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Pilot-scale demonstration of efficient ammonia removal from a high-strength municipal wastewater treatment sidestream by algal-bacterial biofilms affixed to rotating contactors

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ABSTRACT

This report details our investigation of a novel, fixed-biofilm algal and bacterial system for the treatment of high-strength municipal anaerobic digester filtrate. Each reactor in the pilot-scale system comprises multiple Algaewheel™ rotating algal contactors (RACs) that help efficiently oxygenate the anaerobic digester filtrate being treated in a shallow tank. Total ammonia nitrogen (TAN) removal by microbial oxidation and anabolic uptake varied between 45 and 60% at hydraulic retention times (HRTs) of 0.5–2 days. Of the TAN removed during treatment, > 95% was oxidized to nitrite with 27–36% subsequently evolved as N_2 and only 3–11% oxidized to nitrate. The low extent of nitrate formation makes biological nutrient removal less costly, since nitrite reduction demands less oxygen, by 25%, and organic carbon, by 40%, than nitrate reduction. In addition, due to the efficient aeration by RACs, it should be possible to design systems for sidestream treatment of digester filtrate that require up to 80% less electricity than are typical for aerobic ammonia oxidation.

1. Introduction

Raw municipal wastewater contains high levels of inorganic nitrogen compounds, especially ammonia. Since ammonia can be toxic to aquatic life when excessive amounts are discharged into receiving waters, wastewater treatment facilities (WWTF) often include a process that facilitates the aerobic oxidation of total ammonia nitrogen (TAN) to nitrite (NO_2^-) and nitrate (NO_3^-). A growing number of WWTFs follow nitrification with biological nutrient removal (BNR) via denitrification of nitrate and nitrite to dinitrogen gas (N_2). The net effect of combining TAN oxidation with BNR is to release the nitrogen from raw wastewater into the atmosphere as inert N_2 instead of discharging fixed nitrogen species to receiving waters. Since both processes add to the cost and complexity of wastewater treatment, making them more efficient is an important goal.

At WWTFs, the TAN loading to the head of a plant typically comes from two main process streams: raw wastewater and sidestreams of recycled filtrate and centrate produced during the dewatering of digested biosolids. In a typical facility, these sidestreams can account for as little as 1–2% of the water flow, but upwards of 20–30% of the TAN loaded [1]. If TAN could be efficiently removed from this concentrated waste stream, it might be possible to both reduce the cost of nitrogen removal and eliminate the TAN shock loadings associated with intermittent bio-solids dewatering schedules.

One means of increasing the efficiency of TAN removal is to avoid oxidizing it completely to nitrate. In traditional nitrification systems, TAN is oxidized to nitrate in two steps, with 75% of the total oxygen consumed during the conversion to nitrite and the balance used in the nitrite to nitrate reaction. When following nitrification by denitrification, traditional BNR systems add bioavailable organic carbon substrates, often methanol, to drive reduction of NO_3^- back to NO_2^- and then to N_2 gas. If instead the filtrate or centrate can be oxidized only as

Abbreviations: AOB, ammonia oxidizing bacteria; BNR, biological nutrient removal; BOD, biological oxygen demand; C_X, mass concentration of solute X (mg L^{-1}).; COD, chemical oxygen demand; DIN, dissolved inorganic nitrogen; DIC, dissolved inorganic carbon; *e*X, equivalent concentration of solute X (meq L^{-1}); HRT, hydraulic retention time; *m*X, molar concentration of solute X (meq L^{-1}); NOB, nitrite oxidizing bacteria; NOD, nitrogenous oxygen demand; PVC, polyvinyl chloride; RAC, rotating algal contactor; TAN, total ammonia nitrogen ($NH_4^+ + NH_3$); WWTF, wastewater treatment facility

