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ScienceDirect
European Journal of Protistology 58 (2017) 143–151
European Journal of PROTISTOLOGY
www.elsevier.com/locate/ejop

Microfauna community during pulp and paper wastewater treatment in a UNOX system

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Received 5 October 2016; received in revised form 31 January 2017; accepted 20 February 2017
Available online 2 March 2017

Abstract

This study characterized the microfauna community during treatment of pulp and paper wastewater in a UNOX system aerated with pure oxygen, and with a high organic loading rate (0.4 ± 0.06 kg BOD/kg MLSS day), low sludge retention time (3.73 ± 0.33 day), and high oxygen concentration ($\leq$20 mg O_2/L) in comparison to municipal treatment systems. In the aeration tank, temperatures were high, averaging 35.7 °C (March–May), then 38.9 °C (June–August). Effluent quality was acceptable: 180 ± 22 mg COD/L, 7.2 ± 2.1 mg BOD_5/L, and 33 ± 5 mg TSS/L. At 35.7 °C, 5 taxa were identified in the activated sludge: small flagellates (flagellates <20 μm), attached ciliates (*Vorticella infusionum*, *Vorticella octava*), crawling ciliates (*Chilodonella uncinata*) and free-swimming ciliates (*Sathrophilus muscorum*). During this period, the SBI (Sludge Biotic Index) was 6–7, corresponding to Quality Class II. At 38.9 °C, two taxa co-dominated (*Vorticella infusionum*, *Sathrophilus muscorum*). When *Vorticella infusionum* dominated, the SBI was 5 or 7 (Quality Class III/II); when *Sathrophilus muscorum* dominated, the SBI was 0 (Quality Class IV). Slight changes in the abundance of two opposing Madoni keygroups impeded proper classification of activated sludge. However, effluent quality remained the same, showing that these indicators of activated sludge quality do not always reflect effluent quality.

Keywords: Activated sludge; Protozoan community; Pulp and paper wastewater; SBI; UNOX system

Introduction

In biological municipal wastewater treatment plants (WWTPs), influent composition, and technological and environmental conditions determine not only the effectiveness of pollutant biodegradation and the quality of the effluent, but also the composition of the entire biocenosis in the activated sludge. Thus, the eukaryotic component of the biocenosis can be monitored for insight into the treatment process and identification of operational problems and their causes. To accomplish this, it is necessary to understand the structure of the eukaryotic communities, and the diversity and abundance of their taxa in the activated sludge.

During municipal wastewater treatment, for example, a decrease in the diversity of ciliates such as *Vorticella convallaria*, *Epistylis plicatilis*, and *Aspidisca cicada*, and in the abundance of some other taxa, such as the testate amoeba *Arcella hemisphaerica*, indicated low effectiveness of organics (BOD and COD) and suspended solids removal (Chen et al. 2004). Other indicators of a decrease in the effectiveness of wastewater treatment are dominance of small flagellates

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http://dx.doi.org/10.1016/j.ejop.2017.02.004
0932-4739/

and attached ciliates with a narrow peristome (Cereceda et al. 1996; Madoni et al. 1993; Salvadó et al. 1995). A large number of small flagellates in low-loaded, mature activated sludge may be associated with poor aeration, overloading or the presence of fermenting substances (Madoni 1994). Furthermore, a substantial increase in the abundance of these flagellates may indicate deflocculation that can lead to an excessive amount of suspended solids in the effluent (Bento et al. 2005).

Attempts have been made to use microorganisms as indicators of treatment conditions in municipal wastewater with toxic compounds. For example, attached ciliates with a narrow peristome (such as *Opercularia* spp., *Vorticella microstoma*) can indicate environmental stresses because they survive in such conditions better than other protozoans: Papadimitriou et al. (2007) found that *Opercularia* sp. tolerated high cyanide concentrations, and Salvadó et al. (2001) found that *Vorticella* spp. and *Opercularia articulata* resisted high concentrations of NaCl (up to 40 g/L) better than other ciliated protozoa. Moreover, the ciliate *Epistylis* cf . *rotans* was a good bioindicator of the nitrification process during treatment of landfill leachate with a high ammonium concentration (averaging 588 ± 220 mg $N\text{-}NH_4^+$/L) in a system with anoxic and aerobic reactors (A/O SBNR). This taxon was the only ciliate species that was present, and its abundance correlated positively with ammonium removal efficiency (Canals et al. 2013).

