times 15$ mm, with 10–16 pores per cm and a biomass-laden specific gravity close to 1.0. A standard BioCube is hydrophobic. However, a new pseudo-amphoteric BioCube has been developed for rapid start-up of wastewater treatment plants (especially low C/N wastewater) using an especially designed surfactant; a polyethylene oxide–modified PDMS (see details in the Section 3).

2.2. Measurement of cube hydrophilicity

2.2.1. Wettability test

In order to measure hydrophilicity of BioCube media, the time allotted for the media to become totally immersed (sinking time), was measured as an indirect method. Cubic foam samples ($15 \times 15 \times 15$ mm) were dropped onto the surface of distilled water, maintained at 25 °C with no mechanical hindrance, from a height of 7 cm. The sinking time was measured from the moment the bottom of the test cube contacted the distilled water, to the moment the top of the cube was immersed in the water.

2.2.2. Water retention ratio

Water retention ratio (WRR) provides valuable information about the absorption property of a foam media. Cubic foam samples ($30 \times 30 \times 30$ mm) were weighed (A), and then dropped into a 3 l beaker containing 2 l of distilled water, and took out 24 h later, rolled using a 2 kg roller, and reweighed (B). Consequently, the water retention ratio was calculated; WRR (%) $= (B - A)/A \times 100$.