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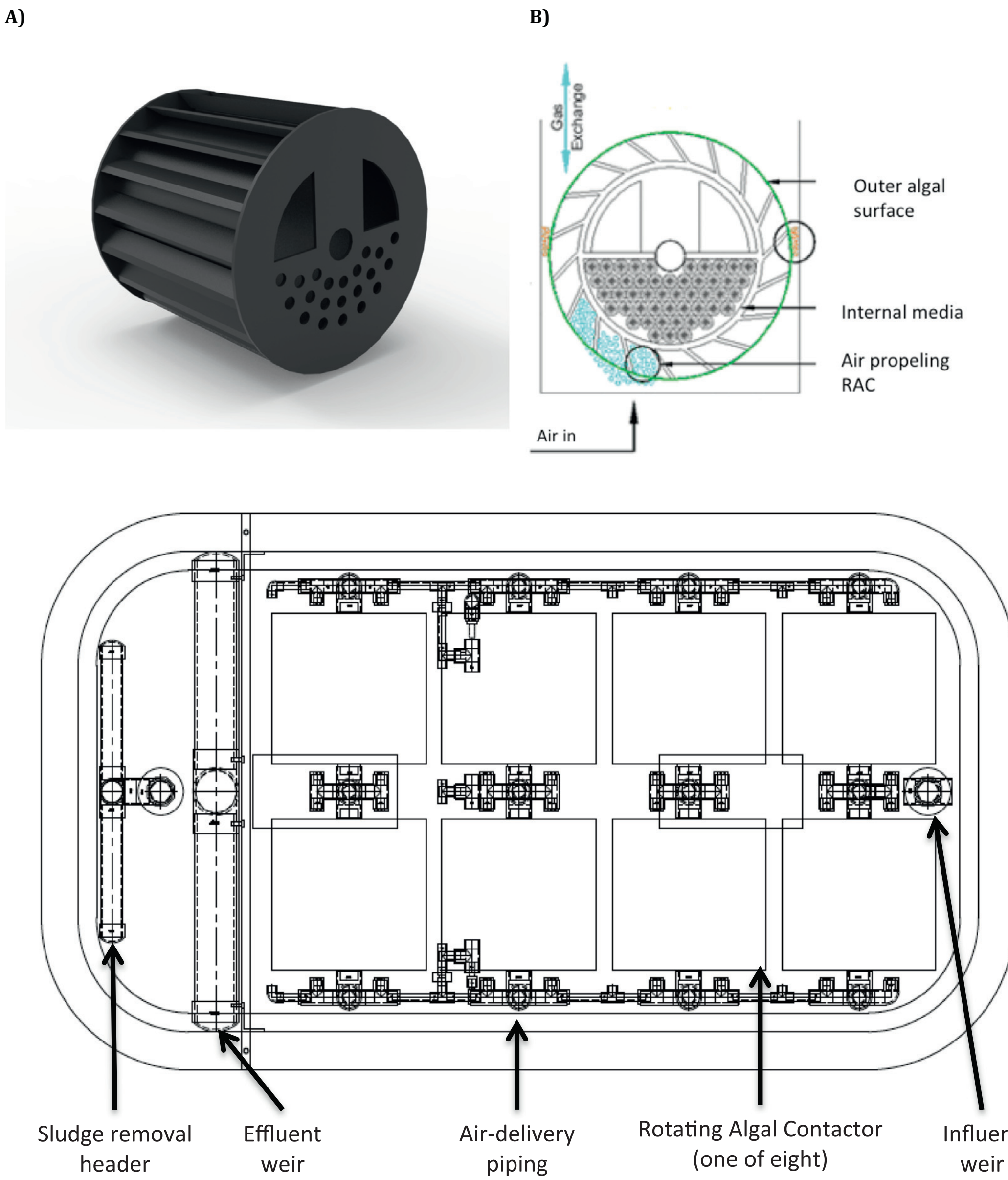

Fig. 1. Reactor components and layout. A) Algaewheel™ rotating algal contactor (RAC), B) RAC showing interactions with air bubbles and water, C) plan view of the reactor/tank (2.43 m × 1.2 m × 0.25 m).

far as nitrite before reduction to N_2, savings of 25% in oxygen and 40% in organic carbon consumed for denitrification are possible [1–3,29].

Some non-traditional, bacterial systems are designed to reduce the need for aeration using nitritation rather than complete nitrification. The SHARON process (Single reactor for High activity Ammonia Removal Over Nitrite) [3,4], also converts approximately 50% of the TAN to nitrite in the aeration stage. After SHARON, nitrite can be removed by heterotrophic denitritation [1] or anammox [5]. Such systems have been demonstrated at commercial scale, where treatment of filtrate and centrate through incomplete nitrification, has been shown to reduce the oxygen required for TAN oxidation by 25% [2,6].

It is possible to further reduce electricity consumption to run aeration equipment by producing oxygen via algal photosynthesis, supplementing the oxygen demand of nitritation [7,8]. The benefits of oxygenic photosynthesis in biofilms have also been demonstrated in trickling filters used to treat municipal wastewater. Kuenen et al. [8] showed that the diffusion layer above algal biofilms on the surface could have daytime oxygen concentrations 500% higher than saturated levels. This very high oxygen level, dissipates when the biofilm is not exposed to light. Within mixed photo/heterotrophic biofilms, light indirectly stimulates heterotrophic biomass production and bacterial enzyme activity as a result of algal photosynthesis [9,10].

Efficient microbial and algal metabolism in biofilms still requires gas transfer between water and the atmosphere. Combining aeration from blowers with rotating biological contactors (RBC), have been shown to stimulate nitrification when the process becomes limited by oxygen transfer rates across biofilm boundary layers or by low DO levels within the biofilm and bulk water [11]. Aeration both increases oxygen levels in the bulk water and increases the contact between air bubbles and RBC surfaces while submerged in the bulk water [11]. The bubbling action also scours the biofilm, reducing its thickness. Consequently, aerated RBC treatment systems can handle higher TAN loadings. For instance, RBCs were shown to nitrify landfill leachate at TAN loadings of 1.92 to 6.63 $g\text{-}N\,m^{-2}\,d^{-1}$, although their efficiency was only 60% at the higher loading rate compared to 100% at the lower one. Since RBCs can be limited by oxygen and carbon dioxide diffusion within the biofilm, there remains a potential for increasing the efficiency of rotating contactor systems by taking advantage of the