Surprisingly, the microbial groups that serve as indicators of poor activated sludge conditions or/and poor effluent quality in conventional municipal wastewater treatment systems can be associated with high treatment efficiency and effluent quality in unconventional industrial wastewater systems.

As one example, in a submerged membrane bioreactor (MBR) treating urban wastewater, indicators of poor treatment conditions were observed, such as small flagellates, free-swimming carnivorous ciliates and rotifers, but the effluent quality remained constant and even improved over time (Arévalo et al. 2009).

Thus, observations of microfauna communities in unconventional systems, which often treat industrial wastewater, can help to describe the structure of the microfauna typical for such systems when they operate properly, and to identify the changes in these structure that are indicators of treatment problems.

One of the industries that generates large quantities of wastewater is the pulp and paper industry. Because of the composition of this kind of wastewater, it often requires sophisticated treatment systems. To address some of the problems with pulp and paper wastewater treatment, a UNOX system can be used (Kawata and Sakata 1998; Ueda 2004; Wilcox and McWhirter 1971). UNOX is an advanced activated sludge process which improves upon the conventional activated sludge process by using pure oxygen. During pulp and paper wastewater treatment in a UNOX system operated at a biomass concentration of 4.5–7 g/L, a dissolved oxygen level of 8–10 mg O_2/L and a short hydraulic retention time of 1–2 h and short sludge age, less sludge was produced than by a conventional process, and the sludge was highly flocculated with excellent settling and dewatering characteristics (Wilcox and McWhirter 1971). However, only certain taxa can flourish in the specific environmental and technical conditions of pulp and paper wastewater systems (i.e. the characteristics mentioned above, and the various characteristics of the influent that differ from those in plants that treat conventional municipal wastewater). However, the microfauna community in full-scale UNOX systems that treat pulp and paper wastewater has not been adequately described, and such knowledge could improve the monitoring and performance of these systems by indicating which taxa could be used as bioindicators in these environments. Thus, the aim of this study was to characterize the microfauna community in a UNOX system that treated pulp and paper wastewater at technical scale, and to determine which species could be useful as indicators of process performance.

Material and Methods

Wastewater treatment system and wastewater characteristics

The WWTP in the present study worked as a UNOX system with a capacity of 110,000 m^3/day. The wastewater treated in the system was a mixture of pulp and paper wastewater (91%) with municipal wastewater (9%).

The wastewater consisted of three streams:

- stream 1—alkaline wastewater from a pulp mill, wastewater from pulping and after pulping, (ca. 80,000 m^3/day); pH 9.5–11, COD 500–700 mg/L, total suspended solids 250–600 mg/L and temperature 38–40 °C,
- stream 2—wastewater after bleaching and chemical pulping (ca. 20,000 m^3/day); pH 2.5–3.0, COD 800–1200 mg/L, total suspended solids 30–60 mg/L and temperature 50–60 °C,
- stream 3—municipal wastewater (ca. 10,000 m^3/day); pH 6.5–7.0, COD 1100–1800 mg/L, total suspended solids 300–900 mg/L and temperature 16–19 °C.

Before entering the UNOX system, the three streams are mixed in a neutralization chamber. The pulp and paper wastewater streams do not contain phosphorus and nitrogen compounds, and although the municipal wastewater does contain these compounds, its contribution to the total amount of influent is too small to ensure the C:N:P ratio of 100:5:1 that is required for the microorganisms in the activated sludge. To address this lack of nutrients, N and P compounds (in the form of ammonium phosphate) were added in the neutralization chamber, along with cooling water and lime milk. Further details on the influent to the UNOX chamber and the technological conditions can be found in *Technological results* section.